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Managerial Decisions and Performance in European Urban Public Transport - a Comparative Analysis

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This thesis is dedicated to my grandmother Erika who just turned 90.

Abstract

Managing public transport operators usually involves a wide range of actions and decisions relevant for their performance. However, state-of-the art literature in that field only vaguely reflects upon any effects from operational, tactical, or strategic managerial choices. In addition, studies are often dominated by controversial cross-sectional approaches unsuitable for the proper incorporation of explanatory variables of performance in general. Therefore, this work proposes a two-stage time-series Data Envelopment Analysis (DEA) to assess the relation between managerial decisions and economic performance of operators over time. Based on annual reports, both notions are evaluated for three operators from Portugal and Germany over the course of 64 years. Different techniques are used to approximate the real world state with modelling. Decision time-series are generated from text-based data with Content Analysis including the classification, operationalization, and analysis of multiple decision categories, such as network, fleet, personnel, schedule, fare, service and management decisions. Following the logic of self-benchmarking, DEA time-series are computed from three inputs and two outputs capturing the broader objectives of public transport provision by means of effectiveness and efficiency. DEA time-series are regressed on the decision times-series and socio-economic variables in an innovative time-series regression approach to assess dynamic effects from management decisions over a period of 10 years. Findings are compared between operators to identify similarities and differences over time in terms of decision-making, managerial focus, performance evolution, performance orientation, magnitudes and time-lags of effects from managerial decisions on performance as well as the role of external variables. Among other findings, this research outlines the importance of service- and customer-oriented management practices and the force of external influences towards operator performance. It further suggests the adequacy of considering effectiveness as an integral component of modern performance analysis in public transport and the need for caution concerning the application of cross-sectional DEA to a set of rather heterogeneous operators.

Resumo

A gestão dos transportes públicos geralmente envolve uma gama ampla de ações e decisões, que são relevantes ao seu desempenho. Entretanto, o estado da arte do conhecimento académico naquela área reflete apenas vagamente os efeitos de escolhas operacionais, táticas ou estratégicas. Para além disso, os estudos são frequentemente dominados por abordagens transversais polémicas, que são em geral impróprias para uma incorporação apropriada de variáveis explicativas de desempenho. Portanto, este trabalho propõe uma análise por Data Envelopment Analysis (DEA) em dois estágios, para determinar a relação entre decisões de gerenciais e o desempenho económico dos operadores ao longo do tempo. Com base em relatórios anuais, ambos os conceitos são avaliados para três operadores de Portugal e Alemanha, por um período de 64 anos. Técnicas diferentes são utilizadas para aproximar a modelação do mundo real. Séries temporais de decisões são geradas a partir de dados baseados em texto utilizando Análise de Conteúdo, que inclui a classificação, operacionalização e análise de múltiplas categorias de decisões, tais como decisões sobre redes, frotas, pessoal, agendamento, tarifas, serviços e gestão. Seguindo a lógica de self-benchmarking, séries temporais de DEA são computadas a partir de três entradas e duas saídas, capturando os objetivos gerais de oferta de transporte público, por meio de eficácia e eficiência (primeiro estágio). É então efetuada uma análise de regressão entre as séries temporais DEA, e as séries temporais de decisão e as variáveis sócio-económicas, em uma abordagem inovadora que usa regressão de série temporal para determinar os efeitos dinâmicos das decisões gerenciais ao longo de um período de 10 anos (segundo estágio). Os resultados são comparados entre os operadores, para que seja possível identificar semelhanças e diferenças ao longo do tempo relativamente a tomada de decisões, objetivos de gestão, evolução do desempenho, orientação do desempenho, magnitudes e lapsos temporais dos efeitos das decisões gerenciais no desempenho, bem como a influência de variáveis externas. Entre outros resultados, este trabalho ilustra a importância de práticas gerenciais orientadas ao serviço e aos clientes, e a força de influências externas ao desempenho dos operadores. O trabalho posteriormente sugere a adequação de se considerar a eficácia como um componente integral de uma análise moderna de desempenho de transportes públicos, e a necessidade de cautela ao se aplicar análises DEA transversais a um conjunto de operadores que são, de facto, heterogéneos.

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As any PhD thesis this final product just shows logical procedures, reasoning, equations, numbers, and figures. The style is rather techno-economic, spotless, clean and free of emotions. *Straightforward* one could say. However, the creation of this work as an amazing stage of my life in general was surely accompanied by a wider range of mixed emotions. In fact, there was sun and rain. There was joyful solitude and bitter loneliness. The feeling of mastery vs. that of simple-minded helplessness. Opportunity vs. loss. Duty vs. idleness. Risking it all vs. playing it safe. Holding on vs. giving up. Imagination vs. capability. On top, a constant feeling of guilt and insecurity that one could have done more or better, work-wise, family-wise, friends-wise etc. It seems precisely the roller coaster of emotions that poses the largest risk to any PhD project. But in the end *deu tudo certo.* I am grateful, honoured and proud that with the help and support of supervisors, friends and family all turmoil could be calmed enabling me to write these final lines.

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Abbreviations

abs	absolute
AC	autocorrelation
ACF	auto correlation function
ADD	additive DEA
ADF	Augmented-Dickey-Fuller
AIC	Akaike Information Criterion
AL	Activity Level
AR	autoregressive
avg	average
BCC	Banker, Charnes and Cooper model
BJ	Box Jenkins
bln	billion
BPG	Breusch Pagan Godfrey
BRT	bus rapid transit
C	costs
CA	Content Analysis
CBD	central business district
CCR	Charnes, Cooper and Rhodes model
Ch	Chapter
classical	linear model (CLM)
CLM	classical linear model
CNG	compressed natural gas
COLS	corrected ordinary least square
CoV	coefficient of variance
CRS	constant returns of scale
DA	data availability
DDEA	dynamic DEA
DEA	Data Envelopment Analysis
DV	dependent variable
DLP	dual linear programme
DMU	decision-making unit
DRS	decreasing returns to scale
DTW	Dynamic Time Warping
DV	dependent variable
DVB	Dresdner Verkehrsbetriebe
DW	Durbin-Watson
e.g.	for instance
EC	European Commission
ED	Euclidian Distance

EE	efficiency-effectiveness score
EEM	efficiency-effectiveness matrix
ERP	enterprise resource planning
Es	effectiveness
ES	effect size
etc.	et cetera
EU	European Union
EX	external
Ey	efficiency
FCT	Fundação para a Ciência e a Tecnologia
FD	first difference
FDH	free-disposal-hull
FP	fractional programme
GA	general aviation
GDP	gross domestic product
GDR	German Democratic Republic
HR	human resources
i.e.	that is
i.i.d.	independently, identically distributed
IN	internal
IP	input
IRS	increasing returns to scale
ISO	International Organization for Standardization
IT	information technology
ITS	intelligent transport/traffic system
IV	independent variable
IVI	Institut für Verkehrs- und Infrastruktursysteme
JB	Jarque Bera
KPI	key performance indicators
L	lag
LC	learning curve
LCCS	longest common subsequence similarity
log	logarithm
LP	linear programme
LPG	liquefied petroleum gas
LRT	light rail transit
MA	moving average
main-cat.	main-category
max	maximum
MB	Mercedes Benz
MI	Malmquist Index
min	minimum
mix	mixed performance measure
ML	maximum likelihood
MRS	marginal rate of substitution
mun	municipality
NP	non-parametric
NRW	North Rhine-Westphalia

nw-DEA	network DEA
OD	origin-destination
OECD	Organisation for Economic Co-operation and Development
OLS	ordinary least square
OP	output
op	operations
OR	operations research
OSDEA	Open Source DEA
P	parametric
PA	performance analysis
PACF	partial autocorrelation function
PE	allocative/price efficiency
Perf.	performance
pk-bs ratio	peak to base ratio
p-km, pax-km	passenger-km
PLP	primal linear programme
pop	population
PR	public relations
Prob.	probability
PT	public transport
R&D	research and development
R^2	R-square
ROW	right of way
SAP	software company
SBC	Schwarz Bayesian information criterion
SBM	slack-based measure
SC	selection criteria
SE	scale efficiency
SFA	stochastic frontier analysis
SLO	service level obligations
STCP	Sociedade de Transportes Colectivos do Porto
sub-cat.	sub-category
TE	technical efficiency
TFP	total factor productivity
TRB	Transport Research Board
UITP	Union Internationale des Transports Publics
US	United States
V	variable
var.	variable
Vis.	Visualization
v-km	vehicle-km
VRS	variable returns of scale
WW2	World War 2
X-mas	Christmas

1 Introduction

1.1 Research Rational

The success story of urbanization with cities accumulating more and more people on less space fundamentally relies on efficient public transport systems, not only to facilitate economic progress and wealth but also to sustain and improve the quality of life of the urban population. Especially in times of economic insecurity, soaring energy prices and increasing environmental concerns, public transport is a promising alternative to cost-intense, congestion-prone individual transport in urban agglomerations. Even if urban travel is still dominated by individual car use, specifically European cities are experiencing a positive trend in public transport ridership in recent years. To exploit theses dynamics, other than the implementation of new technological solutions, the *understanding*, *planning*, *organization* and *management* of public transport in a holistic manner needs to be top of the agenda, both for regulators and operators.

On one hand, regulators and local authorities are in need to design transport policy frameworks that trigger operator performance and maximize public objectives at minimal costs. This again relies on the validity of information about the productivity of operators, costs, market trends, etc. and how interventions such as (re)(de)regulation, ownership, subsidies, contracts, etc. affect these parameters. *On the other hand*, operators are increasingly under pressure to improve operational and economic performance. Chronic underfinancing, car-orientation, economic turmoil, and the ever-changing operational environment require management boards more than ever to seek for innovative, business-oriented and economically viable opportunities for action and to respond quickly to new circumstances. *Management by performance* or other result-oriented management styles dominate nowadays, promoting the utilization of restricted resources at the best possible rate in order to increase competitiveness or value for money. However, the plethora of available data and information makes it increasingly difficult to understand the functioning of organisations. Thus, more complex and interdisciplinary approaches to performance and benchmarking is given a significant boost.

In this context, performance analysis has been gaining momentum in public transport research in order to make inferences about the *efficiency* and *effectiveness* of operators and to arrive at policy recommendations in a normative fashion. Assuming a production-like service creation composed of inputs and outputs, performance analysis enables the straightforward assessment of the multi-objective nature of public transport. Cross-sectional Data-Envelopment-Analysis (DEA) is the non-parametric gold standard of this discipline aiming at the comparative evaluation of the economic performance of multiple operators at one point in time (so-called *peer-benchmarking*). DEA essentially captivates with its handiness and simplicity regarding the absence of any a priori assumptions about the functional form of the production process, even in multiple output cases. However, in its conventional cross-sectional application in public transport performance research, the method is subject to several conceptual pitfalls.

First, the methodological features of DEA imply unrealistic levels of homogeneity, not only across DMUs (operators), but also with regard to inputs and outputs of the service production process. Due to variety of parameters in public transport provision ranging from *city topography* to *fleet age* to *quality of service* one might suspect a set of operators more likely to be heterogeneous than homogenous. With the risk of 'comparing apples to oranges' the validity of any DEA performance ranking becomes questionable at some point. Moreover, DEA is designed for DMUs that share the same environment or that at least operate in a common market. This is obviously not the case for public transport operators in cities wide apart.

Second, the snapshot character of cross-sectional DEA does not provide information about the changes of performance over time, commonly referred to as *self-benchmarking*. For instance, when weak-performers in fact exhibit much higher performance improvements over time than best performers, should a policy framework be designed for best performers or best improvers? *Time-series* DEA would therefore allow pursuing research questions that usually cannot be addressed with a cross-sectional set-up, such as performance trends or the impact of changes in policy, operator organisation, or decision-making.

Third, performance analysis predominantly focuses on efficiency (supply-side outputs) as the only meaningful operator objective. In fact, public transport service has multiple objectives. Thus, the incorporation of effectiveness (demand-side outputs) would give a broader understanding on the impacts of the operator on the (transport) system as a whole.

Fourth, the ranking produced by cross-sectional DEA is deemed inappropriate to test for explanatory factors of performance. The standard narrative of performance drivers in public transport refers to pivotal policy changes and other elements outside the control of the operator management. Favourable regulatory and institutional changes in public transport undoubtedly affect operator performance. However, standard performance analysis cannot provide answers as to how this mechanism essentially works. Several authors argue these changes might in fact function through operator management taking better operational and strategic decisions, enhancing commercial focus and developing skills and accountability due to higher managerial autonomy. In fact, it would be interesting to assess how operators affect performance over time trough certain decisions or practices and to make inferences about them accordingly.

Overall, any one-sided and incomplete assessment of economic performance bears the risk of misleading rankings, flawed policy-making and inefficient operator management. All actors involved require proper tools to increase the quality and impact of choices. However, for regulators to design an adequate policy framework and for operators to choose the strategy that improves performance it is pivotal to better understand the determinants of performance.

(1) By focusing on the temporal interpretation of conventional DEA models - termed *time-series DEA* - the issues described above are circumvented elegantly. A self-benchmarking approach offers a promising way to reconsider the way performance analysis is usually conducted.

(2) The inclusion of both performance concepts - *efficiency* and *effectiveness* - enables to assess the magnitude and interaction of different managerial and societal objectives under the assumption that public transport service is a multiple-output product beneficial to society.

(3) By accounting for new types of explanatory approaches to performance, a more realistic view on the complexity of the underlying production process can be achieved. The assessment of managerial decisions as a proxy for *endogenous* and *exogenous* influences on the operator allows determining how service provision is practically realized and how this relates to the performance observed. As such, operator performance can be explained by decision-making.

DEA time-series approaches are obviously underrepresented in literature, supposedly due to constrained data availability. To the best knowledge between 2002 and 2014, no time-series study was published. The lack of references tackling these issues and beyond, gives a clear indication for the need to perform this research. Thus, the present research proposes a holistic *two-staged DEA* framework to assess the dynamic effects from managerial decisions and other factors on the economic performance (*efficiency* and *effectiveness*) of three public transport operators from Portugal and Germany, namely Hamburg Hochbahn (Hamburg), STCP (Porto) and DVB (Dresden) over the course of 64 years (1950-2013). The two-staged design preserves the nonparametric conventions of DEA at stage one and enables to apply statistical techniques on stage two. Production and decision data is collected from annual operator reports; the latter of which is initially operationalized by means of Content Analysis. In contrast to previous research, the three-inputs-one-output DEA is altered from *cross-sectional* to *time-series*, which - in the *first* stage - allows for an individual assessment of operator performance against its past values, following the logic of *self-benchmarking*. In a *second*-stage, the performance time-series are then regressed on the operationalized managerial decision time-series in a dynamic time-series regression framework. The analysis is conducted for each operator separately. By focusing on the operators one after another, performance as well as managerial actions can be measured in a more comprehensible way. However, individual findings are eventually compared across operators in order to identify similarities and differences.

1.2 Research Objectives and Questions

The following objectives for this PhD thesis were defined in the thesis project of 12/2012:

Extension of the approach of Costa et al. (2014) to three European transport operators.

Creation of databases on (a) input and output data (b) performance data and (c) on decisions taken by each operator over the course of time.

Derivation of suggestions about the evolution of economic performance of operators over time and distinction between different types of performance orientation.

Derivation of suggestions about the nature of the effects of managerial decisions on the performance of the public transport operators to a quantitative and temporal extent.

Objectives are then pursued by answering the sequence of research questions displayed in Table 1.1, which rely on different types of research.

Table 1.1: Research Question, Model Types and Reference. Adapted from Gauch (2015).

Main research questions	Type of Model	Chapter
What is the role of operator management in a public transport production model with respect to decisions?	qualitative, conceptual	'Literature Review'
What are pivotal decisions in operator management, and how can they be grouped?	qualitative, conceptual	'Modelling Managerial Decisions'
How does managerial decision-making behave over time, e.g. the importance of certain decision categories? Are there similarities across operators? Are decision patterns comparable?	qualitative, quantitative, descriptive	'Modelling Managerial Decisions'
What can be learnt from the production data over time? How does operator performance behave over time? What is the relation of operator efficiency and effectiveness over time? Are there similarities across operators? Can one derive other meaningful measures or information from the production or performance time-series?	quantitative, economic	'Modelling Performance'

To which extent do managerial decisions affect operator performance over time and are there similarities across operators? To which extent do social-economic variables affect operator performance? Are there similarities across operators?	quantitative, econometric	'Decision-Performance Link'

Overall, the time-series-based, two-staged DEA is an innovative tool to better understand some basic economic principles of operator management, particularly with regard to the efficiency-effectiveness nexus. It further advances the field of DEA performance research on public transport at methodological and theoretical levels. As to the latter, the approach suggests to test one of the conventional assumptions of cross-sectional DEA in a counter-factual manner. In a set of operators, if management decisions have the same effect on performance regardless of the operator assessed, the issue of operator heterogeneity might be negligible for this type of performance study. In this case, the application of cross-sectional DEA would most likely produce meaningful operator rankings as a comparative analysis of *similar* circumstances. However, when the effects from managerial decisions on performance exhibit more differences than similarities across operators, a cross-sectional DEA should be avoided or only applied to a sub-set of similar operators. In addition, finding similar decisions with different effects allows to draw sound conclusions about the importance of the contextual framework of operators.

1.3 Research Structure

Following an inductive logic over eight chapters, the research commences with *observation* (qualitative conceptual models) followed by *measurement* and *identification* of patterns and similarities (quantitative economic and econometric models). The results ultimately allow the formulation of general conclusions and tentative hypothesis.[1]

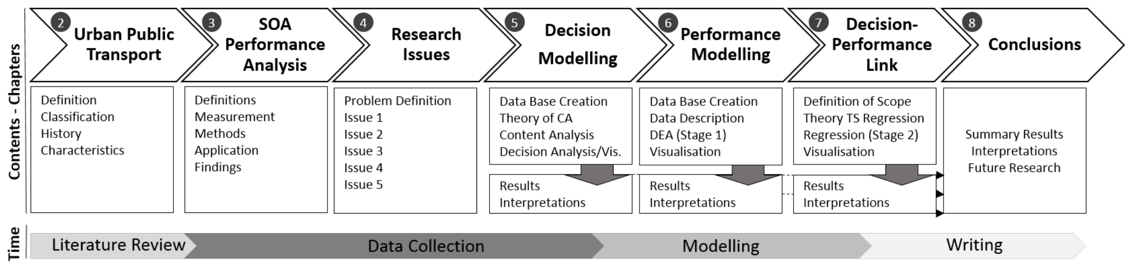

Figure 1.1: PhD Research Structure.

Chapter 2 gives an brief introduction to the nature of public transport in general. The section firstly covers common definitions, technical classifications and system components and secondly summarizes its historical evolution from 1600 until modern times. The third part focuses on

[1]**Note:** Informed readers may want to skip theoretical basics and start with Chapter 4, which condenses the achievements of Chapter 2 and 3. Further, Chapters 5 to 7 contain in-depth summary sections merged in Chapter 8. Very busy readers might directly jump to section 7.6, in particular Table 7.26 and Figure 7.29 to see results at once.

general objectives of public transport for users, operator, society and regulators and further touches the surface of economic particularities such as market failure and regulation.

Chapter 3 provides and in-depth literature review on performance analysis in public transport. First, an introductory notes about performance and benchmarking is given, including the basic terminology from production theory and a conceptual public transport production model. Second, traditional measurement methods are introduced and compared. Lastly, findings from studies with a focus on empirical results and determinants of performance are summarized.

Chapter 4 summarizes five pivotal research issues in the field of public transport performance analysis and referes to previous attempts to tackle these issues. The section narrows down to the overall approach chosen herein to answer the research questions raised in the introduction.

Chapter 5 uses Content Analysis to initially categorize and operationalize text-based decision data over time. This includes data adjustment by learning curves or standardisation. The decision data over time is then assessed descriptively for each operator. Further, measures of managerial characteristics or managerial focus are derived and relevant key findings presented in brevity.

Chapter 6 represents the first stage of the two-staged DEA. *First*, production data is extensively compared. *Second,* particularities of time-series DEA and BCC-DEA model are reviewed. *Third*, key results of the DEA are presented innovatively. Lastly, key findings are summarized.

Chapter 7 - as the second stage of the two-staged DEA - is the centrepiece of this work, bringing together Chapter 5 and 6 empirically. First, the theoretical foundations of time-series regression are assessed with a particular focus on the model building procedure. Second, the larger part of the section focuses on the holistic modelling framework. Further, the software package used is presented and the modelling steps are explained exemplarily. Lastly, results are presented (by visualization and charts) and discussed extensively.

Chapter 8 summarizes findings and interpretations and outlines future research activities in five areas: *improvement* of the approach, *reconfiguration* of the models, *reformulation* of the approach, *conceptual innovations* or development of a *decision-support tool*.

For any scientific research, an essential challenge is to design the communication of knowledge and results in the most effective way. Too complex information might impede the reader to understand the key issues addressed. *"Scientists are now using more interpretive graphic art than ever to convey their ideas and results. New visual techniques are developed to better understand and communicate the experimental and computational results"* (Ao, 2010) Accordingly, this research uses innovative types of visualizations to facilitate making inferences.

1.4 Research Objects - Hochbahn, STCP, DVB

The majority of performance studies in public transport take operators as sample unit. Therefore, three publicly owned operators from Germany and Portugal serve as data sources, in particular their annual reports (recapitulate activities for the public, shareholders, employees, see Appendix 21). They are available as hard copies and a few in digital form. In total, data from up to 64 years is collected for each operator allowing to create unique databases for future research. The lack of availability of time series data is a strong constraint of developing the field.

Table 1.2: Operators characteristics. Figures from 2013.

Operator	City	Modes	Owner	Network	Vehicles	Staff	Pax	Period	Years
Hochbahn	Hamburg	bus, metro	public (mun)	852 km	1560	4836	435 m	1950-2013	64
STCP	Porto	bus	public (state/mun)	490 km	480	1257	81 m	1950-2013	64
DVB	Dresden	bus, tram	public (mun)	402 km	356	1753	152 m	1957-2013	57

Hamburg Hochbahn: 'Hochbahn', founded in 1911, operates 111 bus lines and four predominantly surfaced subway lines. The operator is Germany´s second largest public transport provider and major partner of the Hamburg Transport Association, 1965 the first of its kind worldwide. Hochbahn was the first to implement a fully computer-supported control system to locate buses and calculate delays. It also set the worldwide standard for 'push articulated buses' and operates the world's largest fuel cell bus fleet. From 2020 on the operator aims to run buses entirely on hydrogen, the future storage medium for renewable energies.

STCP: 'Sociedade de Transportes Colectivos do Porto - founded in 1946 - operates 69 bus lines in (the greater metropolitan area of) Porto and a few historic tramlines. The operator runs one of the largest fleet of CNG buses in Europe and intends to increase the share of CNG vehicles to over 90% by 2020. In addition, STCP is the first operator to implement a large-scale network of connected vehicles (moving Wi-Fi hotspots), a technology, which is believed to have great implications for operational performance, service and business diversification of operators.

DVB: 'Dresdner Verkehrsbetriebe AG' - founded in 1930 - operates 28 bus lines and 12 tramlines (up to 45-metre trams plus a cargo tram) in the city of Dresden. DVB is ambitiously testing diesel-hybrid engines to reduce fuel consumption by up to 20%. A fully electric bus line is integrated into route serve. Most recently, in co-operation with Fraunhofer IVI the 'AutoTram' was unveiled, a bus of 30.73 meters length to serve high capacity corridors to and from the university. Since a few years, displays of e-books are used to change timetable alterations remotely and swiftly at low costs (as opposed to manual changes at 4000 stops).

As noted in the research objectives it is pivotal to understand if these operators share some common features with regard decision-making and performance and the interrelation of both.

2 Urban Public Transport

2.1 Definition and Classification

Available literature appears to lack of a common and clear scientific definition for *public transport*. The term is rather defined by *mode classifications*, *system characteristics, and operational concepts* or simply by the observation *perspective* taken.[2]

DEFINITIONS: Technically speaking, public transport is a shared transport service for a large number of passengers, with a predetermined schedule and frequency, working on predefined routes and in exchange for a fare. It aims at guarantying accessibility for the public - *by means of affordable transport service- ,* the reduction of road-born congestion - *by artificially increasing road capacity-,* and the stimulation of sustainable urban development - *by mitigating urban emissions and pollution* (Costa and Fernandes, 2012; Faivre d'Arcier, 2014; Rodrigue et al., 2013).[3] Public transport comes in all shapes and sizes: *horizontally or vertically integrated/separated*, in *public* or *private* ownership, providing *single* or *mixed mode services*, *subsidized* or *non-subsidized*, and so forth. It is generally considered a *labour intense* sector requiring *heavy investments* in infrastructure, usually leading to *high operating costs* in the short or medium term. The economic concepts of *economies of scale and density* can be linked to public transport due to the production under *network conditions*. A variety of *market failures* is associated with public transport such as the *lack of competition* or *failed cost recovery* through ticket sales or subscriptions. This in turn gives reason for *regulatory* and *financial intervention* of governmental bodies (Brons et al., 2005; Daraio et al., 2016; Faivre d'Arcier, 2014; Rietveld and Westin, 2006). When seen from a more holistic perspective, public transport can be also understood as a *derivative of general processes* in a *transport market*. For instance, when public

[2]For instance user-, planning-, management-, operations-, policy-, research-perspective.
[3]Philosophically, public transport seems to be the result of limited resources, e.g. space, energy, time, or technology. Except for social reasons, if all of these resources were freely available, public transport would not exist.

transport shares the same physical network with *private transport*[4], both types affect each other and are traditionally perceived as *competitors,* for users, space and political backing. However, since the options of charging for external costs from private transport are limited, public transport should be subsidized in order to be competitive and attractive (Vuchic, 2007).[5] In the present research, the term 'public transport' is geographically limited to *city* or *metropolitan* levels within Europe contrary to White (2009) who considers a wider definition. In this regard it should be stressed that transport services with similar features as the ones from above but provided for longer distances or in rural[6] areas are not intended to be further assessed herein (e.g. high speed trains, long distance buses, BRT systems).[7,8] In line with Daraio et al. (2016)[9] 'public transport' should be understood as 'urban public transport'[10]. The notion 'urban', however, is subject to some degree of heterogeneity, as modern cities are characterized by large differences in the level of urbanization and so are their transport systems (Wei et al., 2013).

As mentioned before, definitions and classification for urban public transport are majorly of technical nature. Table 2.1 summarizes technical components of public transport systems in general and their function. As indicated in the fourth column, another way to canvass public transport is to simply focus on the variety of sub-systems or modes.

Table 2.1: Public transport system components. Adapted from Vuchic (2007).

Technical Components	Function	Interpretation	Sub-system
vehicle, train	transport of passengers	fleet, rolling stock	yes
carriage way	enables movement of vehicle	infrastructure (fixed)	yes
stops, station, terminal, transfer station	pick- up and drop off points for passengers		yes/no
depot	vehicle storage and maintenance		yes
power supply system	energy distribution for fleet propulsion, lighting		yes
control system	vehicle monitoring, signalling and communication		yes/no
IT, ITS	system monitoring and controlling (operationally, economically		no
lines, routes	regular service references for specific OD pairs	network (flexible)	yes

[4]Private transport - in fact the most common mode - is defined either by the operation of privately owned vehicles or by non-motorized modes (cars, two-, three wheelers, pedestrians, bikes).
[5]For the sake of completeness, *on-demand services* (taxis or dial-a-ride) combine the advantages of public and private transport, e.g. by providing services for individuals or groups that hire them for individual or multiple trips (Vuchic (2007)). Though on-demand services are publicly available, they are specified separately in literature.
[6]The provision of public transport in urban areas differs significantly to that in rural areas for several reasons: complexity/dynamics of urban development, higher passenger demand/throughput, higher volatility of customer behaviour, competition with other mobility services, comparatively higher capital and infrastructure costs, limitations for operators to freely conduct business due to constant construction works, common traffic or fare policies.
[7]These modes mostly do not need subsidies, at least if infrastructures construction costs are excluded.
[8]White (2009) definition includes various modes: rail, coaches, air transport, taxis, private bus, school bus services.
[9]The authors use two expressions for urban context: *local public transport* and *urban public transport.*
[10]'Public transport', is also referred to as '*transit', 'public transit'* or '*public transportation'* according to Ceder (2007).

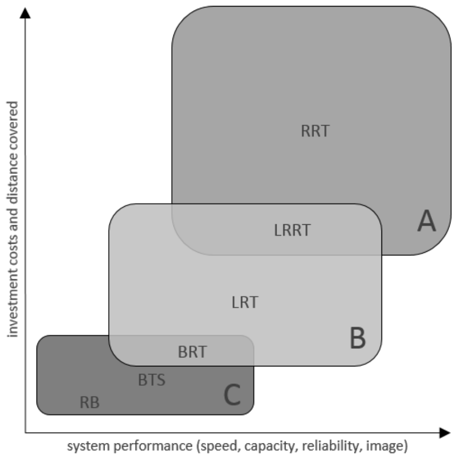

Figure 2.1: Right-of-Way categories for public transport modes. Adapted from Vuchic (2007).

In this regard, Vuchic (2007) notes that *"urban transport modes differ greatly in their technical, operational, and economic characteristics as well as their impacts"* and suggests the following criteria for a better (mode) classification: *right-of-way category*, *technology* and *type of service*.

CLASSIFICATION BY ROW: The *right-of-way (ROW)* relates to physical infrastructure specifics on which vehicles operate and to their interaction with general urban traffic. As shown in Figure 2.1 three ROW-categories are proposed: Modes in category 'C' share public streets with general traffic, modes in category 'B' are partially separated, and modes in category 'A' are physically separated from other traffic flows. Whereas modes in categories 'C' and 'B' are operated either on public streets or on longitudinally separated centre strips with intersections at grade, modes operated in category 'A' feature high levels of system independence granted by tunnels, elevated structures or fully-protected, at-grade rail or roadways. Consequently, performance and costs increase from category 'A' to 'C'.

CLASSIFICATION BY TECHNOLOGY: The *technology criteria* relates to the technical features of vehicles and roadways. The criteria can be sub-divided in *support* (e.g. the connection between vehicle and roadway, such as rubber tires on road, or steel wheels on road track), *guidance* (e.g. whether the vehicle is steered by a driver or guided by some form of guideway), *propulsion* (e.g. internal combustion engine, electric motor, linear induction motor) *and control* (e.g. the means of regulation, operation and monitoring the vehicle in the system[11]).

CLASSIFICATION BY TYPE OF SERVICE: Thirdly, the *type of service criteria* refers to the types of routes provided (interurban, suburban, regional), the stopping procedure (regular, skip-stop) and time of operation and purpose (24/7, peak-hour, nightlines, dedicated services).

[11]In a range from conventional driver systems (STCP Porto) to unattended train operation (Line 9, Metro Barcelona).

SUMMARY: From a *planning perspective*, the right-of-way classification is important since it shows how infrastructural preconditions can be linked to costs and system performance. From a *user perspective*, the technology and service criteria of certain modes seems to be easier to comprehend, since it is relatively straightforward to 'visually' differentiate between bus (line), electric tram (line) and metro (line). However, as the mode classification scheme demonstrates, multidimensionality and overlaps of criteria will not necessarily allow identifying unambiguous (mode) definitions. Nevertheless, Table 2.2 tentatively presents various public transport modes and their characteristics bundled to just three generic classes based *"mostly but not entirely on right-of-way type"* (Vuchic, 2007).

Table 2.2: Generic public transport mode classification. Adapted from Vuchic (2007).

Modes	ROW	Relation Performance and Traffic	Performance	Generic Class
shuttle bus ***bus: regular bus*** bus: express bus: trolley ***tram***	C	depends fully on traffic conditions	low	SURFACE
light rail transit bus rapid transit automated guided shuttle	(C) B (A)	depends partly on traffic conditions (degree and location of separation; level of automatic signalisation)	medium	SEMIRAPID
Automated Guided Transit light rail rapid transit rubber-tired rapid transit monorails ***metro*** regional rail	A	performance is uncoupled from traffic	high	RAPID TRANSIT

The most common modes are marked ***bold***.

In order to better understand the magnitude of differences of public transport modes (also with reference to individual transport) a collection of exemplary *performance data* is given in Table 2.3, complemented by mode-specific information below.[12]

Table 2.3: Performance comparison of urban transport modes. Adapted to Vuchic (2007) and RATP (2016).

Indicator (max)	Unit/Mode	*Private car*	Regular bus	Light rail	Metro
vehicle capacity	*seats/vehicle*	*6*	120	250	280
operating speed	*km/h*	*50*	25	45	60
line capacity	*seats/h*	*1,050*	8,000	20,000	70,000
productive capacity	*10^3 seat-km/h*	*25*	90	600	1800
lane width	*m*	*3.65*	3.65	3.60	4.30
station gap	*m*	-	200	500	500
emissions	*gCO2/p-km*	*206*	95.4	3.1	3.8
cost for pair of lanes*	*10^6 USD/km*	*1*	0.5	10	40

Regular Buses are by far the most common public transport mode worldwide. As to urban rail systems, it its worth to mention that especially in European cities traditional *tram* systems have

[12]BRT is excluded from this research since mostly operated outside of Europe.

widely been upgraded or replaced by modern *LRT* systems. Thus, a ROW categorization for tram-based modes is not always accurate, as there are overlaps between tram and LRT systems.[13] *Metro* systems show that high capacity comes with a price. Despite the differences, all modes described predominantly operate on fixed lines, with fixed schedules, under public, private or mixed ownership, in a highly regulated environment.

REGULAR BUS

- Diesel-, Electric-, Hydrogen-, Hybrid- powered
- surface mode, interaction with common traffic flow
- lane separation and prioritization applicable
- low volume on suburban and feeder lines
- high volume on intra-urban travel corridors
- minibus to bi-articulated bus
- driver and user can interact, e.g. for ticket purchase
- *express bus:* fewer stops, higher speed, other price
- *trolleybus:* higher comfort, less pollution, higher costs

Figure 2.2: Bi-articulated, regular bus.

(TRAM) AND LRT

- electrically powered rail vehicles
- interaction with common traffic flow possible (e.g. at intersections)
- mostly separated roadbeds in road medians, prioritized signals
- separate subsystem of tracks and overhead wires, sometimes stations
- operate in high-density central city areas
- driver and user cannot interact (except for vintage tourist trams)
- less noise and pollution than bus

Figure 2.3: Tram or 'Straßenbahn'.

METRO

- electrically powered rail vehicles
- exclusive separation, no interaction with common traffic, (full control)
- dedicated lane (surface, elevated or underground)
- separate subsystem of tracks, electrification, signalling, stations
- partially automated versions
- driver and user cannot interact
- less noise and pollution than LRT

Figure 2.4: Metro.

Based on tentative definitions found in the relevant literature as well as classifications rather of technical nature, this section describes the term 'public transport' as applied in this research. Vuchic (2007) gives a more detailed overview across all public transport modes.

The next section outlines important historical facts of public transport in brevity.

[13]For Santos et al. (2014) LRT ranges *"from conventional tramway to tram–train solutions"*.

2.2 Historical Overview

Ever since, urban areas have been centres of aggregated economic activity. On one hand, the success story of 'urbanization' with cities accumulating more and more people on less space fundamentally relies on efficiently working transport systems, not only to facilitate economic progress and wealth but also to sustain and improve the quality of life of the urban population. On the other hand, it can be said that only high population densities make large-scale public transport modes such as urban rail and bus systems economically viable. As a starting point to this work, the following section introduces a few historical facts about urban public transport. Figure 2.5 summarizes major developments and pivotal disruptive technologies accordingly.

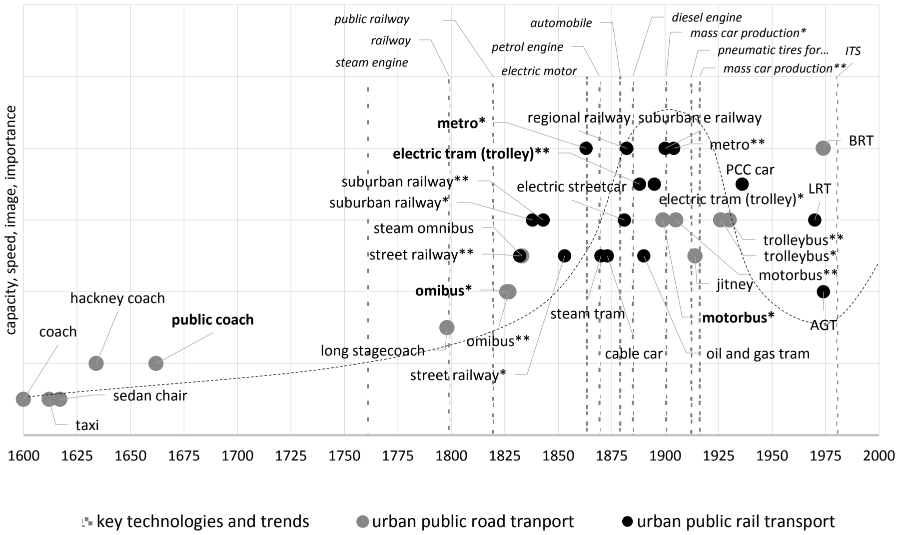

Figure 2.5: 400 years of public transport evolution. Modes marked in bold had a comparatively higher impact on ridership. The dashed line marks the importance of public transport over time. Adapted from Vuchic (2007).

Following Vuchic (2007) the use of boats and ferries as rudimentary means of public transport can be traced back to the time of ancient Greece, or to late-medieval Europe's trade hot spots in Venice and London. It was only in the sixteenth century, when first organized forms of collective transport like *posting services* were established to transport goods and people between cities on horse-powered stage wagons or stagecoaches. Later on, they were gradually adapted to intra-city conditions in terms of purpose, availability and capacity (1600: *hackney coaches* in London, 1612: *taxi* in Paris, 1617: *sedan chairs* in Paris, 1662: *public coach service* Paris). The first large-scale horse-powered urban transport services appeared in the early 19th century in Paris and London and were implemented worldwide until 1860, then called *omnibus*. Since 1832, a more efficient version with rail guidance (referred to as *horse-drawn trams*) was used. A main driver of innovation in these days was the search for a cheaper means of propulsion technology than horses. First steam-powered trams were operated with minor economic success in London from around 1830 on. Improved fireless versions were used in New Orleans, Paris and Lyon, however still majorly restricted by a limited range of only 15km. Different propulsion technologies such as compressed air systems, oil and gas motors, even large springs (1875 London) and the still operated cable traction (1873 San Francisco) marked the transition phase from *large-scale horse* to *engine-powered tram* systems.

Initiated by Siemens, which built the world's first *electric tram* line in 1881 and the invention of the overhead electric cable system (trolley) the era between 1880 and 1910 can be considered as the beginning and breakthrough of public transport as a means of urban mass transport. The rapidly growing market with strong competition among tram operators then gave municipalities favourable positions. Eventually, regulation and municipalisation[14] of services led to a *tram-induced* public *transport revolution* in large and medium-sized cities worldwide.[15,16] However, as depicted in Figure 2.5 from the mid-1900s on urban public transport was triggered, challenged and innovated through the continuous exploration of rail infrastructures (*metro systems* since 1863, suburban systems since 1838) and new propulsion technologies (*motorbus* since 1905, trolley bus since 1926) mostly with the intend to address costs, capacity, speed and distanced covered. In this regard, Costa and Fernandes (2012) argue that *"the success of any new mode of transport mode appears to be related with its ability to drive costs down and provide reliable, comfortable and safe services*". This logic helps to understand why the public transport evolution features similar stages as a *product lifecycle*, going from primarily horse-powered-road-based (introduction stage) to primarily engine-powered-rail-based (growth and saturation stage) to engine-powered-road-based (decline and revival stage) as indicated by the dashed line above.

The downturn of public transport was obviously linked to the invention of the petrol engine and the automobile, which ultimately emerged in full-scale production around the 1920s imposing strong impacts on public transport.[17] Until up to 1970 especially in the US, Great Britain and France[18] the increasing dominance of *individual car use* and the massive decline in public transport ridership, accompanied and reinforced by regulatory failure, conflicting commercial

[14]Market consolidations through mergers led to granted, licensed monopolies, oligopolies under public supervision.
[15]In terms of trams, the US and Europe showed different patterns of urban public transport (r)evolution: up to 1980 the total length of tramlines in Europe was 96 km with threefold increase until 1910. In the US by 1890 already 1,900 km of electric tram lines were implemented, by 1902 26,782 km, by 48,975 km (Vuchic (2007)).
[16]According to Costa and Fernandes (2012) urban public transport in Europe has been revolutionized only once. The mass utilization of the electric tram is the main reason for the comparatively high pace of diffusion around the globe.
[17]For product life-cycle see also Levitt (1965). Costa and Fernandes (2012) in similar manner identify three crucial evolution stages for modes: *entrepreneurial breakthrough, consolidation, public authority involvement stage*. Rodrigue et al. (2013) identify four distinct eras that shaped urban mobility: walking-horsecar (1800-1890), electric streetcar or transit (1890 - 1920s), automobile (1930s - 1950s) and freeway (1950s onward).
[18]To a lesser extend trams were dismantled in Germany, Netherlands, Austria and central Europe. Vuchic (2007): *"European municipalities were willing to accept the overhead system because they recognized the fact that the electric tramway offered positive social benefits, resulting primarily from greatly increased travel speed and reduced fares".*

interests, and the absence of any meaningful financial support for operators led to a severe reshaping of the sector (and consequently cities)[19]. Except for high-capacity rail systems (metro, suburban trains) public transport in many cities became predominately road-based labelled by the large-scale implementation of *bus systems*. Conversely, tram services were significantly neglected and widely dismantled. Only the appearance of *light rail traffic* as a medium-capacity but high-quality means of public transport in the 1970s helped to curb the bus trend partially.

Today urban travel is still dominated by individual car use. However, it appears that in recent years specifically European cities experience a positive trend in public transport ridership. The negative trend imposed by the dominance of individual car use has declined; absolute numbers such as passenger-km as well as relative market shares of public transport have been rising in most European cities (White, 2009). Vuchic (2007) argues that in particular *technological progress* may have influenced the first century of public transport majorly. Nowadays, other than the implementation of new technological solutions, the understanding, planning, organization and management of public transport in a holistic manner needs to be addressed in order to reclaim the importance the sector had 100 years ago.

The next section deals with non-technical, economic characteristics of a public transport system.

2.3 Objectives, Market Failure and Regulation

The role of public transport has considerably changed over last decades. Today public transport is unanimously associated with playing a key role in changing urban mobility patterns, reducing congestion, and exploring new economic opportunities. Moreover, public transport is a main item on political agendas and considered a major contributor for reaching the goals of sustainable urban mobility. The overall economic, social and environmental importance of public transport makes it widely considered as an essential service in cities, sometimes referred to as a public good or even as an essential right (Daraio et al., 2016; Jarboui et al., 2012; Kerstens, 1996). In addition to the seamless physical, operational, and financial integration of public transport into urban travel patterns, the appropriate approach to its regulation[20] as a *public-good-like service* is a prerequisite for eventually reaping the benefits of *modern sustainable transport* (Brons et al., 2005). In this regard Litman (2011) generalizes that benefits from public

[19]Interestingly, the electric railway in the US was organized by the National City Lines Consortium, formed by companies that produced (products for) highway vehicles (buses, cars, rubber tires, oil) causing a conflict of interests.
[20]Kockelman et al. (2013): Regulation is defined as *"controlling human or societal behaviour by rules or restrictions"*. Economic regulation traditionally has been designed to prevent monopolistic behaviour in private-sector firms by controlling maximum prices, rates-of-return on investments, conditions of service provision, market entry and exit, mergers and acquisitions, accounting practices.

transport are often overlooked and undervalued as for instance changes in mobility, vehicle ownership, parking costs or land development fail to be quantified appropriately.

OBJECTIVES: Objectives, obstacles, and benefits of public transport are often discussed rather fragmentarily in scientific/non-scientific literature and depend majorly on the perspective taken. As Table 2.4 illustrates, between the different agents of a public transport framework objectives can obviously vary, oppose, diverge and at some point obviously be 'wishful thinking'. According to Daraio et al. (2016) the objectives of any public transport system are at least twofold. The offer of any public transport system should be efficient and in quality, while simultaneously a reasonable level of access to transport services should be provided. For Costa and Markellos (1997) and Costa (1998) this inherent ambiguity breaks down to the two main functions of any public transport system, namely *"the production of the service* and *its utilization"*. However, both functions are determined by different agents with conflicting objectives, namely *operators* and *users*. From a system perspective, this dualism[21] eventually leads to market failure - or in other words - a scenario where an agent's pursuit of self-interest creates results that are not efficient from the *societal* viewpoint. Then usually a *regulato*r appears on the scene to balance the objectives of all agents simultaneously which should coincide in the best case with its own public policy objectives, such as welfare stimulation, equity and fairness (Faivre d'Arcier, 2014; Jarboui et al., 2012; Margari et al., 2007; Rietveld and Westin, 2006).

Table 2.4: Urban public transport: agents and objectives.

Operator	User	Society	Government/Regulator
revenue (+) outputs (+) subsidies (+) continuity (+) losses (-) costs (-) inputs (-) competition (-)	access (+) quality (+) security (+) safety (+) costs (-) time (-)	sustainability (+) accessibility (+) mobility (+) health (+) employment (+) energy use (-) traffic congestion (-) emissions (-)	equity (+) public service (+) tax income (+) allocative efficiency (+) productive efficiency (+) public expenditure (-) opportunity costs (-) subsidies (-) regulatory costs (-)

MARKET FAILURE: To better understand the motives of regulation, first one has to look at the individual behaviour of *users* and *operators* under the assumption of free, unregulated market conditions.[22] *Operators* aim at working efficiently towards their economic goals on the base of profit or output maximization and cost minimization. *Users* again, generally aim at cheap, fast, convenient and safe travel modes. The supply-demand-like dependency of operators and users could lead to the following scenarios in unregulated markets: When public transport services

[21]Stevenson (2010): "Division of something conceptually into two opposed or contrasted aspects".
[22]For a deeper insight, see Rietveld and Westin (2006) pp. 179ff. See also van Egmond et al. (2003) on stakeholders.

are subject to a seller market, usually monopolistic (or oligopolistic) structures with high prices (and strong competition) and adverse effects on quality of services (and traffic safety) occur.[23] Conversely, in a situation with lower user demand for public transport services, the absence of economic incentives[24] commonly impedes incumbents to expand supply to a socially acceptable level or outside operators to even enter the market. Also, high set-up and fixed costs function as marked entry barriers and protect incumbent operators.[25] Conventional market mechanisms thus appear to (re)enforce a somewhat vicious cycle of quality and supply deteriorations of public transport services at the expenses of society.[26] In economics, similar phenomena are referred to as *market failure*[27] caused by externalities, imperfect information, public goods and natural monopolies. In a broader sense, a market failure is either defined as the occurrence of imperfect competition with the side effects of abusive monopolistic price power or the absence of the service itself due to the lack of profitability of services. As suggested above, specifically two dispositions for market failure can be directly associated with the characteristics of public transport provision: the nature of a public good[28] and a natural monopoly (van Wee, 2013).

REGULATION (THEORY): A response to market failure is regulation. That is when the government essentially defines which form and quantity of service is appropriate for society, based on estimations about the benefits of its provision. Besides primarily intending to avoid the negative by-products of market failure for society in a *practical* sense, there is obviously sound *theoretical* evidence for regulation. High fixed costs and economies to scale lead to monopolistic markets structures. More precisely, economies of scale, scope, and density create certain cost advantages that function as anticompetitive market entry barriers. They then indicate the potential to 'forcibly' adjust operator size and network utilization. Especially economies of scale and density are fundamental concepts in transport economics as they capture the quantitative, spatial and temporal dimensions of service provision and characterise the true nature of the underlying transportation technology and effects in terms of performance, costs and quality (Daraio et al., 2016). The former relates to cost effects from operator size; the latter to cost

[23]Excess of demand over supply of public transport services, e.g. in countries with low car ownership rates. The monopolistic structure is not a natural one, thus the operator abuse its market power to set prices.
[24]E.g. marginal revenue equals zero.
[25]Faivre d'Arcier (2014) argue that public transport provision naturally lacks of competiveness, as supply is not limited to peak hours or central zones, which are the most profitable segments.
[26]The US is a good example that regulatory reluctance leads to devastating performances in public transport. In most of the major US cities, public transport is highly inefficient with aged infrastructures, precarious financial conditions and inadequate maintenance, just like 100 years ago (see Vuchic (2007) and Buehler and Pucher (2011)). In 2008 US public transport subsidies accounted for 40 bln USD; in contrast the EU spent 270 bln USD (Diana and Daraio (2014)).
[27]Market failure is equal to a non-pareto efficient state. In a Pareto-efficient state, none of the agents or individual could improve his position without worsening those of others.
[28]Non-excludability, non-rivalry, non-rejection.

effects from the utilization of the network[29]. Scale economies have been intensely studied as demonstrated in reviews from Ermagun and Levinson (2015) or Graham et al. (2003). The research indicates a 'u-shaped' average cost function for public transport (Rietveld and Westin, 2006). As to the fleet size of operators, this suggests increasing returns of scale for smaller operators and decreasing returns of scale for bigger operators (*diseconomies of scale*). The results also point at the existence of an optimal level of fleet size. A similar logic applies to economies of density, especially in bus services. Depending on demand and economic viability, increased utilization in uncongested networks appears to reduce average costs, whereas increased utilization in congested networks increases prices (*diseconomies of density*) (Borger et al., 2002; Rietveld and Westin, 2006). As noted above, due to economies of scale and density and the characteristics of a public good, a monopolistic market structure with imperfect competition is a very likely outcome if public transport is unregulated.

A monopoly is not necessarily a 'bad thing' from a social welfare point of view if it is one associated with the concept of subadditivity[30]. Typically, so called *natural monopolies* are common in industries with very high initial investment cost (market entry barrier) but infinitely small marginal costs for additional customers (network industries like railways, water, electricity, telecommunication (Rietveld and Westin, 2006)). However, natural monopolies cannot be 'forced' to set prices at marginal costs (which is the price that would be formed in perfect competition). Prices at marginal costs will make the operator leave the market, which obviously is not a desired outcome in public transport provision. In addition, a natural monopoly is always prone to shift to non-natural one posing a substantial threat to consumers, as prices can be manipulated by the exclusive power of the operator over supply. From regulatory perspective the challenge is then to implement a policy in which a natural monopolist produces effective levels of public transport services in a financially viable scenario (with reasonable costs for the user and reasonable revenues for the operator).[31] Daraio et al. (2016) note that in this regards governmental intervention has to consider at which organisational level to intervene (political, planning, administration), which timely framework to target (operational, tactical, strategic) and how to evaluate actions (simple, advanced, complex).[32]

[29]Scope (effects from product mix): almost no studies on public transport.
[30]In a natural monopoly, the production costs C for a quantity of goods x are smaller when produced entirely by one company than if produced by several companies sharing the market. This requires continuously increasing economies of scale at every range of production, also referred to as subadditivity: $C(\sum x) < \sum C(x)$. This implies that for instance a merger of operators might create a better outcome for society than separated operators.
[31]With reference to a u-shape cost function, a naturally monopoly might be of temporary state. Increased demand over time might shift curves to a range of constant or diseconomies of scale, allowing competitors to enter the market.
[32]*Simple:* how much "output", given some input. *Advanced:* how intervention affects the transport system. *Complex:* how the intervention affects a vector of social goals given its use of social resources.

REGULATION (PRACTICE): Despite the fact that urban transport policy in the last decades was dominated by deregulation and privatization of public transport services in most countries,[33] in recent years governments seem to increasingly reconsider regulative measures, paraphrased by Rietveld and Westin (2006) as the *"pendulum swings back"*[34]. Regulatory inventions in public transport occur mostly if the government assumes that the operator's objectives are contrary to that of public interest. Theoretical market interventions for (natural) monopolies range from *do-nothing*, to *rate-of-return pricing*, to *peak-load pricing*, to *price-capping*, to *Ramsey pricing* (Coelli, 2003; Joskow, 2007). In practical terms, four approaches exist to tackle issues of market organization in public transport: public[35] or regulated private monopoly[36] with closed markets, limited competition (competition for the market, competitive tendering) and entirely deregulated markets (see Table 2.5).

Table 2.5: Degree of regulation in public transport. Adapted from Wang et al. (2015) and Coelli (2003).

Criteria	Regulation	Semi-regulation	Semi-deregulation	Deregulation
principle	no competition	no competition	competition for the market	competition in the market
objective	user benefits	user benefits	society benefits	operator benefits
market	public monopoly	private monopoly	granted monopoly	free market
supply control	yes	yes, price regulation	yes	no
subsidization	no	no	yes	no
ownership	public	private	public or private	multiple
operator selection	grandfathering, nomination	grandfathering, nomination	competitive tendering, direct awarding	open entry

Especially in Europe, recently *competition for the market* (also limited competition, franchise bidding) is a politically favoured exit strategy from public monopolies and often accompanied by subsidy schemes and some public transport co-ordination (van Egmond et al., 2003). The approach can preserve the benefits of economies of density and scale while similarly exploiting the benefits of competition in terms of costs, efficiency, quality, and innovation. According to Costa (1998) *"this reflects the desire to have an effective public transport system achieved by the co-ordination of transport authorities and, in the cases of tendered services, also an efficient one with the discipline of market forces driving operational costs down".* In this regard, Public Service Obligations (PSO) are a common but to some extent debatable practice in European public

[33]Guided by the basic assumption that privately owned companies provide more efficient and effective services than public ones, the process of deregulation was induced by rising concerns about public budget deficits in the 1970s, after a long period of nationalization after WW2.

[34]The EU legal framework, regulatory reforms on various levels such as regulation 1370/2007 and organisational models in European are discussed by Faivre d'Arcier (2014), Zatti (2012), Molander et al. (2012), Margari et al. (2007), Rietveld and Westin (2006), van Egmond et al. (2003), Pina and Torres (2001), Button and Costa (1998), Costa (1996). Alternatives beyond competitive tendering are demonstrated by Beck (2012). Competition in deregulated public transport markets is analysed by van de Velde and Augustin (2014).

[35]Similar to municipalisation, preferred in Europe.

[36]Private ownership combined with some form of cost-plus rate of return regulation, where the regulated firm is allowed to set prices to cover noncapital costs plus a fair rate of return on capital, preferred in US. Coelli (2003).

transport policy.[37] PSO grant monopolies for a fixed time, but mandate the operator to provide a pre-defined level of service especially in areas where the provision usually generates losses, such as off-peak service in public transport or in urban fringes. The operator might then cross-subsidize his losses with revenues from the profitable business segments (peak hour, CBD service), or receives subsidies as compensation if the entire service is loss-making (rural service) (Rietveld and Westin, 2006). In doing so, the government guarantees broadly accessible public transport supply even for less profitable connections and areas while simultaneously preventing the cherry-picking of profitable routes (Hensher and Wong, 2011; Pina and Torres, 2001)[38].

SUMMARY: When one recalls the objectives of the stakeholders in public transport as given in Table 2.4 it can be concluded that when public transport is unregulated, not only the objectives of operators and users might stay partially unachieved, but most importantly those of society as a whole. Reduced equity and accessibility and the burdens of externalities caused by individual car use are the consequences. It is safe to say that the lack of a competent regulator leads to immense social (opportunity) costs.[39] With reference to the issue of profit orientation of operators, Borger and Kerstens (2006) claim that *"there is no overall consensus on the proper goals of transit firms in the literature."* Recent research rather suggest a wide variety of objectives on operator levels, especially in regulated environments[40]. Daraio et al. (2016) argue that effects from adequate regulatory intervention contribute to public transport system efficiency (operator objective), quality (user objective) but also offer great potential for indirect effects, such as the reduction of congestion, pollution or improved labour provision (society objective). The latter effects usually justify subsidies for public transport, as the overall benefits would exceed costs. In this sense, the co-benefit potential of public transport makes it not only significantly different from unsubsidized economic activities in regular markets, but also from other common public sector activities, such as health care or education, where the primary focus mostly lies on objectives and benefits directly linked to the users (Diana and Daraio, 2014).

After having introduced the research object 'public transport' with regard to technical, historical and economic specifics, with an in-depth literature review the next chapter leads over to the concept of 'performance', eventually narrowing down to the research questions posed above.

[37]Rietveld and Westin (2006): Theoretically, the functioning of PSOs might create so-called *allocative inefficiencies.*
[38]Daraio et al. (2016): Though *competition for the market* (franchise bidding, tendering) is a widely applied means of cost determination in asymmetric markets, there are still some regulatory pitfalls: cost-minimization incentives could undermine the quality of service. In addition, the ownership of infrastructure could give the incumbent operator a comparatively stronger position at the time of franchise renewal.
[39]I.e. the cost of a choice forgone.
[40]Operator objectives in *normative* models: welfare maximization, distributive objectives, deficit financing, macro-economic objectives (reducing unemployment by overstaffing). Operator objectives in *positive* models: objectives are result of interaction between operator, regulatory environment, and pressure groups.

3 Literature Review on Performance Analysis in Public Transport

In three main blocks - termed *Definition*, *Measurement*, *Application* - this Chapter provides and in-depth literature review on *performance analysis in public transport*, based on roughly 100 publications in the field and neighbouring disciplines. The end goal of this chapter is two-fold. *First*, technical and non-technical readers should understand the basic principles of performance analysis and the achievement of previous studies. *Secondly*, the chapter should be a preparatory step to relate to the issues and approaches proposed in detail in Chapter 4. The chapter is organized as follows:

DEFINITION: THE NATURE OF PERFORMANCE gives introductory notes about *performance and benchmarking*, and leads over to *public transport* and *purposes* for performance analysis from *operator*, *regulator* and *research perspective*. Based on production theory, further, the basic *terminology* of performance analysis is introduced broadly. Finally, as a first output an extended *public transport production model* with the incorporation of *managerial decision* is presented.

MEASUREMENT: MODELLING PERFORMANCE is concerned with methods to assess performance empirically. First, major *intellectual traditions* and *research streams* are presented. Secondly, with *Data Envelopment Analysis (DEA)* and *Stochastic Frontier Analysis (SFA)*, two key methods of performance analysis are introduced extensively. Thirdly, based on a *comparative discussion* upon pros and cons, application, and data availability, it is highlighted why DEA is chosen.

APPLICATION: FINDINGS ON PERFORMANCE summarizes key findings from performance studies with a focus on *empirical results* and determinants of performance. Based on relevant indications from literature, for the latter subject a revised *classification scheme* is presented adding operations and management practices as potential performance drivers.

3.1 Definition: The Nature of Performance

Performance and Benchmarking

Just like the term 'public transport', a few complications are encountered when trying to find a commonly applied and plain definition for 'performance'. In general *performance analysis* or *performance measurement* implies to assess the *"degree of fulfilment of a claim, promise, or request"* or *"the manner in which a mechanism performs"* on individual or organizational level (Merriam-Webster.com, 2016). Poister (2003) circumscribes performance analysis rather holistically as the *"process of defining, monitoring, and using objective indicators for performance"*. In business-oriented writings performance is often equated to products, outputs, services, impacts, achievements, returns, revenues of stocks, firms and sub-divisions. In economic literature however - the research here is considered as such - performance *"can be defined in many ways"* (Coelli, 2005). It is frequently identified as a *productivity ratio*, *efficiency*, or *effectiveness* of public/non-public organizations.[41] Performance can be measured by using the efficiency concept (Avkiran, 2006; Cooper et al., 2007; Dang-Thanh, 2012). When dealing with the performance of organizations the presence of some sort of *input-output-nexus* is a fundamental assumption, also known as the production process, that is the *"ability to use resources to produce some output"* (Coelli, 2005; Graham et al., 2003; Wang, 2011). Important concepts can be derived from this assumption, which are further explored in section on production theory. In summary, these concepts differ significantly in complexity or perspective taken and thus majorly determine how the performance of whatever organization is defined, measured and interpreted. As Diana and Daraio (2014) argue "*performance is usually a more general word to encompass the different points of view that can be considered"*. For instance with reference to public transport Faivre d'Arcier (2014) define performance simply as the network's level of attractiveness, which is a very strong statement without further contextual elaboration. In most cases, however, authors simply avoid explicit performance definitions, as it seems assumed that either the reader is familiar with the term, or that the meaning becomes clear from the context presented.

Even if the terminology is vaguely defined, the underlying mechanisms of performance appear to be similar to those of neoclassical economic theory, specifically *rationality* and *maximization*. According to this logic performance then follows a *the-more-the-better*-principle and is meant

[41]Wang (2011) gives examples: public organization are states, cities, police, and hospitals. Non-public organizations are sectors, companies, branches, departments, sub-divisions. Following Coelli (2005) an organization or firm can be any form of decision making unit (DMU) depending on the level of aggregation (micro: firms, macro: states).

to be maximized by organizations, e.g. through higher revenues, more passengers, more patients, higher productivity, higher efficiency (Lampe and Hilgers, 2015). In addition Coelli (2005) refers to performance as a *relative concept by definition* frequently used in economics for comparative analyses of *"organizations across space, over time, or both…in one sector or across sectors"* (Borger et al., 2002; Jarboui et al., 2012). In other words, a meaningful interpretation of performance requires relating it either to similar past performances (*self-referencing*) or similar performances of similar organizations (*peer-referencing*). One could argue that data availability alone should favour the former over the latter approach, but interestingly in practice peer-referencing studies seem to appear dominant. In this regard TRB (2003) identifies several possible referencing scenarios such as comparison to a baseline, self-identified or industry standards, trend analysis, or peer-systems.

Table 3.1: Benchmarking types. Adapted from Hazel et al. (2011)

Criteria	Peer-Benchmarking	Self-Benchmarking	Multilevel-Benchmarking
logic	performance measurement, comparison, best performer identification		
unit/DMU	work group, department, organisation, company, sector, industry, region, state, year		
dimension	internal or external	internal	internal and external
peers	other units	other years	other units and other years
time	no	yes	yes
data type	cross-sectional	time-series	panel

The process of comparing performance among a set of similar organizations (or years) is also called 'benchmarking'. Benchmarking generally aims at identifying some sort of best-practice with in this set.[42,43] Accordingly, the identification of the best performance leads to benchmarking in a normative manner as per Ozcan (2008) and is considered one of the most effective methods to detect where performance does not meet organizational or competitive goals (Georgiadis et al., 2014). Table 3.1 supports the claim that - depending on the way a comparison should to be achieved - benchmarking can be approached differently. This is in a line with the three benchmarking levels[44] proposed by Santos et al. (2014) and the referencing scenarios described above. Then *peer-benchmarking* can be applied inside an organization (e.g. comparisons between departments) or outside the organization (e.g. comparison of entire organization with other organizations or competitors in the sector). *Self-benchmarking* aims at comparing the unit under observation again itself overtime. *Multi-level benchmarking* is a mixture of this both approaches as it allows for a comparison over-time and against peers. As a management tool based on relatively simple indicators, benchmarking was initially developed

[42]The term 'bench mark', or 'benchmark', originates from the chiselled horizontal marks that surveyors made in stone structures, into which an angle-iron could be placed to form a "bench" for a levelling rod to be positioned accurately.
[43]It appears that business-oriented literature uses the term 'benchmarking'. In contrast, research-oriented works prefer to apply the terms 'performance' or 'efficiency analysis'. This research makes us of the latter notation.
[44]Level I: self-assessment, level II: comparison, level III: partnering.

to let decision makers of multinationals compare their operations with competitors and to draw conclusions regarding productivity, effectiveness and quality in the face of globalization (OECD, 2000). Over time, *management by performance* or other result-oriented management styles became more dominant, promoting the utilization of restricted resources at the best possible rate in order to increase competitiveness or value for money. Further, the plethora of available data and information makes it increasingly complicated to understand the functioning of organisations. Thus, more complex, sound interdisciplinary approaches to performance analysis and benchmarking was given another significant boost.[45]

Especially in the public transport sector, performance analysis is gaining momentum nowadays. Operators are under pressure from users, stakeholders, media, authorities, regulators, and policy. On one hand, they need to improve performance and attract more customers, while on the other hand they are increasingly confronted with competition, financial restrictions, supply obligations, and economic turmoil. Activities in public transport performance analysis as well as related research date back to the seventies when most public transport systems were still governmentally managed and funded. Back then, the need emerged to capture the multi-dimensional nature of public transport services with new quantitative measures in order to track how public money was spent. To this end, authorities and researchers started to define alternative public transport objectives and developed measures to assess the extent to which these goals are achieved (Karlaftis and Tsamboulas, 2012). In this regard Diana and Daraio (2014) conclude that *"public transport systems are often blamed for their inefficiency and better monitoring their operations is probably the first step to try to reverse this trend".*

Perspectives on Performance and Purpose of Analysis in Public Transport

Optimally, performance analysis should concern various issues such as economic goals, operational performance, the relation to road congestion, environmental impacts, social inclusion, and territorial accessibility. However, performance analysis in public transport is usually more constrained and depends much on what it addresses or from which perspective it is carried out. As demonstrated above the different viewpoints and objectives of decision makers in a public transport system might not necessarily coincide. In the same way, the position towards performance might vary between operators, users, and society/regulators (Daraio et al., 2016)[46]. *Operators* might be interested in performance driven by cost cutting measures such

[45]In this research benchmarking and performance analysis are used interchangeably.

[46]Daraio et al. (2016) refer to the group as *"general population and political and regulatory bodies".* Subsequently this group is termed "regulators". Regulatory bodies in urban public transport should be considered as 'lawyers' or 'representatives' of society. With their intervention, they aim at the overall societal benefits of public transport.

as staff adjustment, whereas the *regulator* might be interested whether subsidies are spent efficiently and supply is provided at an intended level. *Users* in contrast are generally concerned with quality aspects of performance, such as punctuality, reliability and travel time.

The complexity of perspectives makes it rather complicated to be reflected in one overall description/model/indicator (Diana and Daraio, 2014; Makovsek et al., 2015; TRB, 2003). Nevertheless, Table 3.2 intents to capture the different perspectives and to add information about the potential outline of a performance analysis in terms of *performance concerns*, *normative principles, economic criteria* and *resulting (pivotal) indicators.*

Table 3.2: Perspectives on Performance. Adapted from Daraio et al. (2016) and OECD (2000).

Perspective	Performance Concern	Normative principles	Economic criteria (function)	Criteria-based ratio measure
Operator Regulator Society	Finances	*The public transport system should be self-sustaining financially.*	A: resources used (input) B: service produced (output) C: service consumed (output) D: market potential (potential output) E: profits, costs, subsidies, fares (output or input) F: externalities (output)	Revenue generation *E/(A,B,C)* Cost recovery E/E
Operator Regulator	Productivity	*The most costly resources should be used at highest possible rate of productivity (to their full productive capacity). Service should be provided with a minimum number of disruptions caused by equipment failure or human factors.*		***Efficiency*** *B/A* Intensity of use *C/B* Service dimension *A/C*
Operator User Regulator	Utilisation	*Capacity should be adequate to fulfil customer demand.*		***Effectiveness*** *C/A*
User Regulator	Service	*The system should be accessible, dependable, fast at peak hours and offer acceptable quality and safe travelling. It should be competitive to individual transport.*		Service coverage *D/B* Market penetration *C/D* Value for money *B/E*
Regulator Society	Environment	*The system should be sustainable and maximize overall benefits for society.*		Externalities *F/(A,B,C,E)*

Following the *input-output-nexus* or *production logic* as suggested in the definitions section, the fifths column of Table 3.2 presents various performance measure[47] that could be of interest for one or more the described groups.[48] With regard to the operators under evaluation, it needs to be stressed that for any performance analysis it is crucial to initially assess the operators´ nature and goals. When *privately owned* and operated - under ordinary market laws with profit maximization and cost minimization - profit can be regarded as a derivative of the optimal input-output setup in the production process and thus might be a valid indicator for performance

[47]Performance measures will be discussed in detail in Section 3.2 Measurement: Modelling Performance.
[48]At this point, it needs to be stressed that the present research focuses primarily on the operator perspective and only indirectly on the regulator perspective. The user and society perspective are not further investigated.

changes over time. However, in a *public context*, performance evaluation can be more complex as market and rationality assumptions will not necessarily hold. Further, the operator´s degree of entrepreneurial freedom might be limited by publicly imposed objectives and constraints. A purely profit focussed assessment would therefore give misleading results. Thus, one has to keep in mind that realistically, public transport provision might serve multiple objectives that ought to be captured accordingly in performance analysis (Borger et al., 2002; Costa and Markellos, 1997; Diana and Daraio, 2014).

Table 3.3: Why measuring performance?

Operator	Regulator	Research
positioning decision support reporting	decision support appraisal standardization leveraging	theory building theory verification policy recommendation

Practically, performance analysis (PA) can be conducted by the operator itself, consultants or researchers based on regularly gathered data at designated times or as a onetime study in response to certain events or to address a specific problem and recommend a specific course of action. In accordance with TRB (2003) there are initially two main reasons why to conduct a PA in public transport:

- *First,* a performance analysis is of high interest for the operator itself.
- *Second*, outsiders need to understand what is going on inside and why.

In this regard, Tables 3.3 outlines purposes for performance analysis in public transport at practical (*operators*, *regulators*) and theoretical levels (*research*). The categories can be considered interlinked in that not only findings from practice could motivate research (and vice versa), but also that regulatory inferences might be relevant for individual operators or trigger research activities to assess interrelations. Table 3.3 is specified in the following.

OPERATOR PERSPECTIVE

Positioning and Orientation: External PA evaluates and compares performances among a set of operators. The method can give managers comprehensive orientation and knowledge about the relative position in a market or sector. Additionally, the method can identify the potential for improvements in form of performance gaps (Costa and Markellos, 1997). PA may also guide decision makers to set more realistic performance targets or motivate them to (re)define future pathways, goals and actions accordingly (Graham, 2008). In the first place, PA might facilitate managerial efforts to understand why an operator underperforms comparatively. In public transport, managers have generally limited options for local comparisons due to the absence of market signals in predominantly monopolistic markets. Therefore, alternative ways are often pursued to gauge their performance, such as *city-by-city* or *operator-by-operator* comparisons.

Management Decision Support: If used for internal or self-comparison purposes, PA might refer to overall, departmental, or individual performance *with* operational, service, financial, or managerial orientation *and* different temporal frameworks such as past, present or future performance. In that sense the method can be used as a multidimensional decision support tool for internal management e.g. to identify best-practices among departments, to monitor how well customers are being served or to assess internal performance gaps (e.g. personnel) or the impact of specific measures over time. If used for external comparison, the identification of performance enhancing decisions and measures of other operators and their incorporation in management strategies can improve the allocation of resources, e.g. by changing policies, procedures, operations or planning (Costa and Markellos, 1997). In addition, if used in a multi-output performance analysis over time (assessing efficiency and effectiveness simultaneously), the operator could evaluate, which decisions were successful to balance both objectives. Santos et al. (2014) propose a scheme of how different benchmarking approaches could be aligned in order to continuously improve the generation of useful information at the operator level.

Reporting: Operators might simply be obliged to report some sort of performance data. Thus, PA is conducted to meet requirements of public transport databases (UITP, Eurostat, Urban Audit), funding and subsidy applications, contractual obligations (e.g. in gross or net contracts), standards specifications (ISO, UITP Charta) or annual information to stakeholders. In addition, operators need PA to allow for the assessment of potential risk and liability for insurances.

REGULATOR PERSPECTIVE

Regulation Decision Support: In a broader sense PA is an assessment and information tool for regulatory bodies or transport authorities to identify current and past market trends as well issues and needs that are important for managing the provision of public transport.[49] In addition PA can provide comparative information about fare-setting, levels of service, costs and productivity of public transport operators in an otherwise asymmetric information environment (Graham, 2008). For instance, usually under regulatory or contractual control fares may need to be set by a regulator in order to ensure efficiency and effectiveness of the system. However, operators are likely to request for fare increases any time their costs increase. As a result from PA, benchmarks from other operators under similar conditions could help the regulator to

[49]Referring to service monitoring and comparison, evaluation of economic performance, contract monitoring, internal communications and communications of achievements and challenges to the public.

overcome the lack of information about the operator´s costs structure and its comparative efficiency position, thus avoiding hasty approvals of fare increase requests, especially in cost-plus regulatory regimes[50] (Hensher and Wong, 2011). In addition, overcapitalisation or overstaffing of operators could be avoided in reducing information asymmetry through PA.[51] Overall, richer information helps to avoid the setting of unachievable productivity targets.

Appraisal: In light of regulatory and organizational changes such as (re)(de)regulation and (re)privatization of public transport, PA can help to understand how these changes affect operator performance, what to expect from subsidies awarded to the operator, and to assess the role of external factors (Brons et al., 2005; Costa and Markellos, 1997). By comparing the performance of different operators, conclusions about the appropriate scale and scope of a system can be drawn and which path has to be taken to improve performance, e.g. through mergers or disruptions (Graham, 2008). Further, if concerned with the assessment of multiple output performance (efficiency and effectiveness) the regulator could use both indicators as a feedback tool for regulatory inventions, i.e. to evaluate the degree of balance between both objectives or simply the *"adequacy of the offer to the demand"* (Tulkens and Wunsch, 1994).

Standardization: In a loss-making business such as public transport, higher performance at equal costs mean less deficit to be recovered by the public. In order to politically justify subsidization or funding schemes for public transport (such as highly controversial transport taxes, congestion charging or parking fees) it appears imperative that efficiency enhancing or cost reducing measures are implemented in the best way possible at operator levels. Performance analysis can help to identify the best-practices in the sector and make them a standard across systems. Only if the cost reduction potential is fully exhausted, increased fares or additional funding would be publically accepted (Faivre d'Arcier, 2014).

Leveraging: Santos et al. (2014) state that PA could also be used as a efficiency enhancer across markets if applied within a sector as a strategy of '*naming and shaming*'. Then the identification and publication of bad performers alone would make operators want to correct their relative position and improve their performance. In addition, the good performers would want to serve as role models and share their success measure and achievements among the sector.[52]

[50]In a *cost-plus* regulatory regime, the government compensates the operator for deficits in service provision. The scheme requires detailed and costly information about the nature of the operator costs and its attempts to reduce them. Since this information is hardly accessible for the regulator, the scheme tends to increase incentives for the operator to operate in deficit and to overcapitalize (termed Averch–Johnson effect).

[51]In a *fixed-price* regime, the operator gets payed a fixed amount for service provision. However, this creates incentives to reduce costs or to maximize profits at the expenses of quality. The regulator needs information on revenues and costs to forecasts and future cash flows of the operator in order to define the period of regulated prices.

[52]See an interesting read from Coelli (2003), Chapter 5: 'Performance Measurement Issues in Regulation'.

RESEARCH PERSPECTIVE

Finally, performance analysis with all the above-mentioned purposes can be used in research in order to verify and quantify theoretical assumptions and hypotheses. When performance analysis is done in a research context, with regard to some scientific theory, it is traditionally employed as *ex-post* evaluation[53] and includes both the development and application of sound methods for assessing system or operator performance as well as the translation of results into different policy recommendations (Daraio et al., 2016; Jarboui et al., 2012). For example, researchers might want to study the effect of deregulation on technical and cost efficiency of operators. In general, performance analysis can be applied in positive and normative manner. Positive performance analysis (*'what is'*) explores for instance specifications of input or output orientation in production processes without providing any policy recommendation. Normative performance analysis (*'what ought to be'*) typically uses different production structures and its determinants in present or historic data to identify the best performing operators and to draw conclusions about the optimal specifications of future scenarios (Costa and Markellos, 1997).

SUMMARY: Overall, it needs to be stressed that performance analysis in public transport is more than just the comparison of operators. It is about gaining perspective and understanding how public transport operators function. The ultimate goal is to understand why performance changes and how to affect it with managerial or regulatory measures. Once a range of operator performances is identified it needs be pursued how top performers have reached their positions and what underperformers can learn from them in order to improve. In this regards it is inevitable to critically discuss potential internal or external constraints or triggers that might affect performance (Randall et al., 2006).

Guidance and Terminology from Production Theory

Performance measurement in public transport intents to make inferences about the 'efficiency' of operators. One of the key assumptions in this context is that of a production-like structure with *inputs* and *outputs*. In this regard, this section intends to clarify on the different terminologies and formal definitions mainly based on the achievements of Walter (2010), Coelli (2005), Poister (2003), OECD (2000), Oum et al. (1999), and Färe et al. (1994).

'PRODUCTION FUNCTION' (also production frontier): As in all other industries, production in public transport can be simplified as some sort of relation between typical inputs and outputs.[54]

[53]Contrary to operations research methods that are normally *ex-ante* methods.

[54]Number of buses as *inputs* and passengers as *outputs*. In comparison to the traditional production of 'real' goods, transport services *cannot be stored*. They require to be directly 'consumed' and thus have to match with client needs…

This relation is usually expressed in a function, which represents a specific production technology or cost structure of an industry, sector, authority, mode or operator[55]. Generally, a production function $f(x)$ defines how much output y can be obtained maximally from a vector of inputs x, given a specific technology. Figure 3.1 shows a simple one-input-one-output case for a set of different operators E, B, C, D that represent different production scenarios. Obviously, the technology is limited at some point as less marginal output can be achieved at increasing inputs. All points on and below the production function are achievable and could be observed within the set investigated. Points B, C and D lie within the so-called feasible production set, i.e. the space between the function and the x-axis. Point E is only theoretically achievable if statistical noise, measurement errors, or differences in operating environment were considered. *Per definition, efficient production happens exactly on the production function.* Consequently, a crucial conclusion for further definitions is that the distance from each point to the production function marks the degree of (in)efficiency of an operator. For instance, the distance for B is zero as it lies on the production function. The operator uses the existing technology optimally and achieves the highest output possible for the inputs used.

'PRODUCTIVITY': Productivity of organisations typically captures the relationship of outputs to inputs. It can be affected by numerous factors such as *technology, environment, management schemes, time, efficiencies, economies of scales, network characteristics and external factors*[56]. The economic interpretation of productivity becomes only meaningful through comparisons

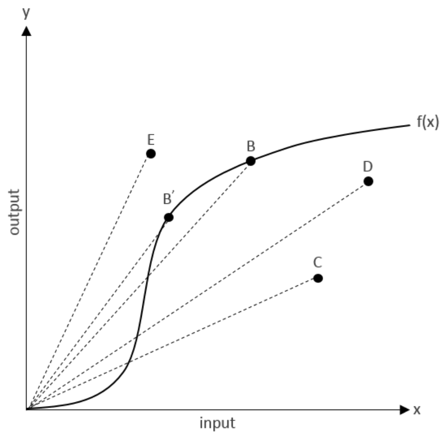

Figure 3.1: Production function and frontier.

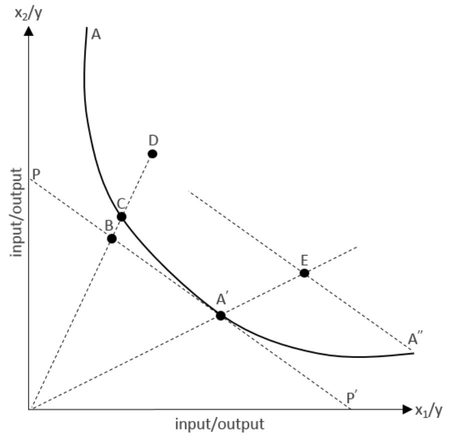

Figure 3.2: Technical and allocative efficiency.

[*cont.*] instantly, as per Hill and Hill (2012). Vehicles must be available at the time and location needed and going to a pursued destination. Public transport is subject to economics of peaks: over/under-capacity runs are a daily business.

[55]Hereinafter all production concepts, terms, or models relate to a 'public transport operator' or 'public transport company' as organizational unit for the production of public transport services. In broad sense, a public transport operator is a physical or juridical person that owns the license to perform passenger transport. Independent from the organizational shape of the public transport market as e.g. summarized by Costa (1996), service production essentially happens at the operator level (even if owned by the municipality or coordinated by a transport authority).

[56]E.g. local traffic, market size and competition, quality of service obligations, weather or terrain condition.

over time or across different organizations. Productivity can be calculated as a ratio of output(s) to input(s), which in Figure 3.1 is represented precisely by the dashed line from the origin to each production scenario, or operator. Productivity as an *absolute* concept allows for a straightforward economic comparison following a the-higher-the-better-principle or ranking (Jarboui et al., 2012). Further, the singular output-by-input division indicates partial factor productivity[57]. In a multiple input-output case with aggregation over all factors - total output compared to total inputs - the so-called total factor productivity can be calculated (TFP).

'PRODUCTIVITY CHANGE': In Figure 3.1 productivity increases when moving from points C to D to B to E due to several causes. From C to D to B the increase is just due to efficiency improvements, namely reaching the same or a higher output with fewer inputs (or costs)[58]. To reach point E a fundamental change in the production technology needs to occur which shifts the production (cost) function outwards (inwards). Productivity growth over time can be initially reached through *efficiency improvements* or *technological change/progress*. Efficiency might be triggered by skills, learning, operational or organisational improvements in production, market reorganisations, etc.; technological change however may is the result of pivotal technological innovations in the sector. With reference to public transport Costa and Fernandes (2012) conclude that *"technological change and incremental technology, at various levels, are believed to have played an important role in the success of urban public transport in Europe."*

'EFFICIENCY': At a most elementary level efficiency is often defined as *"doing things right"*. A more elaborated definition would be *"maximising an outcome with given inputs"*, which sounds similar to productivity. According to Nobel Prize winner in economics Koopmans (1951), a producer is efficient "*if, and only if, it is impossible to produce more of any output without producing less of some other output or using more of some input*". For Cooper et al. (2007) efficiency relates *"to the benefits realized and the resources used"*. Classically, efficiency measures productivity. Efficiency is the core concept of this research and most widely used amongst transport economist to measure financial and productivity related performance of public transport operators. When operators are organised inefficiently services that could have been produced are not achieved or resources such as staff or vehicles are used too excessively to produce them. In economic terms, the efficient use of resources contributes to welfare maximization obviously not only on operator level but also beyond, for instance through aggregated effects on society caused by a reduction of needless vehicle-km or empty buses. Coming back to the example in Figure 3.1, points C and D are deemed inefficient compared to B

[57]However, labour or fuel productivity can lead to misleading indications if conducted isolated.
[58]Alternatively, at given input prices the output is realized at lower (average) costs.

on the frontier. Individual productivity and efficiency increase when going from C to D to B. As mentioned before, efficiency shows as the degree of deviation from the production frontier that is often expressed in percent to the achievable optimum. *Relative efficiency* can also be understood as the relative comparison across productivity scenarios with the highest one serving as a fixed denominator. Technically, this is a *"ratio of ratios"* (Cooper et al., 2007). Expressed either absolutely or relatively, the ranking will not be violated. One could argue that in this case productivity and efficiency can be used interchangeability as the same concept. However, as demonstrated in Figure 3.1 in points B and B' productivity and efficiency are not necessarily identical concepts. Points B and B' are both located on the production function. With zero deviation from the frontier both of them are equally efficient at unity. Thus, going from C to D to B or from C to D or to B' makes no difference efficiency-wise. However, from B to B' the ratio of output to input still increases - that is productivity per definition - as indicated by the greater slope of the dashed lines. Point B' then represents the highest possible productivity, but the same level of efficiency as point B. This suggests the presence of various *efficiency types*.

'TECHNICAL, ALLOCATIVE AND SCALE EFFICIENCY': Assuming multiple inputs and outputs, prices, or different production scales is a more realistic scenario for assessing operator performance.[59] Efficiency then may be a three-fold concept comprising a technical, allocative and scale part.

- *Technical efficiency (TE)* simply compares realised outputs to its potential maximum (vehicle-km or passengers) levels holding inputs (vehicles, fuel, network) constant or vice versa[60], independent of prices and costs. Technical efficiency measures exactly the distance to the production function. TE measures how operators utilize their resources under exogenous constraints.
- *Allocative/price efficiency (PE)* occurs when an operator produces at minimal production costs through a proper reallocation of inputs.
- *Scale efficiency (SE)* shows how close an operator produces to a long run optimal production scale of inputs and outputs. This component is often attributed to the size of operations and thus a regulatory point of intervention to correct for deviations from the most productive scale size of operators.

Graphical Representation: In Figure 3.2 a single output y is produced using two inputs x_1 and x_2. The production function is denoted as $y = f(x_1, x_2)$. The assumption of constant returns to scale gives $1 = f(x_1/y, x_2/y)$ and a unit isoquant along ACA'A''. All points in Figure 3.2 produce the same level of output. All points on a line through the origin reflect the same input proportions/allocations. If the line is tilted, the proportions change and inputs are mutually substituted. An operator producing above the unit isoquant uses more inputs than necessary,

[59]Based on the seminal achievement of Farrell (1957).
[60]Also: output vs. input-orientation. See Brons et al. (2005) p. 2.

which deems him inefficient (see E). Until now, just quantities were used. Cost restrictions enter the scenario in Figure 3.2 represented by the dashed line PP'. The costs for a specific input mix to produce a fixed output are equal on PP' and increase or decrease once moved outwards or inwards, respectively. An operator is solely *technically efficient* when an input mix along the unit isoquant is chosen, i.e. on the production frontier (e.g. C). An operator is solely *allocatively efficient* if the proportion of inputs chosen meets the cost targets, that refers to all points through the line 0A' not located on the production frontier (e.g. E).[61] Then, full *productive* or *economic efficiency* (EE) requires both efficiency types to occur simultaneously. In Figure 3.2 this can only be obtained in point A' where PP' is a tangent to ACA'A''[62]. Economic efficiency is sometimes referred to as the 'behavioural goal' of operators, as it includes individual cost, revenue, profits structures of production. However, as demonstrated above, productivity could still be increased by exploiting so-called scale economies.[63] *Scale efficiency* matters when public sector privatization is promoted. Tendered operators could improve scale efficiency through mergers or break ups. Improved scale efficiency however might result in decreased technical efficiency (Yang and Chang, 2009). Table 3.4 outlines the three efficiency types described.

Table 3.4: Efficiency types and relation to frontier in output-orientated case.

Efficiency types *[Range]*	**Reference frontier**	**Interpretation of reference point on frontier**	**Relation to production frontier**
technical efficiency (TE) *[0 to 1]*	production function	maximal output at given inputs	distance to frontier
allocative efficiency (PE) *[0 to 1]*	cost function	maximal output at cost-effective input mix	determines position on frontier in case of TE=1
scale efficiency (SE) *[0 to 1]*	production function	maximal output at cost-effective input mix and input quantities	determines position on frontier in case of TE=1

In summary, every technical efficiency increase results into higher productivity. However not every productivity increase is exclusively caused by technical efficiency growth. Table 3.5 below intends to give a theoretical[64] example how different efficiency states of operators could translate into managerial action to increase productivity. Changes of technical efficiency will affect the operator´s relative position to the production frontier (to the best performers) and

[61]The MRS of two inputs is equal to the corresponding input price ratio; or the slope of both functions is equal in A'.
[62]In Figure 3.2 technical efficiency (TE) of point D is defined as TE = 0C/0D. Then TE is bound between zero and one and decreases towards zero the further D is away from C. However, point C is just technically efficient. Input proportions could be adjusted towards B where the same output is produced at less costs. Thus, allocative or price efficiency (PE) is defined as PE=0B/0C. PE is also bound between 0 and 1. When C moves towards A', PE rises to 1 as PE in A' equals to 0A'/0A'. The allocative (in)efficiency is equal for all points on one ray (PE of C = PE of D and PE of A' = PE of E). Overall (or cost) efficiency (EE, (CE)) is then calculated as EE=TE*PE under constant returns to scale.
[63]Essentially, *economies of scale* show the effects of increasing outputs on average costs in the long run. Costs could fall or increase with growing output, resulting in economies or diseconomies of scale. The concept is easy to confuse with that of *returns to scale* explaining just the relation between input and output proportions over time (which can be constant, variable, increasing or decreasing).
[64]'Theoretical' because in reality there might be several limitations for managers to improve the efficiency of operators, such as contractual performance targets, unions, a somehow fixed vehicle-to-driver ratio and more.

might be the most important step to aim at from managerial perspective, e.g. by adjusting inputs similarly to those of the best performer´s ratio in the market. Once technical efficiency is achieved or diagnosed, the degree of allocative and scale efficiency would just define the exact position on the production frontier offering further intervention potential in order to increase productivity, e.g. to find the cost-minimal input mix or optimal operation scale. Note that this work will focus solely on technical efficiency. Economists generally stick to technical efficiency for three reasons: Firstly, technical efficiency seems to dominate overall efficiency changes over time. Secondly, neoclassic rationality assumptions as profit maximisation and cost minimisation start from the premise that operators anyways chose input configurations optimally. Thirdly, input price data is often not available, thus allocative efficiencies can hardly be assessed.

Table 3.5: Efficiency states and combinations.

Efficiency states	**Efficiency Combinations**				
technical allocative scale	no no no	yes no no	no yes no	yes yes no	yes yes yes
Located on the frontier?	production: no cost: no	production: yes cost: no	production: no cost: yes	production: yes cost: yes	production: yes cost: yes
How to increase productivity?	efficiency, input mix, scale,	input mix, scale	efficiency, scale	scale	technological change, (only external)
Productivity ranking	5	3	4	2	1

'EFFECTIVENESS': Passengers are believed to be the key elements in the production of service output. The effectiveness of public transport provision is a highly controversial issue in literature as shown in Chapter 4 and in wider range of discussion from Daraio et al. (2016). By taking up the idea that efficiency is equated to *"doing things right"* effectiveness could be referred to *"doing the right things"* (Karlaftis and Tsamboulas, 2012). In contrast to the relatively precise definitions of efficiency, effectiveness appears to be defined rather ambiguously[65] as the following examples show: Effectiveness *"is a measure of the delivery of the consumption of the resource inputs"* (Costa, 1998). For Borger and Kerstens (2006) the concept *"relates realizations to the goals put forward (and) measures the extent to which the specified goals have been achieved*". For Georgiadis et al. (2014) effectiveness consists of two components: *operational effectiveness* is the relationship between service inputs and consumed services; s*ervice effectiveness* relates produced services to consumed services, which is commonly known as occupancy. According to Daraio et al. (2016) several authors *"use the term effectiveness as synonym of efficiency or quality of service"*. Similarly, Jarboui et al. (2012) interpret effectiveness as the service delivered in relation to the service promised, e.g. in terms of punctuality of buses.

[65]In addition Daraio et al. (2016) present a more complete collection of effectiveness definitions across transport performance literature in Table 1.

For Cooper et al. (2007) effectiveness implies the ability to state and achieve desired goals. This list could be continued infinitely. Effectiveness definitions can be grouped in roughly three major topics. *First*, from economic perspective effectiveness functions as the interaction between demand and supply in the public transport system. Then demand could be decomposed into stated and unstated components, where the former equate to the effective physical output of the system (also service use) and the later could be seen as market potential (service targets). *Second*, effectiveness from an engineering and planning perspective focused on the degree of target fulfilment, e.g. of service level obligations or quality. *Third*, effectiveness is interpreted as purely demand-related, e.g. by comparing passenger needs to passenger reality. As this work follows an economic view on effectiveness, some controversies might arise in relation to the efficiency concept. In this regard Borger and Kerstens (2006) stress that objectives in public transport can be achieved with high effectiveness, but in in a very inefficient and costly way (and vice versa). For instance realizing higher levels of passengers might be achieved with comparatively uneconomical measures such as large-scale network, vehicle or staff expansions at the expenses of operational efficiency.[66] The author's further stress the importance of specifying operator objectives properly as poor performance in one indicator might be explained by strong performance in the other.

'PUBLIC TRANSPORT PRODUCTION MODEL': In economic literature, the above-introduced key concepts are often condensed to a simplified schematic *production model* for operators.[67] Schemes as Figure 3.3 stress the key assumption that production in public transport simply equates to the transformation of inputs to outputs. In accordance with neoclassical production theory, the inputs on the left hand side can be grouped into labour and capital. It is assumed that operators usually utilize the same type of primary inputs, e.g. staff, network, vehicles. As

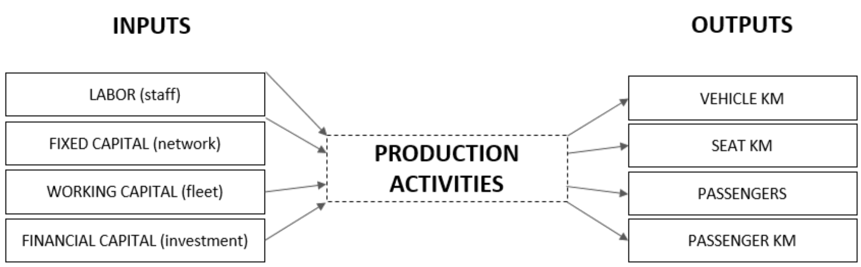

Figure 3.3: Simplified conceptual production model for public transport.

[66]*High efficiency* means providing services at high occupancy and stretched headways to fully exploit vehicle capacity and minimize vehicles and drivers. However, *high effectiveness* in turn means serving as much passengers possible, which might imply compressed headways and the deployment of more vehicles and drivers leading to overcapacity. In this regard Costa (1998) states: *"The problem: Efficient production is better attained without congestion which corresponds to periods of low demand when passengers and a congested infrastructure cause disruptions in the production. Effective production is better attained with high demand and this corresponds to congested periods."*
[67]Similar notations are found in Oum et al. (2013) *"production system"* and Costa (1998) *"process of production"*.

argued above, the resulting outputs in public transport are not per se tangible products. The output is a service. Then one has to apply some sort of output proxies that should at least capture the very basic functions of the public transport system, namely the *provision of services* and their *utilization.* Both 'outputs' are essentially determined by different agents in the system, the operator (supply) and the user (demand), respectively. As noted, this distinction becomes particularly important when results are discussed in the context of efficiency and effectiveness. Frequently used output proxies for public transport are vehicle-km for the supply-side or passenger-km for the demand-side, as illustrated on the right hand side of Figure 3.3. The former refers to the distance covered by the fleet, the latter to the distance covered by passengers (Costa, 1998). Efficiency is then calculated by directly linking primary inputs to final outputs. In most cases, the focus of performance analysis in public transport is exclusively directed to the output-input relation of the operators. Finally, the role of the middle part of Figure 3.3 - circumscribed with the term 'production activities' - is deemed a *black box* in standard performance literature. However, essentially the assessment of the yet "hidden" managerial activities could help to understand better, how service production is practically realized and how this relates to the performance observed. For instance, staff usually affects performance directly, but its productivity depends on numerous parameters such as available technologies, training, education, incentives, or the decision-making layout of the operator.

Extended Conceptual Production Model for Public Transport

Some authors suggest that in fact public transport services are based on numerous *intermediate production activities* by the operators.[68] The numerous activities again lead to various intermediate outputs on the supply side (Costa, 1998; Oum et al., 1999).[69] In addition, it would be interesting to see this functioning in the light of external conditions and constraints. Figure 3.4 gives a more detailed view on that issue by extending the simplified production model introduced above. The more holistic perspective[70] illustrates the overall complexity of public transport service production while still referring to the input-output terminology of *performance analysis*. **(1)** *Column 1* and *4* are similar to Figure 3.3 but a few more options for inputs and outputs are given. **(2)** *Column 2* intends to shed light on plurality of *production activities* and specifies the different functional and organisational departments of an operator and their

[68]Vuchic (2007): *"Transit operations include [..] activities as scheduling, crew rostering, the running and supervision of transport unit, fare collection, and system maintenance."* Li et al. (2002) propose a decision-based conceptual model.
[69]Partial productivity measures often intend to capture intermediate outputs but the complexity of service production makes it extremely difficult to link inputs to specific intermediate outputs. With reference to efficiency, Costa (1998)´s schematized production process indicates that even pure supply could be seen as an intermediate output, which then is "used" by a subset of the potential passenger market, thus creating the final output measure passenger-km.
[70]By no means is the model exhaustive. It is just valid for an ideal-typical operator.

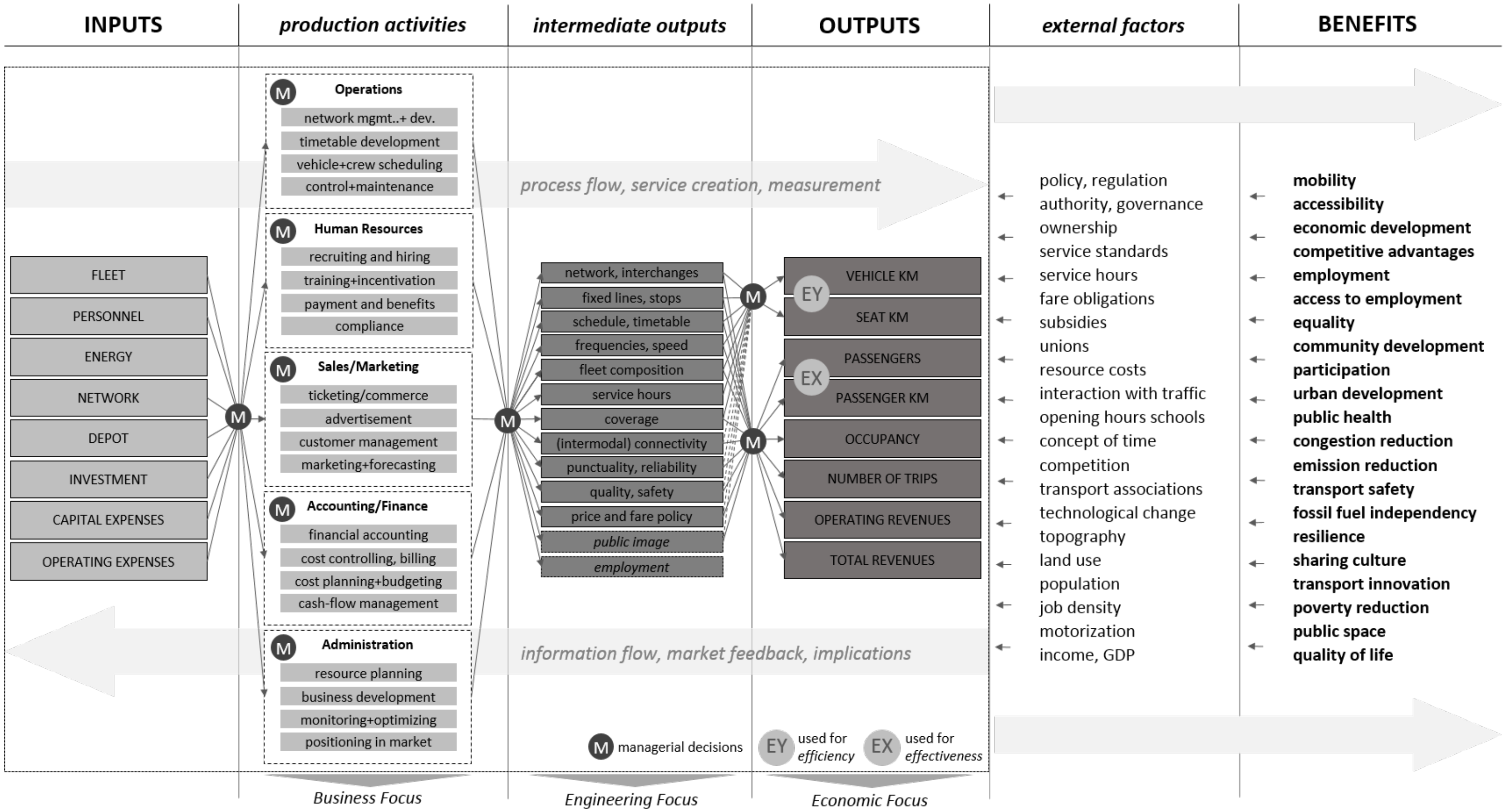

Figure 3.4: Extended public transport production model.
Adapted from Hilmola (2011), Ceder (2007), TRB (2006), van Egmond et al. (2003), Li et al. (2002), Costa (1998), Oum et al. (1999), Schefczyk (1993).

[*cont.*] key purposes[71]. For instance, on one hand the *operations unit* is concerned with planning and executing the service, e.g. by means of network and route design, frequency setting, timetable development or vehicle and crew scheduling and controlling and maintaining. On the other hand, the *sales and marketing department* is responsible for ticketing, advertisement, non-transport related revenues and customer support. Both units have a stake in creating the service. However, the former one covers rather technical aspects, whereas the latter deals with commercial aspects of service. Eventually, operator performance is also a consequence of how well internal processes interplay in terms of synergy effects[72]. These and further activities in other departments displayed in Figure 3.4 demonstrate that the transformation of primary inputs to outputs is *managed* on different functional, interacting levels as well as in exchange with the operating environment and the market. In other words, operator management appears to be a multi-dimensional, multi-staged, and multi-constrained challenge.[73] In a simple case, quantitative changes of inputs/input-mix could strongly affect outputs and might thus be accompanied by appropriate managerial intervention. In this regard, the following example shows how three common inputs in public transport (vehicle, network, and drivers) might be 'managed' along a supposed public transport supply chain:[74]

> *Supply is determined by the number and type of vehicles, and the extent of spatial and temporal distribution of services across the network, say network and route design as well as frequency.[75] The headcount of drivers usually limits the number of vehicles deployed for service. If an operator purchases additional vehicles, in a fixed network supply could be increased through higher frequencies, usually when the pool of drivers is adjusted accordingly. In contrast, new routes without vehicle and driver adjustments might require frequency reductions. Alternatively, the application of vehicle and crew scheduling technologies in operation planning could allow to use both inputs more efficiently (without changing their quantities, even enabling network extension and higher frequencies). Further, as a supporting policy, human resources could apply driver training or monetary incentivation to increase labour productivity. In parallel, the conversion to a more fuel-efficient, green fleet might enable additional vehicle circulation and be eligible for additional financial influx such as subsidies. Marketing could promote these service changes and find the right price mix or fare composition.*

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[71]Hill and Hill (2012): Because of the division of labour, specialists are created/coordinated/grouped through organizational departments. A simple way to departmentalize is grouping activities by its functions, as shown in Figure 3.4. When referred to other organizational units in public transport such as transport authorities or municipalities, departmentalization by products or modes might be applied (see e.g. TfL with London Underground, London Rail and Surface Transport), or other forms, such as the separation from network and services and business.

[72]The input-output nexus can be applied also to each department individually as shown for *operation planning* in Ceder (2007) pp.4ff. Alternatively, *marketing* uses customer-, sales-, cost-data to produce sales strategies and pricing.

[73]Service production is realized in various departments and affects multiple agents *(multi-dimensional)*, in sequential order, e.g. in operation planning *(multi-staged),* subjected to external factors, e.g. regulation *(multi-constrained)*.

[74]Mentzer and DeWitt (2001): "*The systematic, strategic coordination of traditional business functions and tactics across all business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole.*"

[75]Ceder (2007): *"Prudent transit management requires a balance between increasing frequency and the cost of its implementation."*

The example shows that a joint interaction of managerial decisions[76] is needed to affect supply and its consumption. Schefczyk (1993) subsumes the described decision-making complex as *"corporate management"*. Following this notation, the encircled *'M'* in Figure 3.4 relates to *'management interventions' or 'managerial decisions'* in the service production process.

(3) *Column 3* suggest that managerial decision-making in the service delivery processes will create different *intermediate outputs* or *system characteristics.*[77] **(4)** The intermediated outputs are then translated into the aggregated proxies of *Column 4*, which are the well-known final outputs from economic performance. The chart indicates that *network and route design, interchanges, terminals, schedule, timetable, frequencies, fleet composition, service hours, and coverage* are intermediate outputs that predominately relate to supply-side proxies as used in basic efficiency analysis. In contrast, demand-side proxies - as used in effectiveness analysis - additionally relate to other intermediate outputs such as a *system's (intermodal) connectivity, punctuality, reliability, quality and safety, fare policy, and public imag*e of the operator.[78] Passengers are key elements in service production and intermediated outputs should match to customer needs.[79] By adjusting both, internal processes and the system characteristics accordingly, the management might manipulate operator performance. **(5)** In fact, performance can also be strongly affected by external factors as illustrated in *Column 5*. For example subsidies might trigger overstaffing; Lack of funding instead might lead to maintenance shortfalls and curbed services; Motorization or competition might decrease demand, increase traffic disruptions and decrease commercial speed; Increasing population might increase demand but at the same time reduce passenger comfort; and so on. In addition, due to political obligations or the decision nature (operational vs. tactical vs. strategic) some of the intermediate outputs might only be adjustable on an irregularly base (e.g. network design, fares, and coverage). **(6)** Finally, *Column 6* of Figure 3.4 addresses the broader impacts and benefits of public transport service provision. They are partly interlinked with some of the external factors, as for instance societal benefits are the motivation or regulating operators.

The next section introduces common measurement techniques of performance.

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[76]Potential decision-making sequence for the case described: board→finance→operation→HR→marketing.
[77]Vuchic (2007): Four categories of transit system characteristics: *system performance, level of service, costs, impact*.
[78]Another intermediate output of operators is *local employment*, which can be linked to the phenomena of Baumol's cost disease as intensively discussed by Evangelinos et al. (2012).
[79]A illustrative management credo with regard to production, efficiency, and customers taken from Hines (2004): *"Supply chain strategies require a total systems view of the links in the chain that work together efficiently to create customer satisfaction at the end point of delivery to the consumer. As a consequence, costs must be lowered throughout the chain by driving out unnecessary expenses, movements, and handling. The main focus is turned to efficiency and added value, or the end-user's perception of value. Efficiency must be increased, and bottlenecks removed. The measurement of performance focuses on total system efficiency and the equitable monetary reward distribution to those within the supply chain. The supply chain system must be responsive to customer requirements."*

3.2 Measurement: Modelling Performance

Intellectual Tradition and Research Streams

Daraio et al. (2016) suggest two major schools in public transport performance *research*, namely one with an *engineering* and with an *economics* focus. Figure 3.4 indicates that the focus areas of both schools is the service creation process.[80]

'ENGINEERING PERFORMANCE': On one hand, civil engineers, transport engineers, and transport planners tend to focus on performance in a rather isolated, technical manner. Their analysis breaks down to a set of straightforward partial indicators based on simple mathematical operations covering different domains such as operational aspect, economic aspects of production, quality of the service, and external effects (Faivre d'Arcier, 2014; Sousa Freire and João, 1998). Due to several practical advantages such as the simplicity in use and interpretation, these indicators are a popular tool especially among transport engineers. The most commonly used measures in this class are so-called Performance Indicators (PI). They intend to capture the various objectives of public transport service provision based on individual measures. As Vuchic (2007) states *"the evaluation and comparative analysis of transport systems must include performance, level of services, impacts, and costs of each system. The preferred system is usually not the one with the highest performance or lowest costs but the one with the most advantageous ''package'' or combination of the four".*[81] Vuchic's statement suggests that "engineered" indicators might be sensitive to the respective context they are applied in and appear to be problematic with regard to more complex comparative performances assessments of different systems.[82] Karlaftis and Tsamboulas (2012) confirm that individual performance measures yield broadly inconsistent results, but could become more consistent when aggregated to smaller sets of reliable indicators.

'ECONOMIC PERFORMANCE': On the other hand, economists - or analysts with economic propensity - aim at a wider perspective on performance. They pursue how efficient transport systems operate and whether resources could be allocated in a better way based on information

[80]For the sake of completeness, the *business* perspective as shown on Figure 3.4 would represent another potential school, however for unknown reasons this reference has not been mentioned in literature yet.

[81]For an overview on engineering approaches to performance see Vuchic (2007) Chapter 4: "Transit System Performance: Capacity, Productivity, Efficiency, And Utilization", pp. 149 ff.

[82]Early research efforts aimed at defining a set of indicators on the basis of the data that was available, and investigating issues related to the comparability of different systems. In the US, federal legislation set up a reporting system for all transit agencies in order to receive funding (now National Transit Database), which paved the way for a comprehensive effort in evaluating existing transport systems throughout the country.

about the productive functioning of similar systems. Economics-oriented efficiency is best captured through formal approaches that somehow relate to the production frontier. The impetus for this kind of evaluation initially derived from the private sector in the US. In a time of massive deregulation of services, increasing operating costs, and declining ridership economic efficiency was the primary concern of operators. Performance assessment then offered a way to compare to peers. As per Daraio et al. (2016) economic efficiency assessment tools have been proven to be are very useful, both for *public transport operators* and *regulators*. They overcome the barriers and shortcomings in comparative power of conventional indicators and allow to deeper explore the nature of productivity and economic performance as well as cost structure, cost functions, subsidies, deregulation, scale, density and scope in public transport. Two major approaches have been employed methodologically in this direction. With the seminal work of Farrell (1957) in an agricultural context, the foundation for an empirical measure of efficiency was laid, both for *non-parametric* developments such as 'Data Envelopment Analysis' (Charnes et al., 1978) or *parametric* techniques like 'Stochastic Frontier Analysis' (Aigner et al., 1977a). Both methods are widely used to measure the performance of operators based on their deviation from the production frontier.

Table 3.6: Research streams in public transport performance analysis. Adapted from Daraio et al. (2016).

#	Research stream	Content	Beneficiary	Benefits
1	partial efficiency	descriptive performance indicator based performance	operator	self-knowledge
2	technical efficiency	descriptive frontier new methods to old problems no answers to policy questions	operator	cost minimisation, links operational efficiency to service performance
3	determinants of technical efficiency (general)	interpretative frontier, identification of explanatory factors non-controllable factors	operator regulator	improvement of technical efficiency with instruments under control
4	determinants of technical efficiency (regulatory mechanisms)	effects of cost-plus schemes effects of fixed price schemes effects of ownership and/or operation control	regulator	scope of deregulation , evolution of market structure, allocation of subsidies, position in contract renewal
5	determinants of technical efficiency (economies)	effects of density, scope, scale on: *levels/distribution of costs/quality, space and time dimension of service provision*	regulator	characterisation of technology, appropriate size, synergy preservation when multi-modal, multi-operator

RESEARCH STREAMS IN PERFORMANCE ANALYSIS: Five main research streams can be identified in literature which handle performance analysis in public transport by means of the efficiency concept. Based on Table 3.6 one can say that they range from *measuring performance* (1,2) to *explaining performance* (3,4,5). As to the former, Figure 3.5 below illustrates an overview of quantitative methods used to analysis performance, productivity, efficiency, and effectiveness.

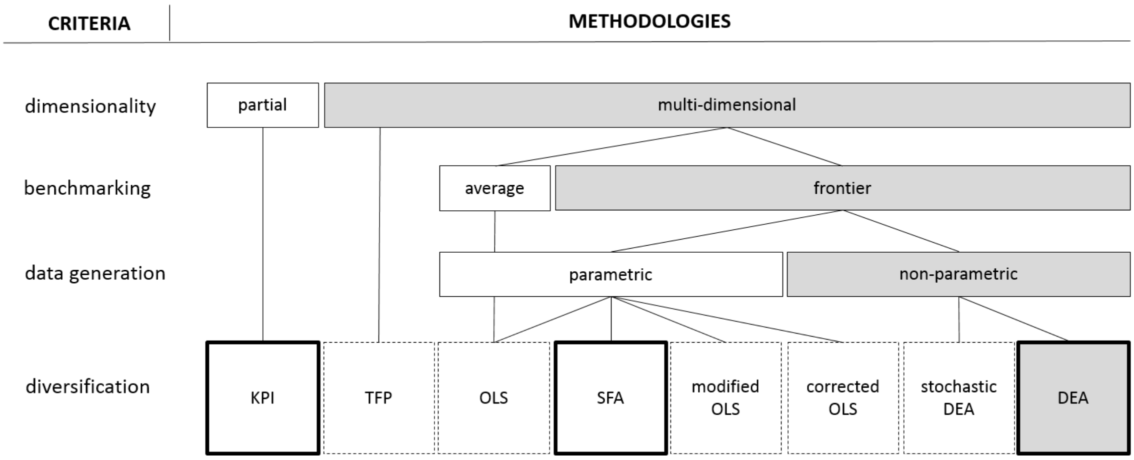

Figure 3.5: Performance measurement methods. Adapted from von Hirschhausen et al. (2007).

The methods can be distinguished by four criteria: (1) '*Dimensionality'* refers to the complexity of a method, i.e. how many aspects are included simultaneously to assess performance. Two main groups are found here: *partial* and *multi-dimensional* indicators. (2) '*Benchmarking'* differentiates how the best-performing units of a sample are constructed. A*verage approaches* use statistical methods, such as regression to calculate an expected average performance value for a unit analysed that might be located on a trend line. *Frontier methods* set the most efficient units of the sample as benchmarks - which essentially is the edge or the frontier of the production possibility set, specifically the production function. (3) '*Data generation'* refers to the assumptions whether functional relationships among variables are modelled *parametrically* or *non-parametrically*[83]. '*Diversification'* relates to how much the approach deviates from standard performance concepts such as technical efficiency analysis, for instance by including cost information or other behavioural proxies rather than just physical inputs and outputs. (Cooper et al., 2007; Daraio et al., 2016).

The overview of Figure 3.5 suggests that literature provides a number of alternative ways to measure the performance of operators. However, the main methods are essentially DEA and SFA. Data Envelopment Analysis (DEA) is a linear programming method using a nonparametric production frontier by fitting a piecewise linear surface over the data points. Stochastic Frontier Analysis (SFA) is econometric method that estimates a production frontier of the form, including an error term and a term that captures technical inefficiency. In the next section, these approaches will be explained in brevity and then compared in terms of advantages and disadvantages. For starters, also the simple indicator-based measures are introduced to capture the engineering perspective and substantiate the need for a more complex assessment.

[83]Kerstens (1996): *non-deterministic* vs. *deterministic* approaches. Fried et al. (2008) and Costa and Markellos (1997) differentiate between econometric (parametric) and mathematical programming (non-parametric) approaches.

Performance Indicators

In order to analytically study the technical performances of a public transport system or an operator, transport engineers, planners, managers and researchers[84] usually utilize heterogeneous kinds of data and form a rather straightforward set of aggregated indicators, sometime referred to as '(key) performance indicators', or simply '(K)PIs'[85]. The collection and compilation of data allows to get an approximate insight into the operator's most basic activities and thus facilitates managerial awareness and proactive intervention. When data is conducted on a frequent basis, time-series may illustrate how these indicators behave over time. As KPIs are common industry standards agreed upon by all operators, a direct comparison with the best operators in the benchmarking group might enable *stimuli* for individual performance improvements (Ceder, 2007; Randall et al., 2006; Santos et al., 2014). The list of KPIs is endless and depends on the specific type of analyses carried out. As shown in Table 3.7 there are several ways to organize the sheer plurality of indicators, the one of Vuchic (2007) is explained below.

Table 3.7: Public transport KPI classifications in literature.

Author	Classification of indicators
Makovsek et al. (2015)	scope, asset utilisation, HR utilisation, operational, financial, quality
Faivre d'Arcier (2014)	operational, quality, impact
Santos et al. (2014)	supply/demand, HR, quality, efficiency, effectiveness, financial
Diana and Daraio (2010)	technical efficiency, service use, intensity of service use, relative service dimension, service coverage, market penetration, revenue generation, externalities
White (2009)	operational, costs, impact, market
Vuchic (2007)	**productivity, consumption, utilization**
Randall et al. (2006)	financial, customer, learning/growth, internals, environment, safe/security
Ceder (2007)	2 groups for 7 standards based on 5 variables
TRB (2003)	availability, service delivery, community, travel time, safety and security, maintenance and construction, economic, capacity, paratransit, comfort
OECD (2000)	operational, financial, commercial
Oum et al. (1999)	general, locomotives, cars, track, capital, labour

When performance indicators capture *productivity* or *efficiency* issues, they can be expressed as a univariate ratio of output produced to resources consumed. In contrast, *consumption* rates relate energy, costs, labour, or space consumed to the unit of work produced. Lastly, *utilization* indicators can be applied flexibly to a number of different items in operation and service of public transport. Based on Vuchic´s classification, a selection of the most commonly applied indicators is given in Table 3.8. Santos et al. (2014) as well as Diana and Daraio (2010) provide more exhaustive lists with further variations; the latter authors with a focus on effectiveness-oriented indicators. The most striking advantage of partial indicators is that they are easy to

[84] see Oum et al. (1999).

[85] The framework of KPIs is usually based on the Harvard Business School "Balanced Scorecard" model, with the initial dimension: financial, customer, learning and growth, and business processes. (Randall et al. (2006))

Table 3.8: Simple performance indicators. Adapted from Vuchic (2007).

Category	Indicator	Interpretation
productivity	vehicle-km/vehicle	efficiency of vehicle use
	passengers/vehicle-km	intensity of service use
	passengers/vehicle	work per vehicle
	passenger-km/vehicle	efficiency of vehicle scheduling
	vehicle-km/employee	labour efficiency
	passengers/employee	labour efficiency
	vehicle-km/kilowatt-hour	technical energy efficiency
	seat-km/kilowatt-hour	energy efficiency of offered service
consumption	kilowatt-hours/vehicle-km	energy consumption per unit of performed work
	operating costs/passenger	average cost per served trip
utilization	vehicle-hours/vehicle	vehicle utilization
	scheduled vehicles/fleet size	vehicle utilization
	load factor	passengers in a vehicle to its total capacity
	work utilization coefficient	utilized service to offered service

[*cont.*] compute and to understand. However, there are also several limitations: *Firstly*, a major flaw relates to their partiality. The mixed use of inputs and related interdependency are not reflected. In reality, efficiency from one input might come at the expense of efficiencies of other inputs. *Secondly*, it is not transparent how a change in the level of an indicator relates to overall efficiency of an operator (Costa, 1998). *Thirdly*, external effects such as topography, government policy or other explanatory factors that might or not contribute to an operator's performance are not directly considered. This makes it hard to practically assess the extent to which indicators actually capture these effects. Without adjusting for exogenous effects, KPIs may be useless. *Fourthly*, the interpretation of a best-practice in a set of operators is somehow difficult with these indicators. Once an operator in the data set is identified as an outlier with significantly higher performance scores than others, one should investigate precisely upon the reasons for this performance gap before naming an outlier as the industry role model or best practice. *Lastly,* comparison of KPIs is not always suitable, for instance in the case of commonly used "unit costs". An operator in one city could have lower prices for inputs (e.g. in rent and wages) relative to one in another city, and hence might have lower unit costs. However, this does not necessarily mean the operator is more "efficient". When applied at all, these indicators should be built preferably from data routinely collected by operators, referring to inputs or outputs that are more or less under the control of the management. When used for comparison purposes, it should be for operators with almost similar operating environments or over time within one operator and relatively stable prices.

In summary, it has long been acknowledged that these traditional measures of organisational performance can be useful indicators to simply give a first glance about the state of productivity of operators. However, they are to be understood rather as an impetus for further economic performance assessment (Button and Costa, 1998; Makovsek et al., 2015; Oum et al., 1999). In-depth efficiency analyses should extend the evaluation principles to *how well an operator performs* and *how resources could be better used* with reference to some sort of production function or allocative constraints. Further, multiple outputs and objects of an operator should be considered. Consequently, the majority of academic and policy-oriented studies focuses on more comprehensive measures of performance as discussed in the next section.

Data Envelopment Analysis (DEA)

Economists tend to use production functions in a rather theoretical manner with inputs and outputs assumed to be allocated *quasi-efficient*. For instance, when the well-known Cobb-Douglas function is applied, it is given that units always operate *on* the production frontier. Larger deviations are mostly ignored. In reality, however, producers or operators are not always solving their allocation problems optimally and thus might *not* be operating precisely "on" the production function. The following section shows how this can be addressed with DEA.

'Data Envelopment Analysis' is a state of the art benchmarking tool for multi-criteria performance assessment. Following Hashimoto and Kodama (1996) it a *"non-uniform, multi-dimensional and relative evaluation tool".* The non-parametric approach was developed by Charnes et al. (1978) to measure performance and efficiency of so-called *Decision-Making-Units.*[86] Since then it became the *"most frequently used model of frontier technology"* (Färe et al., 1996) and has also been applied widely in the assessment of public transport efficiency.[87] The largest difference to other methods in the field is that DEA aims at identifying optimal states of efficiency instead of taking just an "average" or "representative DMU" as reference which, in a tradition going back to Alfred Marshall, were sometimes used for evaluations (Cooper et al., 1995). Practically, in competitive markets managers of whatever organisation would be interested to push their organisations towards the edges of productivity rather than aiming at *mediocre* scores.[88] Compared to other techniques, DEA thus can generate new managerial alternatives to improve performance. Further, DEA allows multiple outputs and multiple inputs to be taken into account. In the following the basic ideas and conceptual highlights of DEA are demonstrated. The corresponding mathematical formulations are illustrated in Appendix 1+2.

In DEA, observations with the highest performance are deemed efficient. They are located on the production function and other observations are individually evaluated against these best performers. Numerically, efficient observations receive a score of '1' and inefficient ones a score

[86] A DMU is generally an entity or organization that transforms inputs to outputs.
[87] Cooper et al. (2007) p. 33 refer to excellent literature on DEA.
[88] Econometric, regression based models with a symmetric error term for noise in this context are known as *average response models*. One-sided error models for to measure inefficiency are known as *stochastic frontier models*.

less than 1 but greater than 0. The score is unit invariant, thus independent from the factors that are measured. *Visually*, the procedure creates a rough illustration of the potential shape of production frontier spanned over the set evaluated.[89] *Practically*, a performance or efficiency index or ranking is produced.

operator	employees per passengers	vehicles per passengers
A	14	7
B	39	13
C	15	5
D	40	3
E	23	5
F	19	8
G	10	29
H	26	4
I	30	20
J	31	8
K	45	3

Efficient operators are marked **bold.**

Table 3.9: Operator input ratios.

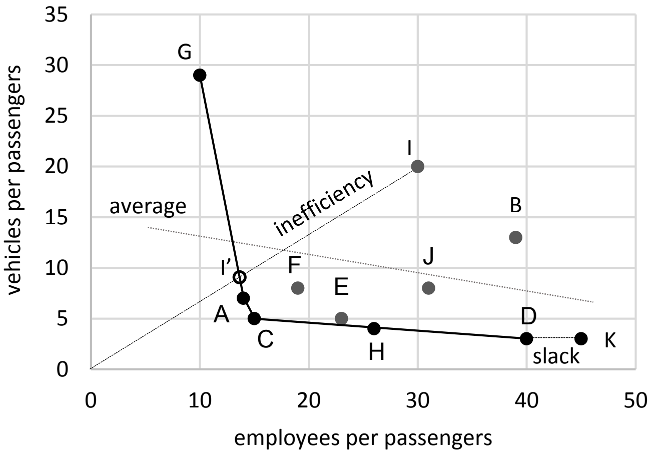

Figure 3.6: Efficiency frontier and relations.

Figure 3.6 and Table 3.9 illustrate the concept of the DEA with a fictitious[90] example of 11 operators. For demonstration purposes, only two inputs are used unweighted (at equal shares) - *number of employees* and *vehicles* - both standardized by dividing them by the *number of passengers* to obtain the standardized utilization of each input per output.[91] In economic terms, one then would refer to so-called *'factor combinations to produce a given or level of output'*, generally expressed by an isoquant convex to the origin. Once all combinations are plotted, operators G, A, C, H and K would mark the edges of the production possibility set. The black line drawn between these points essentially represents the efficiency frontier. These *benchmark operators* - all of them efficient - have the lowest combinations of inputs when both ratios are considered. Consequently, other operators in the set are *inefficient,* as depicted in the gap to the efficiency frontier of operator I (on the dashed line through the origin, II').[92]

Since one can visualize the efficiency frontier easily, the given example might so far be solvable graphically, e.g. by using the length of vectors and their ratios to calculate the extent of inefficiencies of each operator. However, with multiple inputs and outputs this becomes an

[89]The efficient operators gives a guess of the shape of the production function without the need for calibration. However, DEA does not give any information on the function parameters and slope.
[90]The example serves just for demonstration purposes, without deeper investigation if the numbers are practically applicable or if interdependencies impose practical limitations. However, the different magnitudes in combinations might be caused by vehicle size. DEA results can be found in Appendix 13.
[91]The frontier isoquant depicted in Figure 3.6 is a so-called unit isoquant, which shows the technically efficient input option used to produce one unit of output.
[92]As per Cooper et al. (2007) Figure 3.6 also emphasizes the difference to an average efficiency perspective that would result in operator "J" being above average, while in reality being strongly inefficient.

increasingly complicated endeavour especially since the $output/input$ - logic then requires to make assumption about the weighting of outputs or inputs, respectively. To handle these issues, *linear programming* (LP) or linear optimization serves as the backbone of DEA. In contrast to other areas with OR support where LP is used to *plan the future,* in DEA linear programming functions rather as a tool to *evaluate the past*.[93] With DEA, a *relative* and *weight-adjusted* performance measure can be obtained for each operator (also termed DMU). The methods makes use of a sequence of linear programs in order to determine a production frontier from the observed data through optimizing a weighted $output/input$ ratio for each operator/DMU as follows (see as full model and mathematical foundation in Chapter 6):

1) For each DMU p a *virtual input* and a *virtual output* is formed[94], including weights (v) for all inputs (x) and weights (w) for all outputs (y), respectively. The weights are unknown. All variables have a non-negative, non-zero value.

$$virtual\ input \quad = \sum_{i=1}^{n} v_i x_i \tag{1}$$

$$virtual\ output \quad = \sum_{j=1}^{m} w_j y_j \tag{2}$$

2) Weight determination for each DMU p using a LP: the objective is to obtain optimal weights (v) and (w) that maximize the ratio of each DMU p.

$$Maximize \quad \frac{virtual\ output}{virtual\ input} \tag{3}$$

The ratio appears to be *productivity.* However, since the LP applies ratio maximization to all DMUs individually, the highest productivity of any DMU eventually relates to the highest achievable (technical) productivity in the set. As a *ratio of ratios,* this exactly equates to *efficiency,* which is naturally limited to unity.[95] The underlying optimization problem can be formulated in different ways usually involving the transformation from *fractional (FP)* to *multiplier (LP)* to *envelope*[96] *(DLP)* form as shown comprehensively in Appendix 1/2. Since the later form has the least number of constraints, it is generally the one preferred to solve (Coelli,

[93]Bogetoft and Otto (2010): *"DEA models are essentially activity analysis models with the added feature that information about the activities is provided via actual observations rather than, for example, expert descriptions of what might be done."* Some authors conceptualize DEA as *activity analysis* with reference to Koopmans (1951). In activity analysis, different activities of an organization are defined and it is shown how inputs are transformed into outputs. The question pursued is how intensely the different activities are used. The constraints therefore reflect the available resources and their balance. DEA problems are similar to this classical OR models: DEA uses realized input-output combinations as different columns in the LP problem. The activity intensity is then shown in the weights of the resources. For clarification see also Koopmans (1951) and Färe et al. (1996); Bogetoft and Otto (2010).
[94]The term "*virtual"* refers to the unknown weights.
[95]For further explanation see Cooper et al. (2007) p. 35, sub-section "Problem 2.3".
[96]The OR term "Envelopment form" is the original source of the name "Data Envelopment Analysis".

2005). After having solved the problem, key terms in this regard are *theta*, *weights, slacks,* and *lambdas.* As explained in the following, these might serve several purposes in a DEA.

- *THETA:* Theta or θ is the objective value to be optimized for the DMU under evaluation. As a real variable limited between 0 and 1 it indicates the degree of efficiency of a DMU. For instance, an efficiency score less than 1 suggests that inputs need to be reduced by a proportion of 1-Θ for the DMU to become efficient. In the example given in Table 3.9, the optimal efficiency of operator I is 45%. In order to become efficient, it should reduce its inputs by 55% to reach the position I' on the frontier. This recommendation shows the normative power of DEA, as it can advise how much improvement in each dimension of the resources is needed by each inefficient operator. Theta is often equated to a measure of *managerial efficiency*. In this sense, the decisions taken by the operator management might not properly address the exploitation of the input-output relation when an operator is inefficient (as its factor productivity could still be increased).
- *WEIGHTS:* The particularity of DEA is that it does not use a common set of weights for all units. Instead, the optimal set of input and outputs weights (also called multipliers) varies for each DMU. The weights are rather of factual than hypothetical nature because they are strictly derived from the data instead of being arbitrarily fixed in advance. The latter case would make it difficult to interpret an efficiency ranking as it might be strongly affected the choice of weights. However, when received from the data, the relative magnitudes of optimal weights for a DMU suggests which inputs have comparatively higher effects when maximizing a DMU´s efficiency. For the example in Table 3.9 weights $v_{veh} = 0.06$ and $v_{emp} = 0.03$ for operator A suggest, that the input *vehicle* contributes twice as much to the performance than the input *employees*. In addition, the concept of weights can further be linked to the concept of slacks.
- *SLACKS:* Slacks are essentially *unnecessary consumption* of inputs that could be avoided without sacrificing output levels or changing the input mix[97]. A nonzero slack for any given input also indicates that additional performance can be achieved simply by adjusting the variables as proposed in the slack. For instance, in an input-oriented DEA the output stays unchanged even when the amount of inputs is reduced by the so-called *excess-input* $(s-)$ indicated. Similarly, an output could be increased up to the *shortfall-output* $(s+)$ without changing the inputs. Slacks can be identified for both, operators on the frontier and within the remaining production possibility set. In the simplest case the operator is already deemed efficient and located on the frontier, but in sections, where the frontier runs parallel to the axis. For instance, as per Figure 3.6, operator K is associated with a slack of '5' *employees* compared to operator D. Though both of them are technically efficient and located on the frontier, operator K could reduce his *employees* by five units, while keeping *vehicles* unchanged *and* still producing the same output level as before. Another perspective on slacks is to consider them as a sign of allocative inefficiency.[98] Sometimes slacks are also referred to as shadow-prices (Coelli, 2005).
- *LAMBDAS:* For an inefficient DMU, the corresponding lambdas indicate the set of efficient reference DMUs located on the frontier (also termed *target* or *peers*) and the proportions that contribute to its evaluation. The sum of all lambdas per unit is one. From their magnitude, one could derive conclusions about the similarities of the inefficient DMU to individual efficient ones. For instance in Figure 3.6, the peers for operator F are A and C. However, with $\lambda_A = 0.54$ and $\lambda_C = 0.46$ operator F would to be slightly more similar to A than to C. If similar patterns could also be identified for other inefficient DMUs operator A might be considered a role model in the set even among the best performers.

Depending on the outcome of the variables described above, different stages of efficiency can be defined for each DMU as shown in Table 3.10. In summary, DEA and especially the

[97]When referred to outputs, a higher output that could have been produced with the same quantity of inputs.

[98]Coelli (2005) claims that the importance of slacks can be overstated and that multi-stage DEAs offered better solutions to assess strongly efficient points.

corresponding variables such as *theta, weights, slacks* and *lambdas* yield important recommendations for managerial action to increase efficiency, such as reducing the inputs proportionally, or in the first place, changing the input mix accordingly to exploit slacks when present. Coelli (2005) claims that - theoretically - an accurate indication of efficiency in a DEA analysis for any DMU should report *both*, the measure of technical efficiency θ per se *and* the magnitude of the non-zero input or output slacks. Nevertheless, the author argues that practically the analysis of Farrell's *technical efficiency* is more reasonably to avoid confusion about the nature and implications of slack.

Table 3.10: Efficiency stages, variables and managerial action for input-oriented DEA model.

Efficiency stage	Synonyms	θ-value	Slack for input	Weight for input	Managerial action	Examples in Fig. 3.6
not efficient	"inefficient" "CCR/BCC-inefficient"	<1	yes no	=0 >0	adjust input-mix and/or reduce input	B, E, F, I, J
Farrell-efficient[99]	"CCR-/BCC-inefficient" "weakly efficient" "technical efficient" "radially efficient"	1	yes	=0	adjust input-mix	K
Pareto-Koopmans-efficient[100]	"CCR-/BCC- efficient" "strongly efficient"	1	no	>0	none	A, C, D, G, H

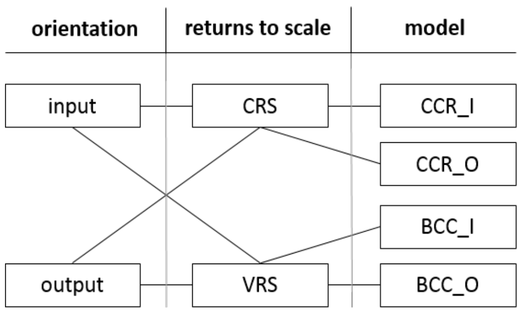

Table 3.11: Basic DEA models.

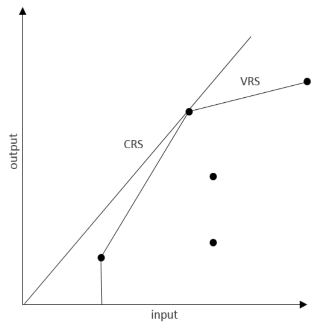

Figure 3.7: Frontiers with CRS/VRS.

A range of DEA models with several orientations and specifications has been developed, falling largely into the categories of being either *input*- or *output*-oriented and with *constant* or *variable* returns of scale. The so-called CCR and BCC models[101] illustrated in Table 3.11 form the very base for all further adaptations in DEA literature. *Input-orientation* - as used the examples above - assumes fixed outputs and indicates by how much input quantities could be reduced proportionally. In contrast, *output-orientation* assumes fixed inputs and indicates by how much output quantities should be increased to become efficient. Here an operator would be deemed efficient if an increase in any of its outputs is possible only by increasing either at least one of its

[99]Named after Farrell (1926-1975).
[100]Named after Pareto (1848-1923) and Koopmans (1910-1985).
[101]Named after Charnes, Cooper and Rhodes (CCR) and Banker, Charnes and Cooper (BCC). A mathematical description of both models can be found in Appendix 1 and 2.

inputs and/or by decreasing other outputs. The model orientation and specification depends majorly on the characteristics of the production process of the sector under observation and the extent to which inputs (or outputs) seem to be controllable by the decision makers. Though output-oriented models appear to be *"very much in the spirit of neo-classical production functions"*, that is, achieving a maximum output with given input quantities (Färe et al., 1994), for the purpose of estimating performance in public transport, input-oriented models have been applied more frequently. Obviously, demand as an output is not necessarily under control of the management, thus the question of how to adjust the controllable inputs seems to be more in the line with managerial ambitions.

Another criterion to be captured in DEA models is the nature of the *returns to scale* (see Figure 2.10). Returns to scale essentially determine how changes in outputs related to proportional changes inputs. Usually two versions are applied to DEA: *constant returns of scale (CRS)* assume that output increases by the same proportion as the change of inputs. The CRS assumption is applicable when all operators produce at an optimal scale. In fact, many factors such as monopolistic market structure, regulations, financial limitation may cause an operator to be operating besides optimal scale. Therefore, *variable returns to scale (VRS)* provide a mixed realization of constant, increasing and decreasing returns to scale (output either increases/decreases by a higher/lower proportion than the change in inputs).[102]

Table 3.12: Overview on DEA models. Adapted from Liebert and Niemeier (2010).

Cross-section Pooled data	Panel data	Externals	Dynamics	Supportive techniques and models
CCR, BCC ADD SBM FDH	Malmquist Index Window Analysis	one-stage DEA two-stage DEA	nw-DEA DDEA	statistical interference *(bootstrap, SDEA)* ranking *(superefficiency)* discrimination *(PCA-DEA)*

In summary, the landscape of DEA models that provide estimates of the technical efficiency for each single observation is many-faceted as shown in Table 3.12. The basic models CCR and BCC are usually applied with various specifications, data types, stages and in combination with supportive techniques.[103] Recent literature reviews from Cook and Seiford (2009)[104], Liu et al. (2013a)[105] and Lampe and Hilgers (2015) suggest that DEA is a constantly evolving research field

[102] Input- and output-oriented methods of efficiency are equivalent under CRS assumption, but can differ under VRS.
[103] ADD: additive DEA models combine input- and output- orientation; SBM: slack-based measures overcome unit-invariance of slacks; FDH: free-disposal-hull bases efficiency evaluation only on observed performances; nw-DEA: network DEA assumes internal sub processes; DDEA: dynamic DDEA assesses intertemporal effects with concepts of quasi-fixed inputs and/or investment activities. An excellent read on DDEA is provided by Färe et al. (1996).
[104] Cook and Seiford (2009) review the major research thrusts in DEA over the three decades by primarily focusing on (1) the various models for measuring efficiency, (2) approaches to incorporating restrictions on multipliers, (3) considerations regarding the status of variables, and (4) modelling of data variation.
[105] Liu et al. (2013a) apply a quantitative and citation-based analysis on 4936 papers in DEA literature.

with numerous advances, as demonstrated in column 1 of Table 3.13. As outlined in column 2, the application of DEA to urban public transport is among the most researched areas, with a relatively broad base of citations from multiple authors.

Table 3.13: Methodological advances and sectoral applications of DEA and corresponding key topics in public transport. Based on a bibliometric analysis from Lampe and Hilgers (2015).

Methodological Advances	**HHI**[106]	***Sectors***	**HHI**	**Key topics** in public transport	**C**
		electricity generation plants	0.07		
neural-nw-models	0.10	*airport*	0.11		
fuzzy set theory	0.12	environmental performance	0.11		
sensitivity	0.15	***urban public transport***	**0.12**	ownership	78
imprecise data	0.16	evaluation and selection of AMT	0.13	risk-sharing incentives	42
sub-processes in DMU	0.16	telecommunication	0.15	effectiveness	35
returns to scale	0.17	supplier selection	0.15	**technical efficiency**	25
composite indicators	0.21	forestry	0.15	social efficiency	20
super-efficiency	0.25	fishery	0.18	impact of different	16
discriminant analysis	0.26	agriculture	0.19	factors (e.g. speed)	
ranking of units	0.26	energy efficiency	0.23		
chance constraints	0.28	resource allocation in companies	0.26		
		political administrative systems	0.28		

In this regard, Daraio et al. (2016) conclude that - independent from the overarching research topic addressed in studies - the focus of DEA-associated public transport research is predominantly on the *identification* and *comparison* of technical efficiency scores. The assessment of their statistical precision or the influence of external variables on the obtained estimates still play a minor role. Only a view exceptions in literature apply bootstrapping methods (Santos et al., 2014) or aim at identifying the effect of a number of external variables onto the efficiency of operators in one- or two-staged DEA approaches (see further remarks in *Chapter 4* below). In the light of present knowledge, methodological advances such as *network*

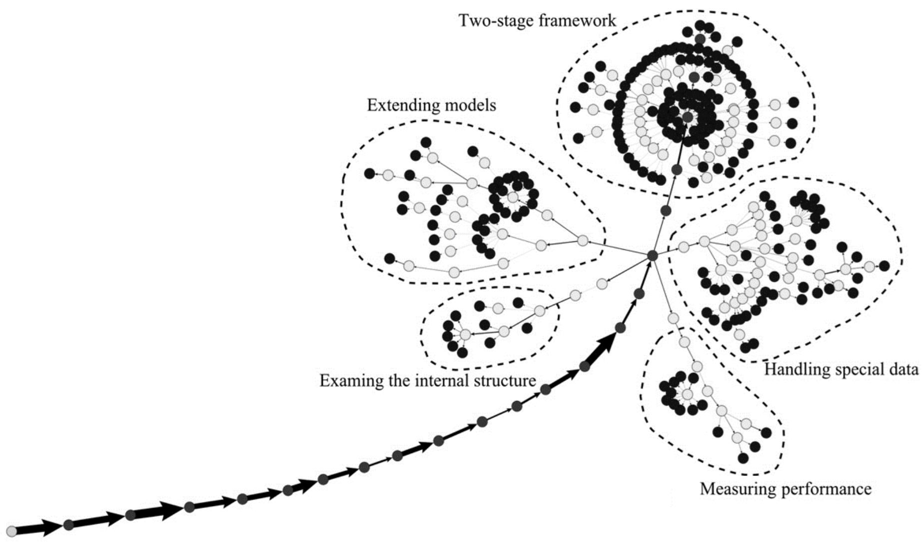

Figure 3.8: Advances in DEA. Adapted from Liu et al. (2013).

[106]'HHI' refers to Herfindahl index, which measures the concentration of intellectual structures within the clusters based on the relation of citations and papers. With a high HHI, only a few publications cause a large share of citations.

or *dynamic* DEA are almost non-existent in public transport performance literature. Following Figure 3.8 from Liu et al. (2013), general development in DEA research might be aggregated roughly to five main paths of different magnitude: '*Two-stage models'* evaluate the effect of contextual variables on efficiency. '*Extending models'* concerns models with restricted multipliers and flexible variables. *'Handling special data'* refers to models dealing with bounded, ordinal, qualitative, negative and fuzzy data. *'Examining the internal structure'* assumes various (intertemporal) sub-processes, interconnections and corresponding efficiencies in DMUs. *Measuring performance* refers to studies based on conventional methods.

The numerous *advantages* and *disadvantages* of DEA are comprehensively enlisted in Table 3.17 to support why DEA is chose as the core modelling technique of Chapter 6.

Stochastic Frontier Analysis (SFA)

'Stochastic Frontier Analysis' is an alternative method to measure performance or the extent of efficiency. The main difference to DEA is that one has to incorporate specifications about the functional relationship between the inputs and outputs in a production process and the distribution of efficiency. Thus, the unknown parameters of the unknown function have to be econometrically calibrated. The method might also capture measurement errors or other sources of statistical noise. In that sense, SFA is capable to (a) isolate the factors for the inefficient behaviour and allow for (b) the estimation of standard errors and hypotheses testing. SFA dates back to the achievements of Aigner et al. (1977b) and Meeusen and van Den Broeck (1977). Following Figure 3.5 and the corresponding remarks, SFA can be classified somewhere between average and deterministic approaches as pioneered by Farrell (1957) or Aigner and Chu (1968). The *basic* SFA model in equation (4 to 6) essentially builds on a log-transformed Cobb-Douglas production function (one-output, one-input), where the scalar y_i represents the output of the i^{th}-unit, x_i the input vector, β_0, β_1 the unknown parameters, v_i a systematic random error, and u_i a non-negative random variable also denoted as *technical (in)efficiency.*[107]

$$ln\, y_i = \beta_0 + \beta_1\, ln\, x_i + v_i - u_i \qquad (4)$$

$$y_i = exp(\beta_0 + \beta_1\, ln\, x_i + v_i - u_i) \qquad (5)$$

$$y_i = \underbrace{exp(\beta_0 + \beta_1\, ln\, x_i)}_{\text{deterministic component}} \times \underbrace{exp(v_i)}_{\text{error}} \times \underbrace{exp(-u_i)}_{\text{inefficiency}} \qquad (6)$$

The notion 'stochastic' relates to the fact that the outputs are bound to a random variable $\exp(\beta x_i + v_i)$. Equation (6) displays the three components to affect the input-output

[107]Ordinary least squares (OLS) estimation of an average frontier is a special case of SFA without the inefficiency term.

relation. Sometimes, the two outer ones are considered as *one error term*, composed of two components: The two-sided error component v_i captures the stochastic variation of the frontier between the units assessed including effects from measurement error, noise, and disturbances from *beyond managerial control*. The one-sided error component u_i captures the effects of the relative inefficiency and is understood as being *under managerial control* (Jarboui et al., 2012).

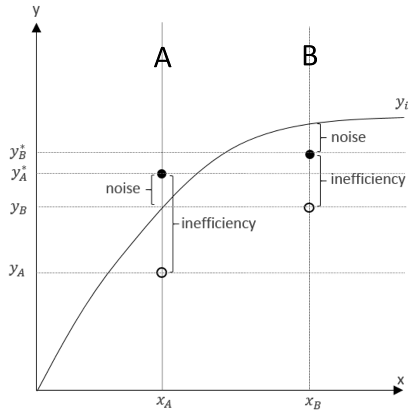

Figure 3.9: Stochastic production frontier. Adapted from Coelli (2005) p. 244.

$$y_B^* = \exp(\beta_0 + \beta_1 \ln x_B) \times \exp(v_B) \quad (7)$$

$$y_A^* = \exp(\beta_0 + \beta_1 \ln x_A) \times \exp(v_A) \quad (8)$$

$$y_B = \exp(\beta_0 + \beta_1 \ln x_B) \times \exp(v_B) \times \exp(-u_B) \quad (9)$$

$$y_A = \exp(\beta_0 + \beta_1 \ln x_A) \times \exp(v_A) \times \exp(-u_A) \quad (10)$$

$$y_i = exp(\beta_0 + \beta_1 \, ln \, x_i) \quad (11)$$

Table 3.14: The relation of noise and efficiency effects.

As shown in Figure 3.9 operator A and B would end up at points y_A^* and y_B^* if there was no inefficiency component (that is a fully efficient unit). In this case, the *deterministic part* and a positive or negative *noise part* would determine the so-called *(unobserved) frontier outputs*.[108] When the *inefficiency part* is added to the SFA model it then dependents on the magnitude and direction of the noise term whether the *observed outputs* y_A and y_B are located above or below the deterministic part. In a multi-input case, it is generally assumed that (unobserved) frontier outputs are evenly distributed above or below the deterministic component of the function whereas observed outputs tend to be located below the frontier. Only when a positive noise effect is larger than the inefficiency part, observed outputs are located above.

The core idea of SFA is to calculate the inefficiency component, namely technical efficiency. It can be defined as the ratio of the *observed output* to the *(unobserved) frontier output*:

$$TE_i = \frac{y_i}{exp(\beta_0 + \beta_1 \, ln \, x_i + v_i)} = \frac{exp(\beta_0 + \beta_1 \, ln \, x_i) \, exp(v_i) \, exp(-u_i)}{exp(\beta_0 + \beta_1 \, ln \, x_i) \, exp(v_i)} = exp(-u_i) \quad (12)$$

The denominator corresponds to a fully efficient unit. The ratio takes a value between zero and one. TE - also referred to as firm-specific efficiency - can be predicted (calculated) only after the

[108] This is a contrast to basic DEA models, which do not allow for deviations beyond the efficiency frontier.

parameters of (4) are estimated via OLS, COLS or ML method. In addition, industry efficiency can be calculated, which is the average of all firm efficiencies in the set of units assessed with SFA.

However, simple production frontier models do not include multiple-output cases or price information and the application is constrained to cross-sectional data. Remedies for the former cases are the use of distance functions, cost frontiers or profit frontier or simply output aggregation.[109] As displayed in Table 3.15 over the years the basic models have been further extended to panel data models (time-varying/time-invariant inefficiency models) that include effects from time, such as the changes in the underlying production technology in an industry. In addition, observed and unobserved heterogeneity has been researched. Often additional variables complement SFA models in order to directly capture external, environmental effects or production risks and to assess the structure and determinants of inefficiency.

Table 3.15: Overview on standard SFA models.
Adapted from Liebert and Niemeier (2010) and Coelli (2005).

Cross-section data	Panel data	External effects	Supportive techniques
Cobb-Douglas Translog Distance Functions Cost Frontiers	time-invariant time-varying (heterogeneity)	non-stochastic production risk	Bayesian statistics

The most used SFA specification is the Battese and Coelli (1995) *Cobb–Douglas* production function in a *panel* set-up that allows for the introduction of external factors affecting the inefficiency term. It can be said, that a large share of SFA literature either applies Cobb–Douglas or *Translog* frontiers. For a thorough review of references, research directions as well as advances indicated in Table 3.16 see Karlaftis and Tsamboulas (2012) and Daraio et al. (2016).

Table 3.16: Methodological advances and sectoral application of SFA.
Based on a bibliometric analysis from Lampe and Hilgers (2015).

Methodological advances	HHI	*Sectors*	HHI
Bayesian analysis Neural-Networks-Based models Heterogeneity	0.15 0.20 0.26	Agriculture Banking sector Hospital/health care sector Fishery Container ports Insurance companies	0.13 0.18 0.22 0.22 0.26 0.51

The next section reflects on important considerations concerning the choice of a particular performance measurement method among the previously introduced ones.

[109]For a deeper insight on related methodological issues see Coelli (2005) pp.245 ff. and Kumbhakar and Lovell (2003).

Direct Comparison of Measurement Methods and Final Selection

From the above stated inferences, it appears to be evident that the choice of a measure primarily depends on the *context and design of research*, *intended results* and *addressees*. Conducting a performance analysis therefore involves a number of trade-offs.

- As to the research design, for instance the intended comparison/reference can frame the method choice. Will performance be evaluated against other operators *or* self-referring over time? The former approach might come with the risk to produce skewed rankings, whereas the latter one lacks of external evaluation.
- The targeted audience or perspective has to be considered. A research community might allow applying sophisticated measures even if they are not perfectly reflecting public transport service reality, whereas operators and regulators might be interested in straightforward measures that give clear suggestions for action.

A general trade-off in empirical performance analysis can be found in the fact that one has to decide between the more robust (but inefficient) nonparametric and the restrictive (but when consistent, more efficient) parametric approach (von Hirschhausen, 2008). *"It would be desirable to make the programming approach stochastic, and to make the econometric approach more flexible in its parametric structure. Limited progress has been achieved in both areas"* is a conclusion from Fried et al. (2008) in this regard. Therefore, Table 3.17 below extensively summarizes the most important features of both methods, which obviously come with several similarities as well as distinct differences in various categories (*data requirements*, *software tools*, *modelling*, *closeness to reality* and *usability*). In the following the main findings are presented, some of which could serve as selection criteria (SC) for choosing a method.

COMMON FEATURES: In summary, both methods are built upon well-developed, theoretical foundations and require access to quality data. Nevertheless, Coelli (2005) indicates several conceptual pitfalls, such as assuming inputs and outputs to be homogenous when they are not, the sensitivity of input and output selection towards results and the risk of neglecting additional explanatory factors for efficiency or ignoring intertemporal aspects of management decision-making. In addition, one could also conclude that the high degree of standardization and levelling down of organisational units and production processes in frontier techniques is quiet unrealistic. A related interpretational problem is that conclusions from frontier techniques and related cross-survey comparisons should be treated carefully against the background of being just relative concepts. They strictly produce relative rankings and not absolute ones meaning, that the inclusion of additional units may change efficiency scores and rankings significantly. Hence, efficiency scores are only valid in the specific data environment they are presented with, which obviously limits comparability. Finally, another risk comes from the potential of measurement errors and outliers. However, the sensitivity might slightly differ in both methods.

Table 3.17: Comparison of SFA and DEA. Sources stated below.

EVALUATION			METHOD	
Criteria	***Sub-criteria***	***Definition***	**SFA**	**DEA**
Performance type		Technical, allocative, scale efficiency.	*all*	*all*
Data requirements		Data on inputs and output and/or cost and/or prices. [cross-sectional: a set of operators in one year; time-series: a set of years for one operators; panel: a set of years for a set of operators]	*medium to high* [depending on function: production frontier, distance function, long-run cost frontier, short-run cost frontier]	*low to medium* [In situations where price information is absent; otherwise price data used for allocative efficiency]
Software Tools		Availability of specialized, ready to use, commercial tools for analysis.	*limited*	*high*
Modelling	Referencing	Identification of a set of peers for each inefficient firm.	*no*	*yes* [along the best-practice frontier]
	Weights	Individual input or output weights for each unit.	*no*	*yes*
	Noise	Measurement error may influence shape and position of the frontier, as well as efficiency scores may be affected by many factors beyond managerial control. If not considered, observations with noise may end up as technically efficient ones.	*yes* [may be affected by the particular distributional forms specified]	*no* [yes, with bootstrapping]
	Statistical testing	Hypothesis testing intents to determine whether a given hypothesis is true, e.g. with regard to the "optimal" model specification.	*yes*	*no*
	Unit invariance	Dependency of efficiency scores from the units in which the factors are measured.	*yes*	*no*
	Sensitivity to outliers	An outlier is a unit that is distant from other units. Outliers may have major effects on results.	*low*	*high*
	Sensitivity to *input/output*	Results are sensitive to the selection of inputs and outputs, e.g. when the exclusion of an important input or output changes results.	*medium*	*high*
	Sensitivity to *sample size and number of variables*	Sample size can have effects on statistical robustness or interpretation. Large sample sizes are generally better to create robust results; a large number of variables however might create misleading results.	*high* [Large sample size needed for robust estimates. Number of observations depends on the number of parameters of the function applied]	*high* [Dimensionality problem: and the number of efficient firms on the frontier tends to increase with the number of input and output variables.]

	Assumptions	Assumption and restrictions about the data, functional form of the production function and the distribution of an inefficiency term and the estimation of parameters.	*strong* [strong a priori assumptions]	*modest* [implicit use of the revealed technology]
	Standardization Similarity	For all operators in a set the same production technology is applied; inputs and outputs are homogenous across operators. Treating inputs or outputs as homogenous when they are heterogeneous may bias results.	*strong*	*strong*
Closeness to Reality	Complexity	Provision of a realistic description of the production activities by handling multiple (inputs and) outputs, or returns to scale.	*modest*	*high*
	Assessment of primary sources of inefficiency	Sources of inefficiency can be analysed and quantified for every evaluated operator.	*strong*	*strong*
	Assessment of secondary sources of inefficiency	Incorporation of additional internal and external effects on efficiency. Not accounting for environmental variations may facilitated misleading results in terms of managerial competence.	*strong* [Environmental variables are easy to add.]	*weak* [Basic DEA does not properly account for external effects, only if 2-staged.]
Usability and Costs	Theoretical grounding	Consistency of the model with economic theory, such as the production concept of efficiency based on maximization principles as well as compliance with mainstream economic methodologies.	*strong*	*medium*
	Interpretability	Straightforwardness of interpretation of results or of the estimated production function (e.g. guidance for inefficient units with regard to which of their activities have to improve and by how much, functional parameters, shape, the contribution of each input, etc.).	*low* [Based on standard econometrics thus interpretation not always straightforward]	*high* [Mathematical programming techniques are "black-box" approaches; conceptually straightforward]
	Comparability	Potential to compare individual efficiencies scores among different studies. They may be bound to each sample and the respective method used, and should thus be carefully treated in terms of comparative conclusions.	*modest*	*weak*
	Flexibility	Capability to assess problems that appear impenetrable. Simplicity and swiftness of application on production like processes in general and with strong unit variations.	*low*	*high*
	Modelling costs	Degree of decision-making required for modelling or coding knowledge requirements.	*medium*	*low*

Compilation based on Costa and Markellos (1997), Button and Costa (1998), Coelli (2003), Coelli (2005), Avkiran (2006), Cooper et al. (2007), Graham (2008), Holvad (2010), Karlaftis and Tsamboulas (2012), Jarboui et al. (2012), Santos et al. (2014), Daraio et al. (2016).

(SC1) PROS AND CONS: SFA's most striking advantage relates to its statistical sophistication and the inclusion of noise to the efficiency score. However, this comes with comparatively high modelling costs, as SFA requires plenty of decisions to be taken by the researcher about the underlying functional form, distributional assumptions and estimation methods. Further, SFA appears to be limited in use for readers other than researchers, since calculation procedures and estimations mostly require specialised data processing and software skills as well as modelling experience. In contrast, DEA essentially captivates with its handiness and simplicity regarding the absence of any *a priori* assumption about a functional form of the production process even in multiple output cases. Recent statistical advances in DEA intend to partially close the gap to SFA but many of these methods are rather complex and have yet to become standard in applied research. In addition, the level of detail might be a selection criterion: fewer detailed DEA will be easier to calculate and present, but the more detailed SFA might be capable to take into account a greater number of influencing factors on performance.

(SC2) APPLICATION IN MAINSTREAM RESEARCH: Consequently, the question arises as to which extent both methods have been applied in literature. Daraio et al. (2016) explore performance literature in public transport through *density maps* for the most relevant terms and objectives as illustrated in Figure 3.10. Initially, the research identifies the two above-mentioned main groups of methods: parametric[110] or non-parametric measures[111] (see left figure, the structures left and right from the diagonal). The former ones seem to dominate the literature compared to the later one in absolute numbers as indicated by the larger coverage of the cloud-like structure. With reference to DEA and SFA as introduced above, the right hand side of Figure 3.10 suggests that SFA could be considered an evolution of traditional regression models - now closely affiliated with the research area of *regulatory policy.* DEA appears to be rather isolated methodologically in the densely aggregated research field on *factor productivity*. The authors conclude that (a) *"the parametric frontier approach has taken the heritage of the traditional*

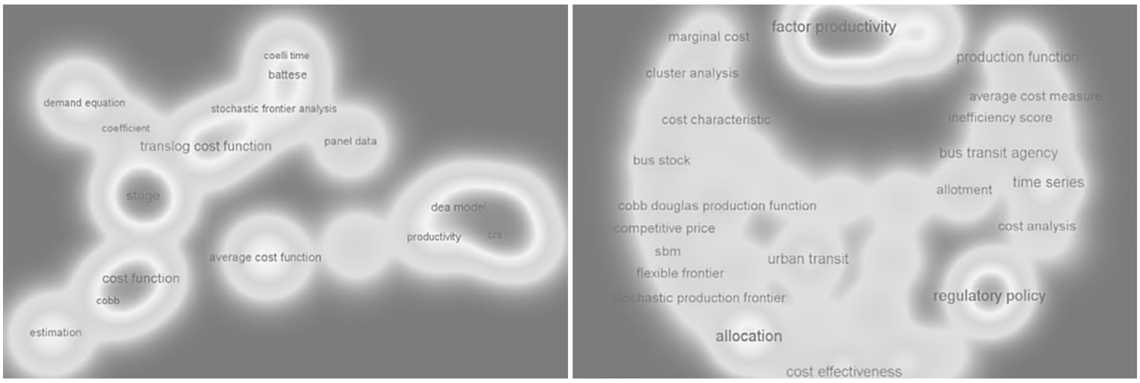

Figure 3.10: Density map (left). Objectives of performance research in public transport (right).

[110]Top terms: cost functions, multi-staged analysis, SFA.
[111]Top terms: average cost functions, DEA.

parametric regression approach" and (b) an increased trend in the use of nonparametric frontier approaches and its advances[112] offers *"great potential for future application"*. In fact, most recently DEA has been the more popular method in performance analysis. This is indicated by the speed of methodological development and numbers of publications in general (Lampe and Hilgers, 2015; Liu et al., 2013a) and in public transport (Brons et al., 2005; Daraio et al., 2016; Graham, 2008; Jarboui et al., 2012).[113]

(SC3) DATA AVAILABILITY: For Daraio et al. (2016) the availability of data is strictly correlated with the production of quality research. As mentioned above an initial decision to make in performance analysis is whether the research design (comparisons, referencing) is cross-sectional, panel or time-series-based. This choice might already determine the method used, especially through the extent of data availability. A cross-sectional approach is rather one-dimensional and aims at comparing many operators analysis at one point of time (e.g. 2015). It is called *a panel* when many operators are compared at different times (e.g. 2010 and 2015). Physical input and output data of operators might be easy to get since - for various regulatory reasons - it is generally well documented either on the operator side, or in publicly accessible databases or previous research. Once price and cost information is included, data consistency across countries can become a difficulty. Daraio et al. (2016) and Brons et al. (2005) indicate that panel (≅50%, but rather short-termed) and cross-sectional research designs (≅30%) dominate performance analysis, regardless from being of parametric or non-parametric nature. In other words, data availability seems not restricted for short observation periods and is therefore not considered a decisive factor for the choice between DEA and SFA. However, time-series approaches - i.e. the assessment of performance over time for one operator or across several operators (e.g. 2000 to 2015) - are obviously underrepresented in public transport performance studies (≅14%). Most probably, this can be explained with the lack of data-availability, as the time-span required to get reasonable results must be lengthy enough. For instance, when one intends to use a function with a large number of parameters, say in a SFA translog context, this might require at least 50 years of data to satisfy the degree of freedom restriction (Coelli, 2003).[114] Moreover, if possibly time-series (or long-term panel) data were available, adjusting the functional relation over time could cause interpretation, comparison and consistency issues. Even more so when periods and operators with significant changes in technology or data

[112]Methodological advances tackle the traditional limitations of DEA: deterministic nature, outlier impact, separability condition of external factors, heterogeneity of the analysed units, etc.

[113]Jarboui et al. (2012): *"It shows that the majority of studies have adopted the DEA method, but there are some studies that adopt the method SFA".*

[114]Button and Costa (1998): It can be said, that the number of observations should be adequate to estimate a translog model (greater than the number of parameters in a translog model).

definitions are included in the analysis. Therefore, it can be concluded that if a time-series-based research is intended, favouring DEA over SFA could be a reasonable option either when data is not available in a sufficiently long stretch of time to properly apply SFA *or* strong and complicated assumptions about the functional form of production over time should be avoided.

METHOD SELECTION - DEA: Making a decision for a single technique based solely on its features and advantages (SC1) appears to be difficult as both methods significantly differ from another. However, a key element here might be the importance of a statistical framework. Other key criteria that could facilitate the selection process are the objectives of the study and the reflection in literature (SC2), and data availability (SC3). Coelli (2005) suggest to make these decisions on case-by-case basis. Another exit is to apply both methods to the same problem as a sensitivity analysis to ensure the reliability and verifiability of the results, since DEA and SFA should generally produce similar outcomes.[115] Costa and Markellos (1997) propose a sequential procedure, which requires initially to apply a straightforward econometric approach and when its assumptions are likely to be invalid, a nonparametric method such as DEA should be pursued.[116] Alternatively, the simplest way to make a specific operator "look good" overall, is trying different methods and various specifications and finally choosing the most “favourable” results. However, in practical terms, this research is limited by time and volume and thus only *one* method is utilized hereinafter. Therefore, a DEA model is chosen[117] despite the several methodological and theoretical advantages of SFA over DEA suggested in Table 2.22. The strongest arguments for DEA refer to its straightforwardness and popularity, best expressed in words by Graham (2008) [*“we choose […] DEA measures for precisely that reason; that they are conceptually straightforward and easy to interpret. Moreover, they are the measures that are most frequently used in the transport literature.”*] and Schefczyk (1993) [*“DEA is [the] only viable methodology that links all factors of efficiency by evaluating the relationships between each input and output to arrive at a scalar measure of performance.”*]. The line of research presented here mainly follows this reasoning. In SFA, the many and arbitrary decisions required to arrive at some precision benefit are paradoxically seen as its largest disadvantage (Coelli, 2005). In addition, it appears favourable to employ DEA as the danger of imposing an incorrect functional form is avoided. In that, DEA facilitates the description of the structure of the production frontier in a more comprehensive way (Cooper et al., 2007; Ermagun and Levinson, 2015).

[115]Efficiency scores from SFA may be larger than that from DEA because SFA includes noise. In contrast, efficiency scores could also be smaller, as DEA is fits data more tightly.
[116]Similar advice comes from Coelli 2005: *“Whenever it is possible, explore alternative models and estimation methods and (formally or informally) assess the adequacy and robustness of the results obtained”.*
[117]Specifically the input-oriented BCC variant with CRS.

3.3 Application: Findings on Performance

This section intends to summarize the most important findings of urban public transport performance literature. As suggested in Table 3.18 several literature reviews have been published on the topic in the last 15 years. The reviews should serve as a valuable source to extract the most mentionable results and to avoid redundancies.

Table 3.18: Overview on pivotal literature reviews in public transport performance research.

Author(s)	Title	Content	Scope
Daraio et al. (2016)	*Efficiency and effectiveness in the urban public transport sector: A critical review with directions for future research*	Review of basic concepts and classification of the empirical literature in categories: inputs, outputs, kind of data analysed, methods adopted; policy addressed.	1970-2014 *[124 empirical studies]*
Jarboui et al. (2012)	*Public road transport efficiency - A literature review via the classification scheme*	Analysis of empirical literature as to nature of the papers', context of the study, adopted approach, configurations, empirical findings.	2000-2011 *[24 empirical studies]*
Walter (2010)	*Modern Efficiency Analysis Applied to Local Public Transport*	Single- and multi-output studies and the influence of structural variables.	1992-2008 *[17 empirical studies]*
Borger and Kerstens (2006)	*The Performance of Bus Transit Operators*	Basic concepts of efficiency, model specifications, summary existing empirical literature and determinants assessment.	1990-2006 *[not defined]*
Borger et al. (2002)	*Public transit performance: what does one learn from frontier studies?*	Review of relevant performance indicators and methods to measure them. Existing frontier studies are systematically summarized and critically assessed and determinants of performance identified.	1990-2000 *[62 empirical studies]*
Brons et al. (2005)	*Efficiency of urban public transit: A meta analysis*	Statistical overview of the literature on public transit efficiency performance. Explaining the variation in efficiency findings in the literature.	1990-2000 *[33 empirical studies]*
Lampe and Hilgers (2015)	*Trajectories of efficiency measurement: A bibliometric analysis of DEA and SFA*	Citation-based bibliometric literature analysis of the field of performance measurement.	4782 studies *[761 for SFA 4021 for DEA]*

The first review of its kind - and by far the most appreciated one - came from Borger et al. (2002). They gave a comprehensive overview on production and cost frontiers analysis in public transport by elaborating, summing-up and discussing relevant methods and achievements published during 1990-2002. A slightly updated version was provided by Borger and Kerstens (2006), however with a focus on urban bus transport only and a more extended discussion on regulatory issues. Eventually, Jarboui et al. (2012) took on Borger et al.´s "review heritage" by covering a period of the subsequent period between 2000 and 2011. Complementary input comes from Walter (2010), who reviews several single and multioutput public transport performance studies. These works jointly cover over 20 years of performance research both with parametric and non-parametric techniques, such as SFA and DEA. Important results are summarized in this section, which is divided in two sub-sections, namely *empirical results* and *determinants of efficiency*. The former one *relates to efficiency scores* presented in studies (e.g.

in minimum, maximum and average values) but also to results concerning the role of *returns to scale and scope* or the relation between the concepts of efficiency and effectiveness. The latter sub-section - *determinants of performance* - shows results from studies that try to explain the sources of inefficiency. Jarboui et al. (2012) and Borger and Kerstens (2006) argue that the interpretation of individual results in performance analysis should always be framed by two principles: *Firstly*, the underlying model and its specifications has to be considered when drawing conclusions, as different techniques may generate differently large performance scores on the same unit. *Secondly*, performance is a relative concept and scores from individual units cannot be compared across studies, however averages might help to some extent.[118] Major findings are listed below in a synoptic manner. If indicated, results from more recent papers[119] with new findings are specifically stressed.[120]

Empirical Results

This paragraph briefly summarizes *empirical* findings. Table 3.19 displays few cut-out average performance scores from different studies with various scopes, contexts, and objectives.

SUBSTANTIAL TECHNICAL INEFFICIENCIES: On average, most studies report substantial remaining technical inefficiencies of operators regardless of whether they are assessed within one country, or among countries (see Table 3.19 Column 'scores').

VARIABILITY OF AVERAGE TECHNICAL INEFFICIENCIES: In country-to-country comparison, average inefficiencies of closed sets show high variability supposedly caused by corresponding differences in the regulatory framework, managerial quality and the operating environment (population density, GDP, topography). Interestingly, operators in generally less car-oriented environments appear to be averagely more efficient than in more car-oriented environments (Europe vs. USA). In addition, SFA and DEA seem to yield different results when applied in the same problem (see Table 3.19 DEA vs. SFA).

LEVEL OF AVERAGE TECHNICAL EFFICIENCY: In cross-country studies with many operators and different contexts being assessed, the average efficiency tends to be smaller, as the spread is larger from worst to best performer. In contrast, in studies with a rather homogenous set of operators, the average efficiency is higher. Thus, the variety of contexts considered might help to detect explanations for inefficiencies operators (see Table 3.19 Spain vs. NRW).

[118] However, Karlaftis and Tsamboulas (2012) find that policy recommendations based averages should be avoided.
[119] E.g. published between 2011 to 2015, but predominantly with DEA focus.
[120] Because specific issues and details of individual papers are intensively discussed in the reviews themselves this sections goes without referencing each paper dealt with separately. If further clarification is intended, one might devote oneself directly to the reviews.

Table 3.19: Recent performance results.[121] Adapted from Jarboui et al. (2012) and Brons et al. (2005).

Context/Comparison	Unit	n	Scores (avg.)
National, Regional	Canada	30	0.78
	India	35	0.83
	Italy	42	0.93
	NRW	41	0.85
	Spain	24	0.51
	USA	259	0.62-0.89
	Norway	154	0.65
	Norway	47	0.72
	Norway[122]	27	0.94
International	Brazil, European Metros	19	0.90
	European Metros	37	0.77
Interurban bus	Germany	179	0.42-0.46
Ownership	Private vs.	15	0.88
	Public	15	0.82
Concept	Efficiency	15	0.84
	Effectiveness	15	0.80
Method	DEA	15	0.3-0.5/0.70-1.00
	SFA	15	0.5-0.7

EFFICIENCY CHANGES: Changes over time tend to be marginal (*"small or zero"*), which can be essentially demonstrated in recent studies for Europe based operators (see Table 3.19 the Norway case, also von Hirschhausen (2008), Brons et al. (2005), Boame (2004)). Odeck (2008) finds that efficiency changes over time might also be cancelled out by regress frontier shift (technological change). General explanations for weaker increases over time can be found in matured technologies for fuel efficiencies or exhausted labour efficiency potential since for instance single-man operations are long-established standards. Also the potential to generate performance from regulatory reforms - as indicated previously by Button and Costa (1998) - seems to be exhausted in recent times. Nevertheless, operational speed still appears to be a major source for performance improvement, achieved for instance by implementing separate lanes or TDM measures such as bus prioritization, sometimes costly measures that require a certain degree of financial independency (Boame, 2004). However, it is important to stress that increased competition for space with common traffic in non-separated network (sections) might risk cancelling out any of these measures. There are also indications that in countries where speed measures for public transport are neglected, growing individual car use and congestion drastically decrease operational speed and efficiency of services. In general, temporal aspects in performance analysis are a relatively underrepresented subject, as demonstrated in Chapter 4.

EFFICIENCY AND EFFECTIVNESS: Efficiency is often tested against the demand side of production, namely effectiveness. When bearing in mind the definitions from above, one might intuitively

[121]An average efficiency score of 0.80 means that averagely all operators together could produce the same outputs with only 80% of their inputs. This would translate to an average cost reduction of 20% cost reduction.
[122]Norway studied in 1991, 1994, 1995-2002 indicates an efficiency increase in the sector over time.

suggest a negative correlation. However, findings are of rather mixed nature (Borger et al., 2002). Correlation can be none, negative or positive, depending much on the output specifications as well as temporal consideration. Brons et al. (2005) found that efficiency tends to be higher than effectiveness (see Table 3.19). Karlaftis (2004) and Karlaftis and Tsamboulas (2012) conclude that both scores are negatively correlated and that effectiveness is markedly lower than efficiency but grows stronger over time, partially opposing findings come from Tulkens and Wunsch (1994). As per Georgiadis et al. (2014) there is no clear positive or negative relationship. However, the authors find that traffic conditions, location of depots and scheduled layover affect the efficiency of bus lines, whereas population density affects effectiveness.

SCALE AND ALLOCATIVE INEFFICIENIES: As to the non-optimal size and non-cost minimum-operation, results suggest that they have a rather small impact on performance. Generally, the nature of these inefficiencies depends heavily on the regulatory environment and on the subsidy regime, which might encourage capital-intensive production and excessive labour utilization.

ECONOMIES OF SCALE, DENSITY, SCOPE: Such-like results strongly depend on the context and the method chosen and most importantly are not necessarily objectives of performance analysis. However, it appears that with regard to *economies of scale* small[123] operators benefit from IRS, whereas large operators suffer from DRS. Average-sized operators seem to work on CRS, which for bus operators is believed to lie between 250 and 400 vehicles. In the overall picture, operating in the zone of increasing or constant returns to scale is a common feature of most public transport operators (Santos et al., 2014). In addition, studies provide evidence for a classical *u-shaped cost function*, indicating that firm size matters with regard to cost-efficiency: smaller operators show over-proportional cost reductions whereas big operators show under-proportional cost reductions. As to *economies of density* - that is unit-cost reduction by increased utilization of the network e.g. by higher frequencies - it has been demonstrated that they predominantly occur in bus industries in the short and medium run, without or with the adjustment of fleet size. *Economies of scope* - that is reduced costs per vehicle-km by offering service with two modes from *one* operator instead of *two* separate operators - are a rarely studied subject. It seems that the benefits of mergers in this regard depends majorly on the modes offered and the number of operators being merged.

[123]Measured by the number of vehicles.

Determinants of Performance

CLASSIFICATION OF DETERMINANTS: When particular operators are found to be inefficient, the subsequent question is *how to identify sources for inefficiency* or *drivers for efficiency*. As demonstrated below, determinants of inefficiency can roughly be classified in four groups. The former two are rather trivial cases related *methodological* and *interpretation* specifics. The latter two actually refer to *real explanatory factors* (Table 3.20).[124]

(1) Observed inefficiencies might simply be caused by data or measurement issues. Those are mandatory to be checked beforehand in modelling (e.g. outlier position, omitted inputs or variables, inputs and outputs quality differences among operators, measurement errors).

(2) Some inefficiencies could be explained by the specific efficiency type measured, such as technical vs. allocative efficiency (observed unused/squandered capacity of operators), or efficiency vs. effectiveness (outperforming in just one performance dimension).

(3) When the focus lies on pure technical inefficiency, so-called exogenous or external factors[125] of non-physical or physical nature are supposed to affect performance. Not surprisingly, performance plays a notable role in political and academic debate upon public transport, with much of the discussion circling around the issues of regulation and privatisation, which are believed to be key factors for performance. Insofar, in particular this group of determinants generates a lot of research interest. One hopes to learn about the effects or consequences of policy measures by comparing operators in different environments of *regulation, competition, ownership*, *subsidies* and *contract design* (from operator side non controllable).[126,127]

(4) Analogously Jarboui et al. (2012) and Coelli (2005) point at the need to introduce another group of performance determinants, which seeks for explanations more "inside" the operator. It is argued that the means under the control of an operator are more robust to assess the determinants of inefficiency. Thus, the group of *endogenous or internal factors* accounts for factors that are - with graduations - *under the control (discretionary)* of the operator such as *operations* or *management practices*, opposed to the previous group that essentially relates to factors that are *not in control (non-discretionary)* of the operator.[128]

In summary, any interpretation of results in performance analysis requires taking account of these potential determinants in order to avoid misleading conclusions. Key findings for *external (EX)* or *internal (IN)* determinants of performance are presented in the following:[129]

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[124]Classification based on Jarboui et al. (2012), Graham (2008), Coelli (2005), Borger et al. (2002).

[125]Coelli (2005) differentiates between non-stochastic, observable external factors and unforeseen stochastic external factors regarded as sources of production risk. This sub-group is also referred to as *environmental* factors.

[126]Including economic, demographic, socio-economic, environmental, geographical aspects. In literature, results from that direction are mostly by-products of the main study. For instance growing car ownership can decrease operating speeds due to congestion. Graham (2008) found positive relationship for GDP and negative one for population with respect to operator performance. Also complementary policies should be considered performance drivers/inhibitors: Following Faivre d'Arcier (2014) in France a transport tax is levied and authorities are obliged to reduce car traffic by offering of alternatives. Makovsek et al. (2015) propose to consider cultural differences as an effect on performance.

[127]*Regulation/competition* is the need for intervention in case of market failure. Deregulated/competitive markets are believed to increase operator performance. Mergers might increase efficiency, in the presence of sub-additivity. (The effects of deregulation are extensively discussed in Borger and Kerstens (2006)). *Ownership* refers to whether the operator is in private or public hand. The hypothesis is that productivity and efficiency are higher in the private than in the public sector. *Contract design* refers to contractual arrangement between operator and public authority.

[128]An extensive list of explanatory factors and their distribution for is given by Daraio et al. (2016) Table 7.

[129]A few more recent results with DEA focus are presented in Chapter 4.

REGULATION, OWNERSHIP, CONTRACT DESIGN (EX): Borger et al. (2002) point out that ownership-oriented studies often lack to control for competition and the degree of governmental intervention. The authors argue that effects from *ownership* are irrelevant in strongly regulated markets, when compared to effects that come from the market structure itself and the nature of competition. Early non-frontier studies suggest that the variation in ownership has no significant correlation with performance. However, the majority of recent papers suggests that the joint combination of deregulation *and* privatisation trigger the efficiency of operators, supposedly caused by measures associated with the principles along the concept of rational decision making and profit maximization. In addition, it was found that - from average perspective - the performance of private operators seems to be higher than that of public operators (see Table 3.19 “private vs. public”). In contrast, other studies indicate that public bus companies have almost the same performances as private bus companies. Moreover, it is argued that the degree of ownership-induced inefficiencies might depend on the public level (nationalised vs municipalised) as well as the governance structure[130] (Wang et al., 2015). In general, a mixed picture is presented in literature about the effect of ownership on efficiency. As to the impact of operator size on performance - which might justify merger or divestiture interventions - recent research indicates a positive effect, especially with regard to output growth. With regard to *mergers*, Odeck (2008) concludes a positive impact on productivity. However, as suggested by Borger et al. (2002), the author confirms that forcing *competition* makes non-mergers always look for means to remain *competitive*. Thus, in fact competition might be the true efficiency trigger. As to the issue of *contract design*, it was found that risk sharing and contract duration enhance operator performance. Margari et al. (2007) emphasize the importance to replace cost-plus subsidization with high-powered incentive contracts. In the context of bus services, Borger and Kerstens (2006) conclude that inadequate contract design is associated with performance disruptions, such as empty buses, split routes and so forth.

SUBSIDIES (EX): Results about the effects of subsidies on efficiency are of mixed nature: they can be positive or negative, and are essentially found to be conditional to their *origin*, *purpose* or *beneficiary.*[131] Some papers argue that subsidies generally work negatively towards operator performance, since they encourage excess capacity or production under higher input costs (allocative inefficiency, in terms of wages). Evidence could be found that capital-related subsidies reduce efficiency, as production gets to capital-intense (Faivre d'Arcier, 2014). Button

[130]A proposed inefficiency ranking would be nationalized operators > municipal operator > private operator.

[131]*Origin*: Federal, state, regional level. A proxy for how well information about the real cost of operators is accessed and monitored. Principles: (I) The closer to the operator the better or (II) tax-based subsidies improve monitoring. *Purpose:* capital subsidies, operating subsidies, investment subsidies. *Beneficiary:* operator or user subsidies.

and Costa (1998) find that the reduction of subsidies leads to increased performance due to *"enhanced managerial focus on input efficiency*". The effect of subsides might be also strongly dependent on the underlying contract design, competition scheme and local specifics as suggested by Link (2016), however in the regional public transport context.

OPERATIONS AND MANAGEMENT PRACTICES (IN): This category relates to effects from *physical and nonphysical resources/means* used in the service production process, as well as general managerial actions and practises beyond. In contrast to the previously described policy-driven factors, this group accounts for a comparatively higher but not necessarily full[132] levels of *managerial control*. Managerial control refers to the capability to determine/affect technical efficiency from "inside" the operator. In this regard Button and Costa (1998) argue that essentially the reformation of institutional frameworks in public transport might contribute to performance enhancement by giving managers more leeway for managerial decision-making.[133] For instance, as to the *network* – obviously a key resource however with several controversies as demonstrated in the next section - performance studies suggest that *network length and number of stops served* may have rather negative impacts on efficiency. These network specifications point at the variable *commercial speed*, which is found to be positively related with performance. Further, overall *line length* seems to increase performance, which might be just a proxy how well a physical network is actually used assuming that the ratio $\sum \text{line km}/\sum \text{network km}$ would somehow be maximized. Other studies however suggest that e.g. the *distance between stops* corresponds negatively to performance. *Fleet age* is mostly negatively correlated with performance. As to *service features*, it was found that a high *peak-to-base ratio* tends to decrease efficiency (Boame, 2004). However, it seems obvious that these configurations are essential decision variables of the operator management. Hence, the term '*management practice'*[134] of the classification in Table 3.20 captures decisions and measures believed to affect performance. These decisions target operations and other relevant segments along the production chain, such as investments in relevant technologies and equipment or measures taken to increase operating revenues, market shares and so forth. As an example von Hirschhausen (2008) notes that small- and medium-sized operators might improve their relative performance by partnering with neighbouring companies in specific segments of their supply chain, e.g. the joint sourcing of buses, sharing repair garages, joint purchase of pollution control

[132]Faivre d'Arcier (2014): contractual relations between the authorities and operators often contain strict technical specifications (frequency, quality of service etc.) limiting managerial freedom and causing inefficiencies.
[133]One could argue here that any political decision will somehow generate managerial reactions operator levels.
[134]This is in a line with the notation given Liebert and Niemeier (2010) who refer to the term *"management strategies"* as an explanatory factor to determine airport efficiency.

equipment.[135] Jarboui et al. (2012) demonstrate that once access to financial resources is limited the management would take measures to improve technical efficiency over time and to sustain revenues by exploring new income sources (outsourcing, enforced commercial orientation, new products, advertisement, and renting-out stops). Borger and Kerstens (2006) and Sampaio et al. (2008) stress the effect from commercial orientation and marketing of services on performance in general, in that fare structures that offer several tickets, multiple trips and season tickets may assure demand expansion.[136] There are also indications that performance may be influenced by factors such as working conditions and the way operations are managed in general.

Table 3.20: Revised Determinants of Performance in Public Transport *(and examples)*.

Methodology-related		**Explanatory Factors**		
(1) Measurement	(2) Efficiency type	(3) External (EX)	(4) Internal (IN)	
		no control	*partial control*	*full control*
outliers omitted var. IP/OP qualities error	TE AE excess IP shortfall OP Effectiveness	regulation, ownership, contract design, subsidies, … [population, GDP, etc.]	operations and management practice vehicle type, schedule, frequency, fares, ticketing	investment policy, product design, orga-nisation, marketing, working conditions, …
		car ownership, congestion		
		network, lines, stops		

Table 3.20 summarizes potential sources of performance according to the classification proposed. This research will set a primary focus on the endogenous/internal factors under partial or full control of the operator management. Note the socio-economic data might constitute a class of its own.

Based on this extensive state of the art review the next chapter outlines five crucial research issues in performance analysis.

[135] On interaction and control von Hirschhausen (2008) sees limitations as operators *"are not directly responsible for advertisements, ticketing and traffic planning."*
[136] Borger and Kerstens (2006)*„a seemingly neglected research topic"*

4 Research Issues and Approaches

The extended literature review indicates *five* conceptual and methodological research issues in the field of public transport performance analysis. In addition, previous approaches found in literature, which tackle these issues as well as relevant results are highlighted in brevity. The presented issues and the corresponding research gaps essentially form the motivational base for the *overall approach* presented in the summary section of this chapter. The overall approach serves to answer the research questions posed in the introduction.

Issue 1: Heterogeneity of Models and Data

The majority of DEA based performance studies in public transport assesses efficiency of operators with different data sets, different properties, different models, different input and output configurations or at different points of time. Consequently, results differ substantially between studies with regard to efficiency scores, scale economies, operator objectives and so forth. The multiple options and configurations offered by DEA might produce varying results even for the same operators in the same context and time just when the approach is just slightly altered.[137] In addition, results are strictly relative and valid only in the context presented (Borger et al., 2002). These modelling and data incompatibilities[138] make it obviously difficult to arrive to broadly valid comparisons, conclusions, policy recommendations or extended theory construction. As indicated by Jarboui et al. (2012) studies and meta-analysis trying to circumvent these issues for instance by testing various models and configurations on the same sample are rare. Kerstens (1996) in particular confirms the substantial significance of methodology choice for efficiency measurement and its respective output specifications. Brons et al. (2005) likewise

[137]Effects from model changes Coelli (2005)*:* An *extra unit* in DEA cannot result in an increase of TE of the existing units. The inclusion can reduce individual TE scores. An *extra input or output* cannot result in a reduction of TE.
[138]Karlaftis and Tsamboulas (2012): *"Studies seem to 'compete' for most exotic and esoteric methodology used for efficiency assessment while employing data from different (usually single agency) systems."* Though transit databases are full of readily available data, for whatever reason researchers rarely use the same or similar data set, which limits comparability. Differences in findings can hardly be validated (aside from approaches constantly being developed).

conclude that the output choice is relevant for the magnitude of the efficiency score. Karlaftis and Tsamboulas (2012) find that different methods might yield fairly similar mean efficiencies but strongly varying efficiency distributions. They further suggest that comparisons based on averages may lead to skewed findings and policy recommendations. Graham (2008) suggest that CRS- and VRS-DEA specification may only in some cases produce similar results.

APPROACH: Unfortunately, the specific research questions of this work requires the creation of new databases and models, thus rather exacerbating than mitigated the heterogeneity issue.

Issue 2: Homogeneity Assumption and Standardization

Cooper et al. (2007) suggest the application of DEA on banks, airlines, stores, supermarkets, carmakers, hospitals, schools, public libraries and so forth. Obviously, the method assumes a high degree of homogeneity in the data set. Cross-sectional DEA is essentially built upon the highly unlikely scenario that (a) each units/DMU/operator in the set faces identical conditions *and* (b) inputs and outputs are rather homogenous across operators. Due to lack of data or appropriate correction measures, differences in population, population density, city size, regulatory regime, subsidies as well as quality and composition of inputs and outputs[139] are often not considered, . Hence, *"the quality of each factor of production must be homogeneous within itself"* (Avkiran, 2006). When a DEA is carried out, homogeneity is usually achieved through two preparatory processes, namely *normalisation* and *standardisation.*[140] These assumptions might be useful and even valid when DMUs are somehow connected via the competitive market (e.g. banks, airlines) or when they handle identical subjects that require roughly identical operating conditions (e.g. hospitals, public libraries). However, applying suchlike assumptions to DMUs that are just *in the same industry* - which, however, is standard in *public transport* performance studies - appears to be highly questionable. Indication to this issue is given for instance in recent a DEA study on Brazilian and European metro systems in the "same industry" (Sampaio et al., 2008). The work suggests that only 14.3 % of Brazilian metro systems were efficient in contrast to 75% of the European systems. Apparently, it seems highly complicated to derive meaningful conclusions from this rather abstract performance scenario. The assessed operators clearly do not share the same market and moreover seem to work under entirely different conditions, if not even on a different subject in terms of how to provide which service for whom (due to different mobility patterns, user behaviour, etc.). Other DEA studies -

[139]Borger and Kerstens (2006): *Staff* is composed of driving and non-driving staff, *labour hours* depends on the roster definition, the *fleet size* might be related to fleet age. A fleet might consist of different propulsion technologies.
[140]Makovsek et al. (2015): Normalisation: capturing differences in economies of scale and density. Standardisation: ensuring that compared activities or materials are alike.

especially when policy-oriented - capture much smaller geographical scales and compare operators for instance “just” across Europe[141] in order to assess effects from regulatory policies. Still these operators fail to be connected through any common market (they are local “monopolists” by nature of their business) and surely are neither universally regulated, nor subsidised by one regulator/agency, nor subject to the same operating conditions.[142] In addition, mobility patterns may vary across Europe, undermining results substantially.

APPROACH: Conventional DEA approaches lacking of a coherent framework[143] for the set of operators assessed, appear problematic in terms of validity and comparability of performance results. Does a calculated inefficiency really come from managerial failure or simply from a “forced” homogenisation and “unobserved heterogeneity”? Thus, changing the referencing of from cross-sectional to time-series DEA would standardize just ‘years’ instead of ‘operators’, preserving the specific characteristics of each operator. Complementarily, heterogeneity might be accounted through explanatory variables in a two-staged DEA approach.

Issue 3: Peer-Benchmarking or Self-Benchmarking

DEA performance is a relative concept. Any meaningful interpretation of an operator´s performance requires to reference it either to similar performances of “supposedly” similar organizations or to similar past performances of itself. The narrative for referencing displayed in Table 4.1 - known as *peer-* or *self-benchmarking* - is very important for the interpretation and validity of results from DEA, in particular with respect to the consideration of *temporal* aspects.

Table 4.1: DEA and time. Adapted from Hazel et al. (2011)

Criteria/Benefit	Peer-Benchmarking	Self-Benchmarking
logic	across operator, vertically	over time, horizontally
dimension	external	internal
peers	other units	other years
time	no (static)	yes (dynamic)
data type	**cross-sectional**	**time-series**
operator +	identifies potential	identifies measures
regulator +	measure preparation	measure assessment
research +	case testing	theory building

LIMITATIONS OF CROSS-SECTIONAL DEA: So far, the discussion was about comparing performance across operators at a given point of time through *cross-sectional DEA*. As shown above this standard *peer-benchmarking* might be associated with several interpretational

[141]One might imagine a comparison between London´s metro and Nuremberg´s metro: apples and oranges.
[142]On top the benefit of these studies for individual operators seems to be flawed, when it comes to implications from identified peers, lambdas etc. that are geographically remote.
[143]At least an appropriate geographical scale e.g. minimum the same city-size for cross-country studies. This would help to justify the strong assumptions of DEA regarding *homogeneity* and *standardisation.*

problems related either to *Issue 1* (the sensitivity to changes of/in the underlying model) or to *Issue 2* (the generally strong assumptions about the homogeneity. The following shortcomings refer to *temporal aspects* of performance, which are commonly ignored:

- *First*, cross-sectional DEA might pose the risk to capture just internally or externally caused one-time effects on the performance of individual operators: *"A study which examines a single year may not give a true reflection of the situation if certain exceptional costs have been incurred or if a downturn in the economy has resulted in a considerable loss of patronage. The best benchmarking studies are those that examine […] operators over a period of time and so reflect longer-term trends in […] performance."* (OECD, 2000; Oum et al., 1999). This also relates to what is argued in the efficiency-effectiveness discussion below. Since there might be the need for operators to balance between different objectives - which can be achieved by iteratively swinging from one side to the other until a point of equilibrium is reached - one-time cross-section measures might only capture a performance state in which one objective is either amplified or neglected.
- *Second*, Costa and Fernandes (2012) assess the different pace of diffusion of technologies in public transport over time. Their study allows to conclude that, theoretically, cross-sectional approaches could just compare operators at different technological stages, which in turn would automatically lead to performance differences, however truly biased ones.

APPROACH: The static nature of the *cross-sectional*, *peer-benchmarking* approach ignores dynamics of performance over time. An adaptation of DEA towards temporal considerations as in time-series or longitudinal studies is recommended. Time-series data is data on a single entity/operator over time (Avkiran, 2006). This shifts the perspective to *self-benchmarking.*

TEMPORAL ASPECTS AND DEA: First, the incorporation of temporal aspects would require (mostly) access to panel data, meaning production data for several operators and over several points of time. Then, from methodological point of view, there are three DEA methodologies beyond conventional use to evaluate performance over time and dynamic effects in the following sorted by decreasing complexity. (1) Färe et al. (1994) developed the concept of Dynamic DEA (DDEA) which deals with so called carry-overs from inputs or investment activities, in that way as they assume that inputs might create an output only after several lags[144]. (2) The Malmquist Index (MI) measures the efficiency change over time as a product of catch-up effect (efficiency change) and frontier-shift (technological change). This method seems essentially useful when one intends to evaluate productivity changes for a larger number of operators, over a relatively short period of time (Odeck, 2008), or in a predominantly comparative and closed framework such as one common market.[145] (3) A more straightforward and flexible method is *DEA Window Analysis* (or window DEA) in which the number of DMUs for the optimization

[144]Since outputs in public transport are consumed immediately, this method is discarded in this research context.
[145]The "common market" feature is mostly absent in public transport, therefore the MI method is not considered.

problem is simply increased by taking each time period k for each operator n as a separate DMU.[146] With *window DEA,* it can be shown that *one specific configuration*[147] exists where just one operator can be analysed individually over the entire time span. In terms of referencing, this method allows for the transition from *peer-benchmarking* to *self-benchmarking* and thus to the temporal interpretation of a conventional DEA where *"operators"* are replaced by "time" units as DMUs. The method is referred to as *time-series DEA* hereinafter.

ADVANTAGES OF TIME-SERIES DEA: Makovsek et al. (2015), Karlaftis and Tsamboulas (2012), Borger and Kerstens (2006), and Brons et al. (2005)[148] argue that using the same DEA method over time is the more prudent and simple approach to achieve stable and robust findings. It is concluded that time-series analysis with DEA makes it possible to track efficiency changes by comparing performance from one year to another. Time-series allows for assessing the effects from policy reforms, organisational, operational and managerial changes over a period of time in the sense of an *ex-post observation* (Faivre d'Arcier, 2014). It would also indicate times during which investment or maintenance was insufficient, thus causing performance problems (Makovsek et al., 2015). Rutledge et al. (1995) review multiple advantages of time-series DEA, such as the indication for the management, which specific inputs and outputs cause which inefficiencies at which specific point of time, or the magnitude of input excess or output insufficiency ("slacks"). A particular strength of the tool is to assist management decisions and efforts aimed at efficiency increase and costs reduction. Further Coelli (2003) concludes that time-series DEA avoids to make complicated assumptions about the functional form of production over time.[149] In so far, *"the method takes advantages from the facts that DEA optimizes on each observation to obtain a "best fit" to the pertinent years for evaluating its performance"* (Cooper et al., 1995). Another advantage relates to Issue 4 below. Time-series DEA could overcome some complications imposed by the use of a network variable that is considered a troublesome issue in cross-sectional DEAs due to its heterogeneity. In so far, more realistic production models can be applied, considering more inputs. Figure 4.1 gives a glance how the results of time-series DEAs in transport look like. The biggest advantage of this approach over the cross-sectional one is obviously the capability to capture and visualize the performance evolution of an operator and thus to allow for the comparison of patterns and similarities. In

[146]A data set s is achieved of dimension (1) $s = n \times w \times p$ DMUs, w is the number of "windows" (2) $w = k - p + 1$, k is the number of time periods (e.g. years) and p is the length of the window. The method include a data reduction technique by aggregating multiple time periods in a moving average fashion Cooper et al. (2007) pp. 323 ff.

[147]In (1), (2) when $n = 1$ and $k = p$ then $w = 1$: one operator is assessed in one time window over all time periods.

[148]Brons et al. (2005) comparing average TE scores from cross-sectional studies at different points of time is valid.

[149]Coelli (2003): *"Consider a translog cost function with two outputs, one fixed input, two variable input prices, and a time trend variable, […], is equal to N(N + 1)/2 = 6(6 + 1)/2 = 21 […]. Thus to get the often quoted figure of 30 degrees of freedom or more, you require at least 51 years of data, which would take you back to the 1940s".*

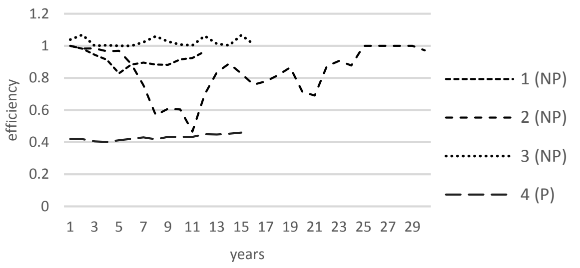

Figure 4.1: A few efficiency curves over-time in transport studies; non-parametric (NP) and parametric (P).

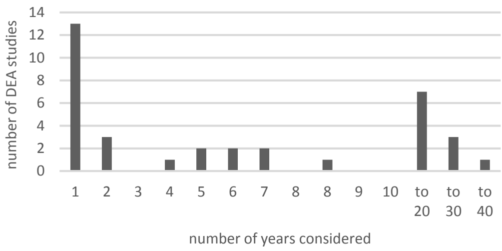

Figure 4.2: Temporal scope of non-parametric public transport performance studies 1988-2011.

short, time-series DEA enables to present results graphically in a manner that will enable to approach further research questions. For instance, it is an interesting phenomenon that - despite of Costa (1998) and Movahedi et al. (2007)[150] studying entirely different subjects and time-spans (public transport and rail transport) - both performance "patterns" seem to indicate a u-shaped efficiency curve over time. This again implies that at some point external or internal measures have been taken to stop the performance decline and catch up to higher levels again.

SOME ISSUES OF TIME-SERIES DEA: Button and Costa (1998), Coelli (2005) and Dang-Thanh (2012) point at several issues as to whether performance should be modelled vertically or horizontally. With time-series data, one might need to correct for the effect of price and quality changes for inputs and outputs over time. In addition, once used isolated, a time-series might just analyse an individual operators rather than a system as a whole. This might be a problem if the study is policy oriented. Borger et al. (2002) conclude that static and dynamic performance patterns need not to coincide. When operators are assessed individually against time, their performance scores might be significantly different from those in a cross-section framework.[151] Makovsek et al. (2015) generally suggest the simultaneous application of both approaches to adequately monitor performance. Then one approach controls for *progress on the system level* whereas the other controls for *progress on the operator level*. In this way, the performance of an operator in a particular time period could be compared not only against those of other operators but also against its own performance over that time. Other theoretical issues arise with this method, such as the interpretation of performance changes over time and its causes[152] as well as related assumptions about the time window lengths or, from a more theoretical viewpoint, the generally existence of a time-invariant universal efficiency frontier.

APPLICATION (SO FAR): Surprisingly Coelli (2005) p. 312 state that DEA, as one principal performance method, is not built upon time-series data conventionally. This is a strong

[150]Transport studies using time-series DEA (Number as in legend in Figure 4.1): 1 Costa (1998), 2 Movahedi et al. (2007), 3 Chen et al. (2012) 4 von Hirschhausen (2008) is non-parametric just for comparison.
[151]Though efficiency over time might increase, compared to others an operator could still be inefficient. An interesting question is whether *best performers* (cross-sectional) are also *best improvers* (time-series).
[152]Performance changes over time can be due to efficiency changes, technical changes, scale economies or all factors.

statement from the author and probably only valid if one sees the negligible share[153] of window DEA and time-series DEA studies in relation to the vast majority of performance literature. As to the research of public transport, Button and Costa (1998) found that time-series approaches are predominately used in parametric approaches and rarely in non-parametric ones. This claim is quantitatively supported by Daraio et al. (2016) and Brons et al. (2005) who refer to a 7% and 14% share of nonparametric time-series studies in their sample or the collection presented by Borger et al. (2002), respectively, among them two notable example from public transport (Thiry and Tulkens, 1992; Tulkens and Wunsch, 1994). Also a few time-series studies from the railway sector are indicated by Oum et al. (1999). Despite the methodological advantages of time-series DEA, to the best knowledge only a few approaches have been added to (public) transport literature since that time. Figure 4.2 above shows the general representation of temporal aspects in non-parametric public transport performance studies[154]. The peak at “1 year” refers obviously to cross-sectional DEAs. The middle-termed studies partially use cross-sectional but mostly panel data and observe time spans up to roughly 10 years, for instance to assess TFP or to apply the MI method. The few long-term studies with up to 40 years time-span are time-series DEAs, however most of them were already published before the year 2000. From a bigger picture it appears that time spans considered in DEA are rather middle-termed. Daraio et al. (2016) estimate 10 years as the mean time span considered in research, including approaches with time-series and panel data. Data availability might be a limiting factor, still favouring the application of either parametrical or non-parametrical peer-benchmarking approaches over self-benchmarking approaches. Operators usually publish production data annually but keep it accessible only for a few years. Thus, it seems much easier for researchers to collect data from many operators for one or a few consecutive years, than from one or more operators over a long time. In addition, policy-oriented studies might generally prefer short-termed and broad samples to assess the impact of measures relying on as many operators as possible.

Issue 4: Complexity of Production Process

A general problem with modelling is to find a middle course between feasibility, comparability, interpretation, and complexity. As for the latter Borger and Kerstens (2006) claim that a realistic description of public transport operations should ideally account for three dimensions: the core *production process* of the operator itself, related *regulatory specifications* and *output and demand characteristics*. The requirements are subject to several issues related to the quantity

[153]Recent *non-transport* studies using time-series DEA: Rutledge et al. (1995), Cooper et al. (1995), Hashimoto and Kodama (1996), Avkiran (2006), Sufian (2010).
[154]Own calculation based on 35 DEA and FHD studies from 1988-2012.

and quality of variables chosen for the model: *First*, the representation of the underlying production process is effectively determined by the adequate selection of inputs and outputs. *Second*, this involves a few considerations about the specifics of certain variables, observed for instance in the network and its utilization. Here obligations for operators may result in strict technical specifications towards network design, service of frequency, quality of service etc., which can majorly effect performance (Faivre d'Arcier, 2014). *Third,* output and demand characteristics may allow to capture operator objectives, price sensitivity and more only when the demand-sided outputs are added to the analysis (*efficiency-effectiveness* discussion below).

WHICH INPUTS AND OUTPUTS TO SELECT? Some contribution to the above-explained heterogeneity of DEA studies comes from the *number* and *type* of input and output variables chosen for modelling. Inputs and outputs should reflect service production as accurately as possible, which is related to some trade-offs and controversies. As to the *number of variables* however, including only a few of them might not describe the production activities realistically but lead to a somehow useful ranking overview. A high number of different variables again can provide an adequate representation of service production but impedes insightful rankings as in DEA then more units are likely to be rendered efficient, particularly in small samples[155] (e.g. tested by Hilmola, 2011). Figure 4.3 and 4.4[156] below suggest that the most applied scheme is a *three-input-one-output case*. As to the *type* and definition of inputs, the list of variations is almost endless, but all derive somehow from labour and capital such as personnel, fleet, fuel and other materials or corresponding cost proxies. Often the largest cost drivers are selected, namely staff and fleet. Costa and Markellos (1997) stress, that some of the input might be highly inelastic due to contractual commitments etc.[157] Jarboui et al. (2012) indicate the limited potential of substitution among inputs[158]. As mentioned earlier, *outputs* in public transport can be quantified in various ways, but in contrast to other industries, service is not storable and thus

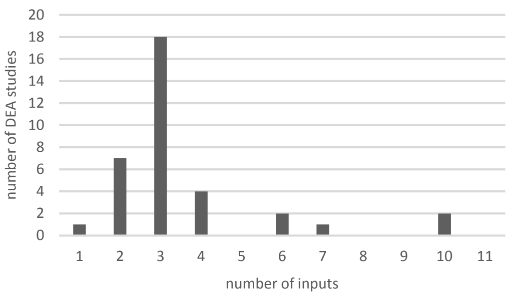

Figure 4.3: Number of inputs used in DEAs.

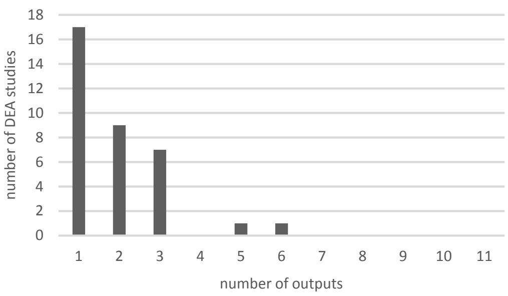

Figure 4.4: Number of outputs used in DEAs.

[155]Rutledge et al. (1995): A general guidance and rule of thumb: *"the number of inputs and outputs in a DEA should be as small as possible, subject to their reflecting adequately the functions performed by the units being assessed…there should be at least twice as many DMUs as inputs plus outputs*"

[156]Own calculation based on 33 DEA and FDH studies from 1988-2012.

[157]Implication: managerial smartness needed to use fixed inputs wisely and increase performance anyway.

[158]From production theory, it was learnt that a fixed output could be reached with different input compositions. In fact, realistically the swap of labour for vehicles, or vehicles for energies is quiet limited if not meaningless.

not clearly identifiable. Proxies are used. In a single output-case, the issue is about choosing a supply or demand sided indicator according to the interpretation intended. When multiple outputs are chosen, their relation becomes an issue. They might represent conflicting objectives.

Table 4.2: Frequently used inputs and outputs in DEA and distribution in %. Adapted from Daraio et al. (2016).

Inputs				Outputs	
number of employees*	66	*maintenance expenses*	4	vehicles-km	53
number of vehicles*	64	*overhead expenses*	4	passenger-km*	32
fuel consumption	59	*other operating expenses*	4	seat-km*	28
operating expenses	17	hours of work	2	number of passengers	26
employee-hours	15	number of depots	2	*operating revenues*	9
seat capacity	9	*price of capital*	2	*revenue-vehicle kilometre*	8
fuel costs	9	*possession costs*	2	*vehicle-revenue hours*	6
materials costs	8	*price of labour*	2	vehicles operation hours	4
operating costs of vehicles	6	*price of fuel*	2	number of bus traffic trips	4
drivers	4	*operating labour expenses*	2	*seats-hours*	2
non-driving employees	4			load factor	2

*n=54 studies. Cost variables are marked italic. * refers to chosen variables in model section.*

Contrary to Borger et al. (2002), recent studies from Daraio et al. (2016) and Jarboui et al. (2012) find relatively homogeneous patterns concerning the definition and use of inputs and outputs in public transport research. A Table 4.2 shows in over 50% of the DEA studies, production activities appear to be rather simplified than exhaustive. The models essentially rely on the *number of employees*, *vehicles* and *fuel* as inputs, and *vehicle-* or *seat*-km as outputs. The distribution of variable-use might be taken as a proxy for limited data availability and certain research “habits”. This may prevent the development and application of different inputs and outputs. However, two notable exceptions are found in recent literature: Ermagun and Levinson (2015) uses conventional operator inputs but *accessibility to jobs by transit* as output to assess the efficiency of US metropolitan area.[159] Link (2016) uses various types of *subsidies* as inputs and vehicle-km and passenger-km as output variables. Though ignoring the fact of limited data availability Jarboui et al. (2012) and Borger and Kerstens (2006) suggest that financial variables might be more robust, reducing problems associated with demand or supply-orientation.[160]

APPROACH: Standard set-up according to Table 4.2 to comply with the majority of studies.

HOW TO TREAT THE NETWORK VARIABLE?: For Borger and Kerstens (2006) input and output definitions and applications are not always straightforward and *“give rise to some controversy”*. A large controversy in performance analysis is upon the nature and use of the network variable and whether to consider it as part of the production process or not. *Network* is treated as a factor with some non-separable unobserved heterogeneity, or as an *“environmental condition”*

[159]The average efficiency score of the system is 0.54 (with share of workers, vehicle revenue kilometres, and length of routes for both bus and rail services as the inputs). It means a metropolitan area on average could provide the same level of accessibility to jobs by transit with 54% of the current inputs.
[160]The authors claim that “number of passenger” and “seat-km” is consistent with “revenue” and “sales”.

(Costa, 1998) which is distinctively different for each operator in terms of outline and utilization.[161] The variable is therefore suspected to strongly affect the outputs of a system and thus performance scores and returns to scale. Karlaftis and Tsamboulas (2012) find network characteristics simply incompatible across cities. For Borger et al. (2002) they *"are largely outside the control of the operators, and imposed by the regulatory environment"*. Likewise von Hirschhausen (2008) agrees that in some specific contexts a certain level of service is *"ordered"* and changing for instance the network length *"is not in the simple discretionary decision power of the operators"*. From an engineering perspective like Ceder (2007), network planning seems to be outside the operators reach either. Studies from Margari et al. (2007) and Kerstens (1996) differentiate network as external factor. The authors conclude that network should not enter DEA since its non-discretionary and in the short run quasi-fixed nature may reduce the set of peers by creating too many efficient units. However, most recently White (2009) claims that planning the network structure is generally a *"work done by the operators"*. In fact, more than a few conventional DEA studies use network as regular input variable.[162] Walter (2010) also refers to several studies using the network length as *additional* output variable. An advanced solution to the network heterogeneity is provided by Cullmann (2012).[163] These examples show the ambiguities about the nature of the network variable, and whether there is managerial control over it, or not. Over the past decades, many models have tackled at least some of these issues. Nevertheless, in DEA the variable is often disregarded, also because relevant data is unavailable. When considered, network is either treated as a regular input[164] (or output) in the production process or as external variable as indicated by Table 4.3.

Table 4.3: Frequently used explanatory variables in DEA and distribution in %. Adapted from Daraio et al. (2016).

used as inputs		used as outputs		used as parameters					
network km	19	frequency	8	speed	15	frequency	4	mixed transport	2
population	8	speed	4	car ownership	13	ownership	4	owners	2
pop. density	6	fleet age	2	pop. density	9	unemployment	4	number of lines	2
fleet age	4	departure times	2	fleet age	9	population	2	overlap lines	2
location	4	gender	2	location	6	accessibility	2	poverty	2
speed	2	served/needed	2	contract type	6	alternative PT	2	line length	2
intensity	2	on-time perf.	2	stops	6	area size	2	satisfaction	2
stops	2	stop distance	2	pk-t-bs ratio	6	CNG vehicles	2	owner size	2
op. costs	2	share bus-km	2	network km	4	distance stops	2	size of operator	2
spares ratio	2	travel time	2	climate	4	GDP	2		

APPROACH: Network is assumed as endogenous/internal resource, fully contributing to service production. Further, it is assumed that operators have some control over the network.

[161] *Network nature:* network length, density, links, knots, stops. *Utilization:* number and range of lines, speed, punctuality, frequencies, peak-to-base-ratio, often specified by a minimum output level from outside.
[162] Movahedi et al. (2007); Santos et al. (2014); Button and Costa (1998); Link (2016); Costa (1998).
[163] Proposing a panel data model allowing for non-separable firm-specific heterogeneity in an input distance function.
[164] Drawback: increasing network means decreasing efficiency in input-orientation?

THE RELATION BETWEEN EFFICIENCY AND EFFECTIVENESS: As shown above, another common problem is the uncertainty about the (number and nature) of *outputs* in public transport. This issue is often generalized to concerns about the objectives of an operator[165] as there seems *"no overall consensus on the proper goals of transit firms in the literature"* (Borger and Kerstens, 2006). Knowing the definitions of conventional efficiency raises questions which other output(s) would be appropriate to capture production of public transport services in the most appropriate way. *First*, it is a fact that a single output measured in whatever unit might not fully reflect the true economic impact of service production in the first place and might thus impose limitations to assess the true nature of performance. *Second*, it appears also straightforward to assume that the objectives of an operator and therefore its performance are clearly determined by the environment it works in. For example, a heavily subsidised operator might be encouraged or even mandated to use labour excessively to provide above average service. This makes him prone to be highly inefficient following the common performance definition, but probably highly effective when another perspective would be chosen.[166] A response to this issue is the distinction between supply side and demand side outputs[167], which translates to the concepts of *efficiency* or *effectiveness,* respectively. As learnt, conventional efficiency associates with the characteristics of the supply-side. Effectiveness is by nature a concept with many more facets and different definitions. However, often researchers consider efficiency as the *only* meaningful performance dimension, largely based on the assumption that operators are constrained in their managerial choices towards the demand-side. In these approaches, control is just on the supply-side and non-manageable, non-controllable demand-side variables are not regarded in this type of analysis.[168] Borger et al. (2002) claim that the *"discussion of demand vs. supply indicators becomes irrelevant when the output and network characteristics are appropriately represented in the model"*. Interestingly, the reversal of this statement implies that when output and network characteristics *cannot* be represented appropriately - e.g. due to methodological trade-offs in DEA - it might be *relevant* to incorporate *both* type of indicators into the model.

APPLICATION SO FAR: As to the practical application of both concepts in literature, Jarboui et al. (2012) summarize that despite the awareness about multiple objectives in public transport the

[165]Jarboui et al. (2012) state that it is imperative to know the objectives of the organisations assessed: public transport may serve a set of objectives from a welfare economic viewpoint: efficiency, equity, financial balance and macroeconomic stabilisation. Stakeholders are interested in benefits as reduced pollution to improved social equality. For a wider range of perspectives on effectiveness (managerial, policy, qualitative) see Diana and Daraio (2014).

[166]Example from Margari et al. (2007): Operators in large and congested networks → higher subsidies → service above average level → excess production capacity → overuse of inputs such as drivers, fuel and materials and service costs → supply performance (inefficient) and demand performance (effective).

[167]Notation by Karlaftis and Tsamboulas (2012): produced output type; consumed output type.

[168]von Hirschhausen (2008): *"Capacity utilization does often not lie in the public transport company's area of influence."*

focus lies still mainly on productivity and efficiency. This can be confirmed by Table 4.2, which shows a much lower share of DEA studies using demand-like output data like *passenger-k*m or *passengers*. A potential explanation comes from the fact that for efficiency, methodically sound concepts have already been developed and applied quiet frequently, unlike for effectiveness. More importantly, the primary objective of any public sector activity is to operate efficiently.[169] Accordingly, the dominating research interest in many performance studies is efficiency. However, recent research points in the direction of assessing temporal aspects of the efficiency-effectiveness relation. For instance, Costa (1998) and Costa and Stanislau (2005) propose a straightforward DEA tool called Efficiency-Effectiveness Matrix (EEM), which relates the relative efficiency of an operator to its relative effectiveness in order to track the degree of balance between these objectives over time and to draw conclusion about cause for changes. When the score $\mathrm{EE} = \frac{\mathrm{Efficiency}}{\mathrm{Effectiveness}}$ equals one the objectives of supply and demand are balanced. If the score is greater than one, the operator´s objectives are more efficiency-oriented. If the score is smaller than one the focus is on effectiveness and on passengers. Obviously, there might be a range of combinations located either above or below the unity diagonal. Results suggest that in the long run efficiency and effectiveness might be balanced objectives, which is achieved by a somewhat iterative adjustment process (management practices for example) swinging from one objective to the other and back. This in turn means that in particular negative correlations indicated by other studies would just express temporary states on the way to be balance. The principles of EEM are also applied by Carvalho et al. (2015)[170] who find that the distribution of performance objectives of Brazilian Metros is relatively equilibrated.

APPROACH: The inclusion of both outputs gives a better understanding of the relation between efficiency and effectiveness, especial under temporal considerations. However, the fact that both concepts appear to be interlinked could lead to valuable inferences. Both concepts enable to assess the (temporal) magnitude and interaction of different performance dimensions and objectives under the assumption that public transport service is a multiple-output product.

Issue 5: Accounting for Explanatory Variables

LIMITATIONS OF CONVENTIONAL DEA: Conventional DEA identifies and compares different quantitative input-output configurations of operators. The method further assumes that operators can turn their inputs on and off in order to use them in the best mix to maximise productive efficiency at their own discretion (Avkiran, 2006). The relative (in)capability of some

[169]Costa (1998): *"[…] the aim is to make available a level of service to users at the lowest possible factor input use"*
[170]Inputs: municipality inhabitants, number of urban buses; outputs: average daily passengers, average gratuity.

operators to adjust processes properly to further exhaust production - as expressed in a technical efficiency score (deviating from one) - is also considered a measure of managerial (in)efficiency. But apart from indicating which inputs or outputs are to decrease or increase by which amounts, or identifying the relevant peer to "learn" from, conventional DEA does not provide any further indications as to the source of the managerial inefficiency. DEA scores are essentially just "gross" scores, which already aggregate sheer productive efficiency *and* effects from the operating environments (Oum et al., 1999). As shown in Chapter 3 the ability to transform inputs to outputs - and thus the resulting technical efficiency - might indeed be influenced by numerous favourable or unfavourable factors. In this regard, the common understanding in performance analysis is as follows:

- The model should describe the reality of the production process best possible.
- Inefficiencies might be ascribed to external or internal explanatory factors.
- These factors indirectly reflect the degree of control the management has over certain aspects in the production and provision of transport services.

Not accounting for either of these explanatory variables might lead to over/under-estimated performances and misleading conclusions as such that presumably inefficient units (bad management) might be in fact (more) efficient (good management) if corrected for other factors (Cooper et al., 2007). The question is then how to integrate the explanatory variables in the analysis. The good news is *"that extending the method to include a term for environmental differences, either across firms or time, is easy"* (Coelli, 2005). In parametric approaches such as SFA, explanatory factors can "simply" be included to the frontier estimation process as additional variables in order to assess the effect on the efficiency term (see equations 4-6). With the deterministic nature of DEA, however, other approaches would be needed. In recent years, various DEA studies have applied two major options[171] to assess the effect of explanatory variables on performance, so-called *one-stage* or *two-stag*e DEA. In *one-stage* DEA approaches, explanatory factors are added directly to the calculation of the efficiency frontier. This may require some changes in the DEA model like the introduction of equality constraints, or restrictions for the linear combinations (see Model 3, Coelli (2005) p. 192). Often the data set is divided into various groups according to the explanatory variables to test for efficiency differences (e.g. trained staff vs. non-trained staff). However, this approach comes with many limitations and requirements.[172] One major of them is the *a priori* assumption about the

[171]See Coelli (2005) pp. 191 ff. for other methods, e.g. to run various DEAs separably and to assess the frontier changes or to separate group variables as discretionary and non-discretionary.

[172]Further limitation of one-stage DEA approaches to explanatory variables: no statical testing, no categorical variables, no negative variables, no nonlinear variables, the assumption of free disposability, the risk to inflate efficiency by too many inputs or outputs, the impact on the reference technology.

direction of the effect of the variables to be included. In short, when assumed positive an additional input is added to the LP. When assumed negative, an additional *undesired output*[173] is added to the LP. However, one-stage DEA approaches is not given much attention anymore in particular due to the strict assumptions needed (Borger et al., 2002; Daraio et al., 2016).

TWO-STAGE DEA: In contrast, *two-stage* DEA maintains the very rationale of DEA that operators use common inputs to produce similar outputs. Hence, in stage *one* the efficiency scores are calculated with regular DEA without any explanatory variables added. In a *second* stage the results are then regressed on several explanatory variables that were not in the first stage DEA, by using a regression-like method, such as OLS, TOBIT, or ML (Liu et al., 2013a). Essentially the second stage aims at analysing whether the first stage results may have been influenced by the environmental, categorical and *other factors* chosen. The basic idea here is that the explanatory variables do not affect the shape of the efficiency frontier but rather explain the distance to it. Then sign and size of the regression-type coefficients and their errors initially indicate the direction and magnitude of the effects from the variables, which could also be used for predictions. Two-stage DEA has many advantages over other DEA methods that incorporate explanatory effects: It is not limited in the number of variables. The focus is on the variables instead them being hidden in the LP algorithm. There is no need to make assumptions about the direction of a presumed effect. The relationship can be validated statistically. Regression results are generally easy to calculate and straightforward in terms of interpretation, in particular when log-transformed data is used. Finally, an interpretational advantage concerns the wording of "inefficient" or the evaluation of distances to the frontier. Conventional DEA in its binary manner strictly assumes any form of deviation from the frontier - even if very small - as "managerial inefficiency". Two-stage DEA might, however, give marginal deviations in performance a more realistic representation and treat them as virtually negligible or quasi-efficient.

EXPLANATORY SET-UP - EXTERNAL VS. INTERNAL VARIABLES: Table 3.20 of Chapter 3 shows two relevant groups of determinants for performance both of which separated by the level of control from operator side. When explanatory variables are considered in two-stage DEA, they are commonly believed to be rather of *external* than *internal* nature, thus being outside managerial control.[174] This relates to the basic DEA assumption that *technical efficiency* already captures *all effects* from factors over which the operator has control. It is further assumed that every available and controllable means[175] to maximize performance is used in the best of a manager's

[173]Particular outputs like pollution are undesirable, collateral outputs in DEA. See Avkiran (2006) pp. 184 ff..
[174]Regulation, ownership, subsidies, contract design, and more, maybe network.
[175]Operations, schedule, frequency, fares, network, investment, product design, marketing, working conditions.

ability, in a *homo-oeconomicus*-like fashion[176]. With this being said, ordinary two-stage DEA approaches would then primarily address factors *external* to the operator, evaluating efficiency by virtue of the principle *"managers could have done better, if it was not for the obstacles imposed from outside"* (Figure 4.5). When deviations from the efficiency frontier could then even be explained by external factors - say competition or private ownership - other potential explanatory variables - say *operations* or *managerial skills and practices* - would be rendered "irrelevant" for contributing to performance. This obviously seems an incomplete assumption.

In the public transport context only a few DEA studies evaluate external effects on efficiency with a two-stage procedure recently: Tsamboulas (2006) link performance to ownership variables(+). Cowie (2002) regresses efficiency scores on a time trend(+) and a merger dummy(+). Kerstens (1996) do likewise for ownership(+), network(+/-), subsidies(-) and contract specifics(+). Pina and Torres (2001) use input and output-like simple performance indicators as explanatory variables, such as costs per traveller(-), fuel per km(-) and km per bus(+). Oum and Yu (1994) found subsidies(-), and managerial autonomy(+) significant to affect efficiency. Link (2016) relate the efficiency of subsidy spending in public transport to the share of tendering(+), the share of gross contracts(+), and contract specifications(+). Wang (2011) suggests that governance mode(+), competition(+), and scale(+) affect efficiency. Santos et al. (2014) regress Metro performance scores on network specifications(+), GDP(-) and population(-). Conclusions from similar *impact assessment* studies in public transport are commonly as the following: *"Hence, changes in regulation and/or environmental characteristics may induce higher efficiency in the use of more controllable inputs (e.g. labour) compared to less controllable ones (e.g. fuel)"* (Margari et al., 2007). To this extent, however, it remains yet unclear how the described efficiency improvements are practically achieved at the operator level.

Already Borger et al. (2002) argue that for instance in the context of subsidies, allocative inefficiency is largely caused by factors *internal* to the operator. With respect to mergers, also Cowie (2002) find indications that performance increases cannot be fully tied to economies of scale but rather to the change of internal efficiency as a managerial response to the eradication of competition. Brons et al. (2005) point out that the lack of managerial flexibility from operator side to adjust to regulatory reforms may prevent efficiency increases. Leverty and Grace (2012) go on step further by indicating evidence that managers feature certain styles that might frame the underlying decisions of a company (e.g. "aggressive" R&D investments or merger and

[176]As demonstrated, pure technical efficiency from conventional DEA without any explanatory attempts can be understood as an *initial* representation of managerial efficiency. However, it captures *all* internal and management-specific efficiency drivers and is thus likely to over- or underestimate real managerial ability.

acquisition policies). Researchers - predominantly from other fields than (public) transport - have long argued that in particular entrepreneurial and managerial abilities and skills are major determinants of efficiency and a significant reason why performance varies among organisations or over time. Managerial skill[177] can be defined loosely as "*the manager's capacity to deploy the firm's resources"* (Leverty and Grace, 2012).[178] As per these authors, managerial skills may affect performance for instance through negotiations of the contractual relationships of the firm, configuration of management and organisational structure, and technology choices and workflow organisation. Managerial skills determine managerial practices[179], which in turn become an *internal factor* to explain differences in efficiency when operationalized and measured accordingly. The hypothesis then is that management skills and resulting practices might be linked with performance, in particular when applied to other controllable factors of an operator. Demerjian et al. (2012) assume more able managers *"to better understand technology and industry trends, reliably predict product demand, invest in higher value projects, and manage their employees more efficiently than less able managers."* However, managerial practices might also be strongly correlated with *external factors* since a skilled manager, theoretically, would undertake everything in his power to offset/exploit any negative/positive impact on performance from inside/outside the operator. For instance Costa and Markellos (1997) point at the high inelasticity of inputs, as changes in workforce are often limited by unions or driver-to-vehicle ratios, and so on. The better the skills of the manager, the better the managerial response to these issues and the lesser/stronger the effect on performance. Hence, the variable *managerial practices* would also capture responsive actions orchestrated by the management. This notion of an impulse-response-like relation between *external* and *internal* factors may tempt to conclude that the former one could be obsolete in the analysis, since the latter one is just its "negative copy". In fact both (and more) perspectives have to be considered in an analysis as there are still events outside the control and responsiveness of an operator, which even the most skilled manager would have to comply with rather passively in spite of performance deteriorations, e.g. in the case of regulatory interventions, subsidy cuts, or external shocks.

MANAGERIAL DECISIONS AS A PROXY: When the application of just one explanatory variable is insufficient to account for the full extent of effects (Figure 4.5), but in contrast, using both jointly may bear the risk of *double-counting* or *off-setting* of effects due to correlation amongst them (Figure 4.6), a proxy variable might be the preferred solution (Figure 4.7). *Managerial Decisions*

[177]Coggburn and Schneider (2003) refer to "*management capacity*" in a broad political context.
[178]Coelli (2005) extends the definition: age, experience, education, training might affect operator performance.
[179]See Table 3.20: Element with 100% control over from the operator/manager side compared to other elements with partial control: largely referring investment policy, product design, marketing, organisation, working conditions.

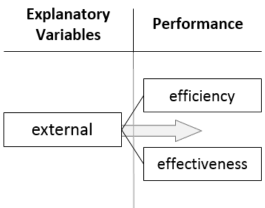

Figure 4.5: Conventional two-stage DEA.

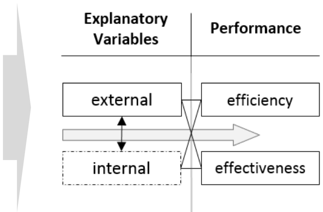

Figure 4.6: Advanced two-stage DEA.

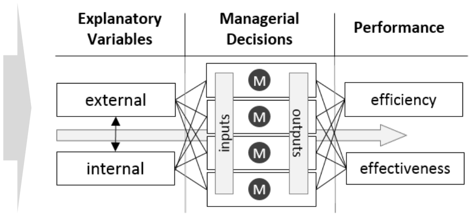

Figure 4.7: Proposed two-stage DEA.

could serve as an ideal-typical proxy for both explanatory variables.[180,181] The idea behind the proposed measure is that any impulse - regardless of its origin or direction and uncoupled from the issue of control - corresponds to some sort of managerial decision within the process of transforming inputs to outputs. Externally imposed constraints or petitions force internal decisions; regulatory policy simply *"addresses a more rational and thrifty management of resources"* (Margari et al., 2007). *Internal factors* such as changes in operations or skills or managerial practice trigger and shape *internal decisions.* Then the conglomerate of managerial decisions would affect performance of an operator as learnt from Chapter 3:

- If service or production targets were mandated by authorities from "outside", say a frequency, the management would need to implement this frequency accordingly by changing operations from the old to the new regime.
- If a fare increase was imposed, counter-measures such as quality improvements or new product concepts might be marketed in order to avoid passenger loss.
- If ownership or market changed due to deregulation as referenced e.g. by Button and Costa (1998) or Borger et al. (2002) managers might apply cost-orientation or profit-maximizations schemes, or as Costa (1998) terms it "*cost discipline*".
- If the management intended to streamline processes from "inside**"** it might become observable by redesigned organizational structure.
- If low productivity of labour is assumed, a management might apply decisions related to training, optimization of production or human resource management (Costa and Markellos, 1997). Otherwise, the management might simply swap resources (less administration staff, more vehicles) and compensations measures like part-time work for older employees would be observable decisions.

The set of applicable management decisions in public transport is manifold. It ranges from new approaches to customer retention and acquisition to the introduction and alternation of pricing schemes to innovations in infrastructure, vehicles, control systems, or ICTs (European Commission, 1996). Therefore, a skilled management might be very active upon using the set of decisions along the public transport production process as suggested in Chapter 3.

APPROACH: Two-stage DEA framework with managerial decisions as explanatory variable.

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[180]Recognized also by Graham (2008): *"…there are unobservable influences on the productivity of urban rail firms. These will include a series of unknown or unmeasurable system specific characteristics as well as influences that arise through managerial or organizational decisions."*
[181]Adaptation of the extended public transport production process from section 3.1 to the two-stage DEA concept.

APPLICATION (SO FAR): The incorporation of managerial skills (managerial practice or some sort of managerial decision proxy) is yet a rarely studied issue[182], specifically in combination with a two-stage DEA framework. The following few examples referee to *non-transport related*, *transport-related* and *public transport-related* literature.

- *First*, in *non-transport related*, general management science, Demerjian et al. (2012) measure managerial ability by regressing total firm efficiency on six of its determinants (firm size, firm market share, cash availability, life cycle, operational complexity, and foreign operation). Peltokorpi (2011) operationalize operative and strategic decision variables and relate them to several hospital productivity measures via regression demonstrating that the former decisions have a higher impact on productivity than the latter one. Leverty and Grace (2012) - in a fishery context using SFA-based efficiency scores as DVs - found boat captains with better managerial skills - defined as years of experience in fishery and education level - tend to have higher technical efficiency.
- *Second*, as to *transport related* studies, Gillen and Lall (1997) regress efficiency scores from airports on their non-managerial (environmental, structural) and variables of managerial influence, the latter of which are *use of gates*, *financing regime*, *noise strategies*, *proportion of GA, existence of hubs at airport*.
- *Third*, as to *public transport related* studies, Costa (1998) descriptively ties organizational changes to result in higher managerial cost-orientation which, in combination with a better fare system, eventually contributed to efficiency and effectiveness increases of Metro Madrid. The same author advanced his approach lately by relating managerial decisions in several categories descriptively to the long-term performance curve of a bus operator (Costa et al., 2014). Margari et al. (2007) use a DEA-SFA approach to decompose efficiency drivers to exogenous effects, managerial inefficiency, and stochastic events. The authors demonstrate that managerial skills play a minor role as opposed to regulatory policies. Most recently Jarboui et al. (2014) use SFA-based efficiency scores of public road transport companies and regress them on two proxies for managerial optimism. Their findings suggest a negative relation which is suspected to be caused by irrational decisions as managers overestimating the probability of good events and underestimating the probability of bad one. *Finally,* Odeck and Bråthen (2007) assess the effect of water type(+), ferry type(0) and vintage year(+) on the efficiency of ferry service provision. Similarly, Boame (2004) assess the effect of speed(+), fleet age(-) peaking(-) and time on efficiency(+). Though the latter two studies seem to fit rather in conventional external explanatory patterns, they at least indirectly cover managerial decisions upon fleet and operation characteristic.

This rather meagre collection of studies shows that - to the best knowledge - so far no research

[182]Costa et al. (2014) conclude that in management science two general research paths exist to approach the relation of managerial decisions and performance. First, at the *micro-level scale,* the effects of *particular decisions* on the performance of a company are analysed and quantified (investments, operational decisions, specific management practices, IT investments, HR measures) or the role of *knowledge capital and innovation* towards productivity growth is being assessed. Due to the difficulties to show how different structural administrative and managerial arrangements affect the global performance, most studies focus merely on isolated levels of organization, such as IT, or HR etc. Second, at the *macro-level scale*, the main concern is upon how the performance of particular territories and government administrations is affected by the implementation of *public programs and policies, institutional features as well as structural and administrative arrangements* and the adoption of management or institutional practices.

has further examined the relationship between managerial skill/practice/decisions and technical efficiency/performance in the urban public transport context in a quantitative manner.

Summary of Research Issues and Gaps - Overall Approach

Table 4.4 condenses all research issues and gaps found in performance analysis literature, the corresponding partial approaches to solve them and the resulting overall approach applied herein. Further, an indication about the degree of research innovation is given. Below, *THREE* pivotal remarks summarize the essential features of this work and methodological motivations.

Table 4.4: Problems in Performance Analysis and Approaches.

#	Research Issues and Gaps	Solvable Issue?	Solved Issue?	Partial Research Approaches	Research Innovation
1	Heterogeneity of models and data	no	-	data base creation	*high*
2	Homogeneity assumption	yes	yes	time-series DEA	*high*
3	Peer-benchmarking or Self-benchmarking	yes	yes	time-series DEA (long-term self-benchmarking)	*high*
4	Complexity of production process	no	-	standard model set-up	*low*
	Input and output selection	no	-	three inputs, one or two outputs	*low*
	Network variable	yes	yes	input variable	*medium*
	Efficiency and Effectiveness	yes	yes	inclusion of both types	*medium*
5	Accounting for explanatory variables	yes	yes	two-stage DEA	*high*
	External explanatory variables	yes	yes	Proxy: Managerial Decisions	*high*
	Internal explanatory variables	yes	yes	Proxy: Managerial Decisions	*high*
	OVERALL APPROACH: Two stage DEA for three operators. Stage 1: Self-benchmarking via long-term, time-series DEA, standard inputs + network, supply and demand side output. Stage 2: Time-series regression of DEA scores on operationalized managerial decisions as explanatory variables.				*high*

FIRST, changing the referencing perspective of DEA from cross-section to time-series is a fundamental step in this research. Again, it needs to be emphasised that these concepts have quite distinct meanings. Standard cross-sectional DEA models are used for the analysis of efficiency across *multiple operators*. Time-series DEA is typically used to assess performance for *one operator*. One may then consider comparing performance patterns over time across a few operators. However, the use of time-series data directly solves several issues at once:

- As to Issue 2, a homogenisation and standardization of operators, inputs and outputs would be reduced to acceptable levels, while preserving the specific characteristics of each operator. The risk of misleading comparisons across operators can thus be reduced.
- As to Issue 3, the time-series approach allows to assess temporal patterns of performance, which means a comparison of past performances for one operator.
- As to Issue 4, it seems that problems from heterogeneous network characteristic as in the cross-sectional approach may not appear with time-series DEA. The analysis can be built on a more complete public transport production model.

SECOND, while taking advantage of time-series research design, the inclusion of efficiency *and* effectiveness is another important feature (Issue 4). Public transport is a *"multi-dimensional and multi-product effort".* Thus, performance evaluation has to include *"the production and the utilization of the service".* [183] There are also sound economic reasons why:

- In most cases, public transport is just the agent for higher political objectives as shown in Figure 3.4. Transport policy and regulations cannot be based simply on the supply side. Accordingly, the response from the *demand-side* can serve as a baseline to assess the degree to which policy objectives are met over time.
- A simultaneous assessment of efficiency and effectiveness might serve as a trade-off analysis for the management but especially for authorities or regulators since one of their many duties should be to balance both objectives and to align public and operator goals. In that sense, it could be argued that supply-side performance tends to be meaningless anyway, when not evaluated against the demand: the service might be efficiently provided, but what does it say if demand is low?
- The demand side captures the economic motives of the operator.
- Concerning the modelling and result heterogeneity, the inclusion of another output might help to reduce uncertainty about the origin of inefficiencies by understanding the plurality of operator objectives as well the strong interdependency between demand and supply.
- Unlike efficiency, which determines the *performance of the operators*, effectiveness depicts the *performance of the system* (Costa, 1998).

THIRD, the pivotal approach in this research concerns the explanation of performance over time (Issue 5). Time-Series DEA is joined with regression to two-stage DEA for the following reasons:

- The two-stage DEA enables to approach the assessment of effects from any explanatory variables on performance in public transport in a different, innovative way. All determinants of operator performance should be factored in, in particular the role of managerial skills and practices.
- Since it is not always clear how external and internal factors generally function and influence performance, their nature might become more observable/measurable by applying a proxy, such as managerial decisions.
- Decision makers in public transport often face uncertainty about recognizing the true impact of their strategic choices and operational judgments. Hence, modelling managerial decisions and using them as explanatory variables for performance over time could help to understand this relation better.

To the best knowledge, between 2002 and 2014 no time-series DEA study was published in public transport performance research. In addition, only the few older time-series publication discussed above cover a proper time stretch to draw meaningful conclusions. However, none of them applies a two-staged framework. The *overall approach* proposed in Table 4.4 is thus unique in public transport literature and addresses a considerable research gap as well as the potential

[183] Costa (1998); Makovsek et al. (2015); Daraio et al. (2016).

to advance the field of performance analysis as a whole. In particular, the operationalization and incorporation of managerial decisions yields interesting research questions and further touches other scientific areas, such as behavioural economics and finance (Jarboui et al., 2012):

> *“In the transport literature, the implications of the emergence of behavioural economics and behavioural finance are ignored. These areas consider the managerial psychological bias and especially the overconfidence or optimism as powerful factors that can explain many firms’ decisions and policies. It will be an interesting way to initiate an open and original debate: can managerial optimism and others psychological and emotional bias affect the transport’s operators’ efficiency?”*

5 Modelling Managerial Decisions

5.1 Introduction

The starting point for the empirical analysis of this work is the *collection*, *operationalisatio*n and *assessment* of managerial decision taken by operator management. However, only a few publications provide theoretical and practical guidance. Moreover, relevant quantitative data is non-existent and has to be constructed from scratch. Thus, the primary concern of this chapter is to gain *quantitative* decisions data from *qualitative* text-based information. A preliminary decision classification and rudimentary data base is proposed by Costa et al. (2014). In order to draw on these achievements, up to 64 years of management decisions from the three operators are analysed, based on their annual reports. Overall, the chapter pursues the following goals:

- Proposal of an innovative, straightforward and scientifically valid procedure.
- Upgrade and refinement of a decision classification/categorization scheme.
- Creation of a database with decision time-series suitable for regression.
- Resolution of data related problems induced by the methodology.
- Decision analysis with regard to similarity or differences between operators.

First, *Content Analysis* is introduced as adequate tool, to arrive from text-based to numerical data in six steps. *Second*, data *pitfalls* are identified and resolved through *learning curves* and *standardisation* over time. *Third*, the categorized decision data is assessed descriptively and visually with two approaches: The simple *static-cumulative approach* concerns cumulated decision counts. The *dynamic-relative approach* concerns decision-making patterns over time. In addition, *managerial characteristics* are quantified and *managerial focus* is displayed by the relative importance of decision categories (over time). The *last* section summarizes key findings.

Key research questions: *How does managerial decision-making behave over time, with regard to the importance of decisions? Are there similarities across operators?*

5.2 Theory of Content Analysis

Nature and Definitions of Content Analysis

In order to model the management decisions for the three operators from the text-based, qualitative data, apparently some sort of text analysis procedure is needed. The wide accessibility of text material in electronic form has given rise to a number of automated and non-automated text-mining methods used in various fields to generate information from the statistical analysis of word patterns. These text analysis tools - in their purest form based on text reading and word counting - make use of complementary processing techniques such as data systematization and data categorization to obtain a quantitative representation of the text and eventually numerical figures. Those might then be used in mathematical and statistical models for further purposes. Despite the existence of several automated methods, a still commonly applied and widely accepted tool is given with the so-called *manual or directed Content Analysis (CA)*, described extensively by Krippendorff (2004) and Neuendorf (2002).[184] Broadly speaking, in manual CA a predefined categorical coding scheme is applied to text (elements) manually by a so-called trained human *"coder"*, as schematized in Figure 5.1 (Lowe et al., 2011).

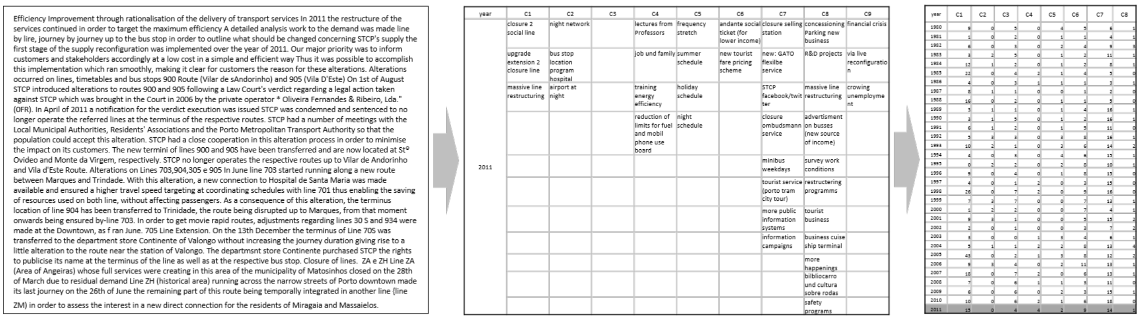


Figure 5.1: The idea of Content Analysis - from text to tables to numbers.

DEFINITIONS: CA is a research technique *"for making replicable and valid inferences from text to the contexts of their use"* with the purpose of *"providing knowledge, new insights, a representation of facts and a practical guide to action"* (Krippendorff, 2004). As per Neuendorf (2002) CA is "[…] *a summarizing, quantitative analysis of messages that relies on the scientific method*[185] *and is not limited as to the types of variables that may be measured or the context in which the messages are created or presented."* The method is applied to written texts and concerned with meanings, intentions, consequences and contexts traditionally derived from newspaper articles, political speeches, and recently from psychiatry, public health studies and

[184]Text mining and conventional non-manual CA share the same goals and allow categories to emerge from data. However, text mining can also capture contexts of the words analysed (for comparisons and classifications see Yu et al. (2011); for discussion refer to Grimmer and Stewart (2013)).

[185]*"including attention to […] a priori design, reliability, validity, generalizability, replicability and hypothesis testing"*

any form of written, verbal or visual communication messages. The method is also used for assessing political position of political actors based on mass surveys, bill sponsorship and predominately from political text, both cross-sectionally *and* over time[186] (Lowe et al., 2011).

Table 5.1: Advantages and Disadvantages of Content Analysis.

Pros	Cons
simplicity (sufficiently quantitative)	
flexibility of research design	simplicity (insufficiently statistical)
content-sensitivity	category building requires experience
structured approach in stages	time-consuming if manual CA
straightforward results	

In summary, CA is a systematic and objective means of collecting, analysing, categorizing and operationalizing qualitative contents of texts with the goal to obtain *quantitative* data and to *quantify* phenomena in a condensed description.[187] The outcomes are usually quantitative realizations about concepts or categories that describe the phenomena.[188] Among other advantages (Table 5.1) CA enables to enhance understanding of the (hidden) data by observing patterns and testing theoretical issues (Elo and Kyngäs, 2008; Yu et al., 2011).

FUNCTIONING: The *key idea* of CA is to build a model - or rather a conceptual framework - about a certain subject/phenomenon/theory through so-called *content categories* that presumably constitute the subject. In so far, the information of many words is condensed into much smaller content categories. These categories are (a) either derived during text processing or (b) pre-defined by expert or researcher knowledge[189] (Hsieh and Shannon, 2005; Stemler, 2001). The former approach is inductive and recommended when there is not sufficient or only fragmented knowledge about the subject/phenomenon/theory. It then mostly relies on automated techniques and algorithms that try to "find" dominant categories. The classification and categorisation itself could be considered an output of this type of CA. The latter approach - (b) - however is deductive[190] since a priori knowledge serves as a basis to structure the text data by categories accepted in the research area. This type of CA is based on manual techniques, since the content has to be assigned to the pre-defined categories using the coder's intelligence. The next section will introduce the sequential process and the respective stages of Content Analysis.

[186]Text is a by-product from political activity. CA estimates political positions from speeches, debates, or manifestos.
[187]There are few concerns in literature as to whether CA essentially is a *qualitative* or *quantitative* method. Text is essentially of qualitative data nature. Even when analysed this stays unchanged which makes Krippendorff (2004) reach to the former conclusion. Neuendorf (2002) promotes for the latter conclusion as *"content analysis has as its goal a numerically based summary of a chosen message set"* just as other quantitative methods that produce counts of key categories and measurements of the amounts of other variables. The issue will not be addressed further.
[188]Krippendorff (2004) pp. 47 ff.: research goals of CA a) extrapolations about the subject(s) assessed based on trends, patterns, differences, b) observations of relations between phenomena, c) documentation of institutional processes.
[189]Categories are *unknown*: conventional CA or emergent coding; when known: directed CA or *a priori* coding.
[190]*Inductive*: from the specific to the general; *deductive*: from the general to the specific.

Six Stages of Content Analysis

Yu et al. (2011) argue that CA might be applied differently by different researchers with different research backgrounds. However, in their view, most strategies and principles applied during CA are common standards for qualitative-analytical analysis, specifically that data is *collected, processes and analysed in sequential order* and that the end goals are to *advance in under-researched fields*, *seek for explanations* and/or to *create data for subsequent quantitative analysis applications*. Further, all CA methods pursue *data reduction* by selecting, focusing, and condensing data to categories. Though there are no explicit systematic *rules* for CA, Srnka and Koeszegi (2007) in accordance with Krippendorff (2004) established pivotal *guidelines* for conducting a qualitative analysis in sequential order. Those are adapted for this study in order to model management decisions through the following stages (Figure 5.2):[191]

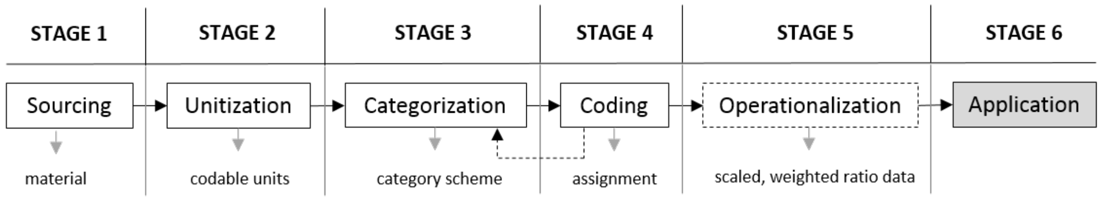


Figure 5.2: Sequential Content Analysis. Adapted from Srnka and Koeszegi (2007), Neuendorf (2002).

S1-SOURCING: This stage refers to the collection of data, in particular the transformation of data from non-written into written form. Apparently, this stage does not apply when the data is readily available in the latter form.

S2-UNITIZING: In this stage, first the *general units* of analysis are selected and if needed the material is divided into coding units according to the purpose and scope of the research. The units can be small text segments, paragraphs, chapters, or/in full documents, such as different newspaper, articles from different publishers or publications from different years. As a rule of thumb, units should be large enough to be recognized as a whole and small enough to be processed in the analysis with reasonable time efforts.[192] Second, the overarching *unit/content of key interest* might be defined, which could be specific topics or research questions.

S3-CATEGORIZATION: This stage is the most *crucial* one as it intends to structure and condense the data by theoretical useful grouping, based on the assumption that words, phrases and the like share the same meaning when classified into the same categories. As per Srnka and Koeszegi (2007) categorization (also *"coding frame"*) is an informed and creative process. It should be undertaken by rather experienced researchers in the respective field, as it has to be decided, e.g. whether existing "standard" categories might be usable and detailed enough in the context of research or if new ones would have be to

[191]Each paragraph is supported by findings and remarks from Stemler (2001), Elo and Kyngäs (2008), Schreier (2012).
[192]Another type of unit, however trivially, are the so called 'units of coding', e.g. how many time a similar item entered a category, thus each count would be one 'unit of coding'.

developed. Pre-defined categories should be conceptually grounded and at best be based on earlier works such as theories, (conceptual) models, mind maps or literature reviews. Further, they might differ in complexity and nature, as they can be hierarchical (sub-categories), single levelled, generic, aggregated etc. Units and categories jointly form a structured or categorization matrix as proposed by Krippendorff (2004) p. 143 which is filled in the coding step. As indicated in Figure 5.2, there might be a loop between S3 and S4 when the classification starts deductive and gets inductive to further refine data.

S4-CODING: *"The specific segment of content that is characterized by placing it in a given category"* (Krippendorff, 2004). In this step, usually the text or content for each unit is assigned to the categories (using codes or numbers) where proper category definitions and thus clearly defined coding rules ensure consistent coding/assignment. The step is also referred to as *"recording"* and is the *most time-consuming* stage of Content Analysis.

S5-OPERATIONALIZATION: This step translates the previously obtained assignment in some metric-scale in order to give a numerical appearance. A simple way is to initially convert the text units to absolute category counts[192] for each unit assessed, which is often uses in political speeches analysis as indicated by Yu et al. (2011). In further steps, those values might expressed as frequencies (over time) and in need to be scaled in order to become handy and comparable across categories, units, samples or studies.

S6-APPLICATION: This step refers to (a) the reporting, presentation, comparison and interpretation of results from the analysis (identification of themes, patterns and relations in the data) and/or (b) further statistical utilization of the operationalized data or (c) the induced (re)arrangement and revision of data/categories in order to verify, test, or confirm the themes and patterns identified.

In summary, the process of CA is defined by three main phases:

- data preparation and collection (Stage 1 and 2),
- data organisation and data generation (Stage 3 to Stage 5)
- data representation and or application (Stage 6)

Theses stages are applied in the next section. It should be noted, however, that CA herein simply serves as methodological guidance and as a helper method to create quantitative data. The underlying question - *how to gain data from text-based information* - is very similar to that of rather linguistics or policy science oriented research fields. Over decades, these fields have been very successful in using CA to generate numbers from texts. The true potential, foundations, roots and interpretation of CA thus truly lie(s) in these fields. However, relevant ideas and procedures are borrowed and adapted accordingly in this study to the purposes pursued.

5.3 Implementation of Content Analysis

Elo and Kyngäs (2008) advice that *"the researcher must aim at describing the analysing process in as much detail as possible when reporting the results. […] To facilitate transferability, the* *researcher should give a clear description of the […] data collection and process of analysis."* Therefore, this section will give a detailed reflection on how the proposed sequential process of Content Analysis is used to model and quantify the decisions taken by the management of the three operators during the time period assessed.[193]

S2 - Unitizing: *Annual reports* and *Managerial Decisions*

Since data from the operators is readily available, the *sourcing* stage did not apply. Stage 1 and 2 follow the principle of *relevance sampling*, which is the selection of text samples that directly contribute to answering the research questions. In terms of *unitizing*, the intended time-series character of this study requires to use *annually* published data. Thus, the units for content extraction are the previously described *annual* reports published by the three operators in the years assessed. The *content of key interest* are announcements and remarks that indicate or refer to any form of *decision taken* by the *operator management* or other *responsible individuals*. These *managerial decisions*[194] are defined as follows:

- *First*, any actions or measures applied or implemented by the operator on its own behalf or on behalf of other entities, being part of its daily business (repetitive, of regular importance and immediacy), or a response to some sort of (operational) crisis situation, or with strong potential to realize long-term operator gains.
- *Second*, whether a managerial decision is taken without external influence (controllable) or due to regulations or other governmental intervention (non-controllable) is assumed irrelevant (see impulse-response notion in Chapter 4).
- *Third*, the focus lies on *software/qualitative* decisions. Differences are explained in Table 5.2 below. *Hardware/quantitative* decisions are mainly captured by DEA. To some extent, software/qualitative decisions could be understood also as pre-conditions, complements, consequences for hardware/quantitative decisions.[195]

Table 5.2: Differences of hardware/quantitative and software/qualitative decisions.

feature	**hardware/quantitative**	**software/qualitative**
nature	physical	mostly non-physical
origin	internal	internal and external
apply to	just inputs (fleet, network length, staff)	inputs and outputs, customers, all
aim at	input changes, input mix, stock	input productivity (and output generation)
effect	prompt software decisions	enable hardware decisions
section	Performance Modelling (Chapter 6)	**Decision Modelling (Chapter 5)**

The structure of the annual reports is similar across operators. Relevant information about decision can be found in the following sections: *chairperson's statement*, *general corporate information* and *operation review* and alike. Complementary information can be gained in the

[193]The chosen research design can be classified as a *relevance sampling* based (Krippendorff (2004) p. 119), *directed content analysis* (Hsieh and Shannon (2005)) with *deductive-inductive* loops, using *hierarchal categorization* for coding (Krippendorff (2004) p. 135) and a presentation in *absolute (frequencies)* or relative values that are also *partially aggregated* (Krippendorff (2004); Lowe et al. (2011); Srnka and Koeszegi (2007)).
[194]For clarification of the term 'managerial decisions' see also Hill and Hill (2012) or Schefczyk (1993).
[195]See also Clemen and Reilly (2001).

financial sections (e.g. accounting policies, balance sheets, cash flow statements). In addition, information about incidents completely outside the control of the management and explicitly stated as such in the reports are of interest.

S3 - Categorisation: *7 Decision Groups, 19 Sub-Groups*

As learnt from a brief overlook of the annual reports, managers in public transport seem to face multiple problems with multiple decisions to take. Text screening and structuring by singling out relevant information about decisions could in fact largely condense the data volume. However, results would still be very heterogeneous and without any meaningful interpretation. In contrast, a more detailed (*a priori* available) categorization could organize the vast information in a better way. Therefore, the development of an adequate scheme is pivotal for further data reduction and structuring. The intended categorization has to meet the following requirements:

- strict relation to the research objective
- straightforward identification and assignment of managerial decisions
- sufficient intuitive meaning, even for non-expert
- mutually exclusive and detailed categories
- unambiguous and consistent, so that it could be used also from other coders[196]

Under these assumptions, seven decision main-categories are applied based on preliminary work from Costa et al. (2014): *network, fleet, personnel, schedule, fares, service,* and *management decisions.* The former six might be understood as being of *operational* and *tactical* nature. In contrast, the later one is rather *strategic.[197]* In further refinement steps, nineteen sub-categories are added (Figure 5.3). In addition, *contextual information* is categorized in four subcategories to cope for interferences outside to the operator.

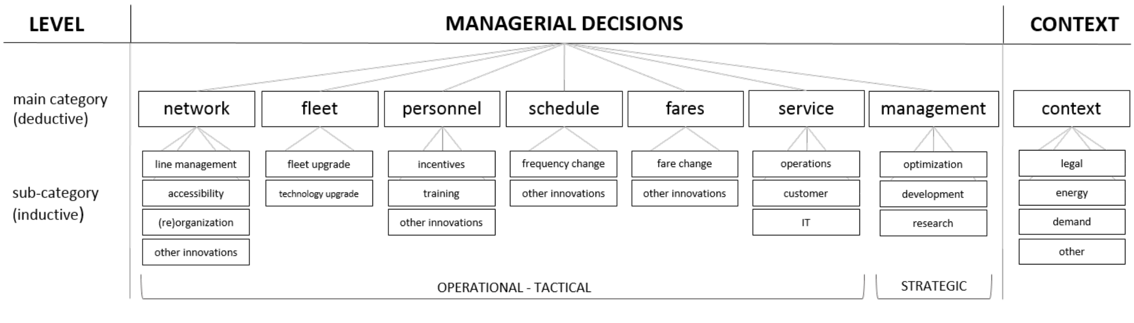


Figure 5.3: Final categorization scheme for decisions in public transport management.

The following paragraphs and tables elaborate on the interpretation of the central elements of the proposed classification scheme as well as its sub-categories. Accordingly, decision examples found in the reports are presented[198], which is a central outcome of this thesis.

[196]Adapted from Srnka and Koeszegi (2007).
[197]See similar classifications in Zatti (2012), Daraio et al. (2016), van Egmond et al. (2003), Ceder (2007), Vuchic (2007).
[198]The examples could be considered a qualitative representation; the end goal however is to get a quantitative one.

NETWORK DECISIONS: A public transport network is both the backbone of urban mobility and a key element for management decisions. It generally comprises various sub-networks, e.g. for trains, trams, and buses as shown in Chapter 2. The network could be differentiated by length of the physical network itself or by length of the lines applied to the network.[199] A rail-based transport networks requires specific fixed infrastructures and is thus less suitable for changes or managerial interventions in general. Bus-dominated services, however, provide much more managerial options, since (in theory) lines could flexibly be adjusted and altered within the existing road network of a city. In this analysis, network decisions thus represent measures of an operator that relate to the utilization and making-use of the underlying network predominantly achieved by line adjustments and alterations. In this regard, four sub-categories constitute the cluster of network decisions, namely *line management*[200]*, accessibility, (re)organization* and *other innovations.* The first of which could be interpreted as *network management* and the last three as *network development* decisions. See Table 5.3 below.

Table 5.3: Network decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
line management	routine and frequent but moderate network alterations	line introduction or dismissal, line rerouting, line cutting or extension, start or terminus swaps, *and more*
accessibility	irregular, infrequent establishment of first-time connections or major (line) expansions; construction, integration and operation of terminals, stations and interfaces to facilitate access and interchangeability	lines to new settlements or to activity centres (CBD, airport, shopping malls), diametral connections across the network, opening of new terminal, more stops, *and more*
network (re)organization	extremely rare but large-scale re-organization of the entire network, lines or their routing in the network	network or sub-network optimization measures, adaptions due to changes in traffic routing or imposed intermodality standards, adaptions due to competition, renaming of lines, *and more*
other (innovations)	frequent service and product related measures and innovations within the existing network	establishment of night network, express bus lines, feeder lines, dedicated lines (e.g. X-mas, stadium), network for elderly, tourist lines, network and line changes due to mode changes (e.g. introduction, closure/re-establishment of tram), transport association induced changes, *and more*

FLEET DECISIONS: *Public transport […] includes major devices such as trams and buses, components such as engines and sub components such as wheels and tyres. Each of these parts has a function of its own to support the overall function 'public transport' (Costa and Fernandes, 2012)*. The fleet is the group of vehicles that the operator utilizes to provide transport services. Fleet composition is defined by the underlying (sub-)network characteristics, transport demand and the management strategy envisaged. For instance, one could simply adjust capacity to

[199]Assumption: $\sum linekm \geq \sum networkkm$.
[200]Faivre d'Arcier (2014) and Georgiadis et al. (2014).

demand (expressed in changes of the number of trains, trams or buses) or additionally focus on establishing a *"green"* and sustainable low-cost fleet. Corresponding to the latter approach, the sub-categories *fleet upgrade* and *technology innovation* aim at identifying major fleet related decisions closely linked to vehicle specifics that are often imposed by the vehicle industry (e.g. lifecycles and technical trends in general)[201]. See Table 5.4 below.

Table 5.4: Fleet decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
fleet upgrade	renewal, upgrade and modernization schemes applied to entire vehicles	upgrade of vehicles to next models (model MB O305 to model MB O405), introduction of new vehicle types with specific features (e.g. midi-buses, double-deckers, express-buses, articulated buses, trolleybuses, hybrids, diesel-hybrids, high capacity cars, CNG buses), *and more*
technology upgrade	modernization programs of individual vehicle components or technologies	changes in seat capacity, engines, motorization, gearbox, springs, current supply, implementation of environmental standards or measures (filters, lubricants, EURO 2,3,4,5 norm), introduction of telematics devices, *and more*

Table 5.5: Personnel decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
incentives	motivational programs to encourage the employee´s commitment	salary increase, pension payments, supplemental payments, privileges, reward systems, career opportunities and internal job market, reduced work time, flexible work time, improved work conditions and facilities, dismissal protection, work-and-family programs, gender equality programs, paid study programs, *and more*
training	improvement and development of specific employee skills and knowledge	skill enhancement in management, leadership, accounting, eco-driving, new technologies, social media, software, customer relations, service, maintenance, *and more*
other (HR schemes)	additional human resources management measures and activities	staff reorganisation and optimization, severance schemes and other complementary actions as part of major dismissal and hiring programs, worktime increase, salary and benefit cut programs, working safety and health programs, psychological care, programs for disabled staff, staff monitoring and appraisal, staff information policies and tools, company suggestion system, establishment of legal obligations (e.g. minimum wage), vocational training and apprenticeship schemes, *and more*

PERSONNEL DECISIONS: The third major resource to be managed as a resource is *personnel,* which essentially relates to people employed by the operator. (Human resource) Managers could simply adjust the numerical ratio of staff to work demand ('hire and fire') or additionally apply productivity targeting measures to the pool of employees to fully exhaust their potential in an economic interpretation (maybe without being forced to hire). This decision category depicts predominantly measures with the latter focus, expressed in the sub-categories *incentives*, *training* and *other (HR management schemes)*.[202] See Table 5.5 above.

[201]This category does not represent decisions taken with regard to individual annual fleet changes (e.g. stock-related decisions, demand-adjustment of the very number of vehicles needed).
[202]This category does not illustrate individual annual stock-based decision (e.g. quantitative changes).

SCHEDULE DECISIONS: This category refers to public transport schedules available for customers to plan their travels. For the public transport system´s main arteries, a schedule could represent a form of urban rhythm. Thus, changes imposed by the management often relate to simple capacity-oriented measures such as *frequency changes* or to *other* measures with resource- or customer-orientation. See Table 5.6 below.

Table 5.6: Schedule decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
frequency change	frequency increase or decrease of service on one or several lines	change of service from every 10 min to every 5 minutes (increase) or change from every 15 min to every 30 min (decrease), *and more*
other (innovation)	general schedule optimization and (re)organization	optimizing for less vehicles deployed, optimizing for connections, prolonged schedule (e.g. night, holiday frequency), *and more*

FARE DECISIONS: Fares generally determine how much customers have to pay in exchange for the transport service provided, with a given mode, at any given time. In other words, the fare *prices* the product. A transport operator´s revenue - and so its economic sustainability or the need of subsidies - majorly depend on the underlying fare and pricing system. Continuous adjustments of fare prices are represented by the sub-category *fare change*. Then *fare innovation* summarizes innovative pricing strategies, price remodelling and price discrimination measures applied through the managers. See Table 5.7 below.

Table 5.7: Fare decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
fare change	fare increase or decrease	10% increase, less stations with short trip ticket, *and more*
other (innovation)	(re)modelling of fares and products, introduction and/or modification of specific fare schemes	social-, school-, student-, tourist-, monthly-, annual- and job-passes, fare integration schemes (e.g. transition to multimodal fares), fare promotions, special and dedicated fares (e.g. X-mas fare, shopping fare), *and more*

SERVICE DECISIONS: The provision of transport service is the primary product of any public transport operator. As shown above, service is defined as the operation of vehicles (using personnel + fleet) along a predefined route with fixed stops (using a network), based on a published timetable (using a schedule) for a fixed price (using a fare system). In the given context, the category *service decisions* expresses the management's efforts to affect the transformation of resources to the final product in an integrated manner. Three sub-categories with various foci are defined: *Firstly*, the subcategory *operations* reflects primarily technical decisions applied to infrastructures, vehicles or facilities and process-oriented decisions both aiming at aspects, which guarantee a certain flow of operations. *Secondly*, the sub-category *customer* illustrates sales/service-delivery decisions that majorly address system users, with either supply, quality or customer information and support focus. *Lastly*, the *IT*[203] sub-category summarizes all relevant decisions and measures that indicate any use of information technology in order to facilitate the provision of transport services. See Table 5.8 below.

Table 5.8: Service decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
operations	*infrastructure, vehicle, facility focus:* use and implementation of gear, devices and infrastructures required along the process of service provision	bus lanes and corridors, track doubling, shared stop islands, turnout heating, turnstiles, barriers, escalators, elevators, automatic vehicle doors, *and more*
	process focus: optimization and monitoring of internal and external processes required to provide faster, more reliable, safer and less costly services	optimization of headways and circulation, acceleration and speed measures (e.g. bus-prioritization, speed-increase), improvement of passenger service systems, ticketing, machines and devices (e.g. ticket printing, ticket obliteration, on-board fare boxes, coin and note changers), vehicle parking and depot measures (e.g. refuelling, maintenance), safety and security programs, change of school opening hours, queueing of passengers, *and more*
customer	*supply focus*: adjustment and extension of services (core product) and cross-selling measures (by-products)	capacity adaptation (e.g. increase during peaks), dedicated services (e.g. city-buses, midi-buses, flexible service concepts, night service, airport service, mega events), intermodality, guaranteed connections, service on-behalf of a company (e.g. shopping bus, transport of workers from/to factory), improved purchase and payment options (e.g. e-ticket, pay cards, MultiBanco), extras (e.g. bicycle transport, bicycle parking, Park+Ride, Wi-Fi, mobile communications, shopping concepts, promotions and vouchers), *and more*
	quality focus: improvement of specific product criteria	increased overall quality (e.g. punctuality, connections, travel time, cleanliness), quality surveys, stops and shelters changes (e.g. implementation, (re)design, management, weather-proof, included shopping facilities, non-smoking areas), passenger safety and security, *and more*
	information and support focus: pre- and after sales and "on-board" contact with customer	customer information (e.g. announcements, maps, plans, brochures, magazines, media terminals, internet and smartphones), customer advisory service points, opening hours of service points, customer friendliness and supervision schemes, complaint management, ombudsman establishment, PR and marketing campaigns, *and more*
information and communication technology	computer-aided operation planning	routing, scheduling, fare calculation, SAP packages and updates, energy-optimized operations, traffic statistics and analysis, punch card machines, wireless operations monitoring, *and more*
	computer-aided operations	analogue computers, remote control, automatic real-time vehicle location and control systems, remote monitoring and automatic train handling, real-time information, radiotelephony, IT devices at stops, vehicle communication, trunked radio system, digital radio, *and more*
	computer-aided customer management and information	webpages, apps, interactive terminals and panels, text and message services, social media, *and more*

[203]Brynjolfsson et al. (2011) and McDonald and Li (2015).

MANAGEMENT DECISIONS: The previously introduced decisions are rather short termed and thus with *operational/tactical* character. In contrast, the category *management decisions* summarizes predominantly strategic actions related to the management's key functions *planning*, *controlling*, *organizing*, and *leading.* These decisions target the operator's middle to long-term economic, financial and social viability. Three sub-categories are introduced: *Business optimization* reflects cost-oriented remodelling or reorganisation schemes and further policies to trigger the operator´s long-term core business performance; *business development* refers to any form of business expansion schemes; the sub-category *research and development* sums up management efforts with regard to in-house research, studies, test trial etc. See Table 5.9 below.

Table 5.9: Management decisions sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
business optimization	extensive modernization or cost-cutting and streamlining measures with focus on *resources, services, administration* or *public image*	*applied to resources:* fleet modernization (e.g. fleet replace schemes (buses for trams , leasing, sale-and-lease-back or charter programs), staff streamlining (e.g. major hiring or dismissal schemes with compensations, health programs), other cost-cutting measures (e.g. eco-driving, fuel, electricity, facility management), infrastructure preservation (e.g. infrastructure maintenance schemes), *and more* *applied to services:* major supply adjustments and optimization schemes (e.g. introduction or cancellation of specific modes such as tram, trolleybus, ferries, market driven adjustments to demand changes), *and more* *applied to administration:* streamlining and optimization of procedures, methods hierarchies (e.g. sub-contracting and outsourcing, insourcing, centralization, business division remodelling), certifications (ISO), software (SAP) and decision-support systems (ERP), appraisal and evaluation schemes, strategic management and controlling schemes, risk assessment, failure management, *and more* *applied to public image:* environmental programs (emission reduction, water recovery, recycling), accessibly schemes for people with impairments, public awareness schemes, corporate identity schemes (UITP Charta), anti-fraud/anti-corruption regulations, *and more*
business development	forward-looking business decisions either to expand the core-business activities (horizontal expansion) or to explore additional business areas (vertical expansions) in order to increase revenues from common or new sources	*horizontal:* long-term infrastructure investment schemes, transport association expansion, market gap exploitation, concessions, commission-based transport, *and more* *vertical:* holdings and subsidiaries (e.g. in public transport, apartment construction, touristic companies, shopping malls, car parks, security), networking and consulting activities (e.g. sales of software solutions), advertisement on/in vehicles or shelters, education and training, business models, wind-fall gains through lobbying and negotiation, *and more*
research and development (R&D)	tests, trials, research projects, studies, academic involvement	double door tests, automatic doors, automatic driverless trains, vehicle development (XXL buses, emissions), traffic simulation and optimization, alternative engines and fuels (LPG, CNG, electric), intelligent traffic systems (ITS), (process) standardization, *and more*

CONTEXT: To capture the operator's environment at least partially, supposed non-manageable interferences and disruptions referenced in the reports are grouped in four sub-categories, according to their origin: *legal*, *energy*, *demand* and *other*. See Table 5.10 below.

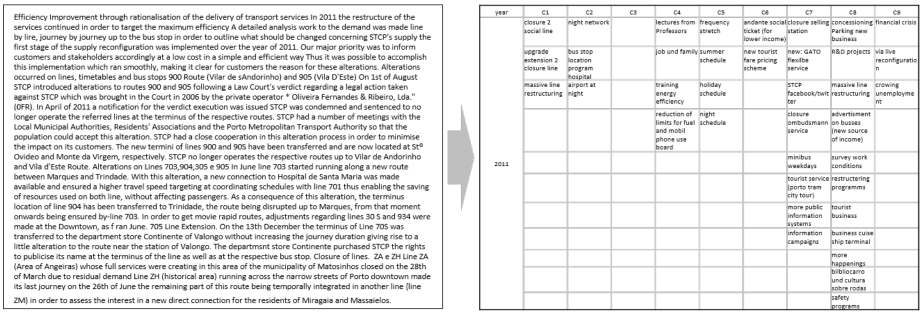
Table 5.10: Contextual interferences, sub-categories, interpretation, and examples.

Sub-Category	Interpretation	Examples
legal	any changes in the contractual arrangements of the operator, mostly with financial effects	subsidy reductions, EU regulations, changes in laws, changes in transport associations, restricted permission for using the road network, increased interests, organisational changes in authorities, *and more*
energy	increased energy prices	war, oil crisis, energy cuts, *and more*
demand	demand-side effects	increased car ownership, rising individual transport, unemployment, competition, changes in mobility patterns and urban structures, *and more*
other	other effects for various sources	energy supply issues, reduced operational speed, increasing material prices, shortage of resources, deteriorating infrastructure, strikes, vandalism, garbage, capacity limits, weather, economic crisis, political changes or programs, *and more*

SIDE NOTE: The final classification proposed in Figure 5.3 and in the tables above is in fact the results of a two-step procedure jumping back and forth between Stage 3 and Stage 4 of the CA. As per Srnka and Koeszegi (2007) this approach is called deductive-inductive. The authors found that "*starting with categories identified in the literature, the category scheme can be adapted in reiterative steps to the specific research problem or content of data.*" In a first step, a deductive and directed CA was executed based on a priori knowledge and elaboration about a possibly valid structure for management decisions in public transport. This classification is obtained from Costa et al. (2014) and applied, however, with slight adaptations, in a first iteration to all annual reports of each operator [Stage 4 "Coding"]. Since after the first iteration the information per category is still highly dispersed and unstructured, the procedure is repeated in a second step to further refine the main decision categories by introduction of sub-category levels. This step can be considered being partially inductive. The sub-categories are generated mainly from the data assigned to each main category, but also with support from several studies which contain valuable information about how a refined decision structure in public transport management and its specific sub-components could look like (see European Commission (1996), Tam and Hui (1996), Matzoros (2002), Randall et al. (2006), Vuchic (2007), Buehler and Pucher (2011)).

S4 - Coding of Decision Data: Structured Decision Matrix

Insights in managerial decisions can only be gained through a detailed year-by-year analysis of the annual reports including careful examination of textual data in three languages as well as plenty of note taking and documentation. While reading the reports, the given information is cognitively processed, classified and eventually decided, whether an aspect presented would fit the decision (categorization) scheme (relevant) or not (irrelevant). If considered relevant text/data is analogously assigned to the corresponding decisions category by hand. Since scanning already for individual, specific references of decisions taken, relevant information can usually be derived from a few phrases at most. The process of data transferal is organized for each operator independently by using a structured matrix/tableau with columns as categories



Efficiency Improvement through rationalisation of the delivery of transport services In 2011 the restructure of the services continued in order to target the maximum efficiency A detailed analysis work to the demand was made line by lire, journey by journey up to the bus stop in order to outline what should be changed concerning STCP's supply the first stage of the supply reconfiguration was implemented over the year of 2011. Our major priority was to inform customers and stakeholders accordingly at a low cost in a simple and efficient way Thus it was possible to accomplish this implementation which ran smoothly, making it clear for customers the reason for these alterations. Alterations occurred on lines, timetables and bus stops 900 Route (Vilar de sAndorinho) and 905 (Vila D'Este) On 1st of August STCP introduced alterations to routes 900 and 905 following a Law Court's verdict regarding a legal action taken against STCP which was brought in the Court in 2006 by the private operator * Oliveira Fernandes & Ribeiro, Lda." (0FR). In April of 2011 a notification for the verdict execution was issued STCP was condemned and sentenced to no longer operate the referred lines at the terminus of the respective routes. STCP had a number of meetings with the Local Municipal Authorities, Residents' Associations and the Porto Metropolitan Transport Authority so that the population could accept this alteration. STCP had a close cooperation in this alteration process in order to minimise the impact on its customers. The new termini of lines 900 and 90S have been transferred and are now located at St® Ovideo and Monte da Virgem, respectively. STCP no longer operates the respective routes up to Vilar de Andorinho and Vila d'Este Route. Alterations on Lines 703,904,305 e 905 In June line 703 started running along a new route between Marques and Trindade. With this alteration, a new connection to Hospital de Santa Maria was made available and ensured a higher travel speed targeting at coordinating schedules with line 701 thus enabling the saving of resources used on both line, without affecting passengers. As a consequence of this alteration, the terminus location of line 904 has been transferred to Trinidade, the route being disrupted up to Marques, from that moment onwards being ensured by-line 703. In order to get movie rapid routes, adjustments regarding lines 30 S and 934 were made at the Downtown, as f ran June. 705 Line Extension. On the 13th December the terminus of Line 70S was transferred to the department store Continente of Valongo without increasing the journey duration giving rise to a little alteration to the route near the station of Valongo. The departmsnt store Continente purchased STCP the rights to publicise its name at the terminus of the line as well as at the respective bus stop. Closure of lines. ZA e ZH Line ZA (Area of Angeiras) whose full services were creating in this area of the municipality of Matosinhos closed on the 28th of March due to residual demand Line ZH (historical area) running across the narrow streets of Porto downtown made its last journey on the 26th of June the remaining part of this route being temporally integrated in another line {line ZM) in order to assess the interest in a new direct connection for the residents of Miragaia and Massaielos.

year	C1	C2	C3	C4	C5	C6	C7	C8	C9
	closure 2 social line	night network		lectures from Professors	frequency stretch	andante social ticket (for lower income)	closure selling station	concessioning Parking new business	financial crisis
	upgrade extension 2 closure line	bus stop location program hospital		job und family	summer schedule	new tourist fare pricing scheme	new: GATO flexilbe service	R&D projects	via live reconfiguratio n
	massive line restructuring	airport at night		training energy efficiency	holiday schedule		STCP facebook/twit ter	massive line restructuring	crowing unemployme nt
				reduction of limits for fuel and mobil phone use board	night schedule		closure ombudsmann service	advertisment on busses (new source of income)	
2011							minibus weekdays	survey work conditions	
							tourist service (porto tram city tour)	restructering programms	
							more public information systems	tourist business	
							information campaigns	business cuise ship terminal	
								more happenings	
								bilbliocarro und cultura sobre rodas	
								safety programs	

Figure 5.4: Coding of decision data as per categories - schematic display.

and rows as years, as suggested in Figure 5.4.[204] At the end of this stage, a then "filled-up" tableau allows for getting a first glance about the patterns and structure of decisions in public transport management, however yet a qualitative one, as the data is still text-based.

S5 - Operationalization of Decision Data: Decision Counts

The text-to-category-assignments from the previous stage(s) needs to be operationalized to numerical values to make meaningful conclusions or conduct further analysis. As suggested in section 5.2 a commonly applied method is to convert the assigned text elements per category and year to simple counts, which essentially is the application of a ratio scale.[205] Ratio scales appear very suitable to specify a *how many* of something appearance. Since the coding stage had already focused on individual, specific decision elements, a data transformation to counts is apparently a suitable mean to answer the question, *how many* decisions in a respective (sub-)category were taken.[206] The operationalization procedure is based on the following key assumptions: *(1) individual decisions and thus counts are equal in weight (or un-weighted), (2) one decision corresponds to a count of one, (3) categories are uniform (or un-weighted), (4) decisions in the same (sub-)category are totalized per year and expressed as frequency sum.*

Accordingly, all elements are counted semi-automated by using a spreadsheet in Excel. Figure 5.5 shows in an exemplary manner, the complete procedure at the main category level for STCP in 2011. According to the analysis, the management of STCP made 48 decision in total, fifteen of which were network-related, four of which were personnel-related, nine were service-related decisions, and so forth. This is done over all years to achieve a *final tableau* for each operator as displayed on the right-hand side of Figure 5.5, comprising absolute counts for all years and all (sub-) categories. The final decision tableau for each operator can be found in Appendix 5.

[204]In fact, it was multiple rows per year to account for multiple decisions in one year.

[205]A ratio scale is the highest measurement scale, with a true origin, order characteristics, and capable to express absolute differences in the unit of measurement. It is termed ratio scale as it permits the construction of ratios. These properties also apply to the number occurrences, say counts of an event.

[206]Similar count based operationalization in the managerial decision context have been found by Peltokorpi (2011) and Gillen and Lall (1997). van Egmond et al. (2003) code local expert information with a trichotomy classification to enable performance comparison based on a coded data matrix.

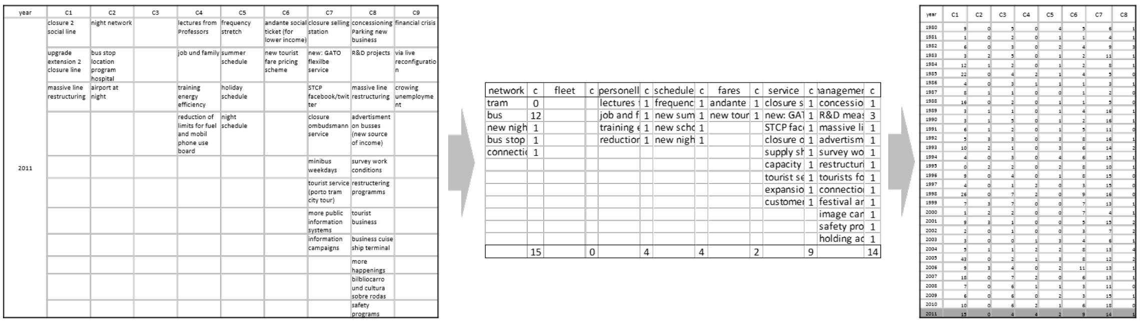


Figure 5.5: Operationalization of text-based decision data- schematic display.

S6 - Decision Analysis: Problems, Approaches and Data Adjustments

As demonstrated, in CA usually frequencies are calculated. A frequency is the absolute or relative number of occurrences per *term, topic, political opinion, content category* and so forth. In the context presented, it is defined as the number of decisions per (sub-)category per year. Table 5.11 summarizes the simple mathematical background for a decision analysis based on the so-called *decision tableau*.

Table 5.11: Decision tableau and formulas for operator i.

years		**individual (sub)categories**			**SUM**	**main/super category**	
		1	…	n		1	
1950	1	c_{11}	…	c_{1n}	$RS_{i1} = \sum_{1}^{n} c_{1n}$	RS_{i1}	*dynamic-relative approach*
…	…	c_{m1}^{*}	…	c_{mn}^{*}	…	…	
2013	m	c_{m1}	…	c_{mn}	$RS_{im} = \sum_{1}^{n} c_{mn}$	RS_{im}	
SUM		$CS_{i1} = \sum_{1}^{m} c_{m1}$	…	$CS_{in} = \sum_{1}^{m} c_{mn}$	$S_i = \sum_{1}^{m}\sum_{1}^{n} c_{mn}$	$SRS_i = \sum_{1}^{m} RS_{im}$	
		static-cumulative approach					

$c_{mn} = \{0,1,2,3 \ldots\}$; c_{mn} = adjusted decision count; c_{mn}^{*} = column maximum;
RS, CS = row sum, column sum; S = SRS

PROBLEMS: To analyse the decision data, first four main *problems* associated with pure count data need to be solved. The problems are termed '*absoluteness*', '*uniformity over time*', '*dominance*', '*lack of weighting*'. They derive from the four key assumptions applied in the operationalization stage, with particularly strong effect coming from the first assumption.

- PROBLEM (1): The '*absoluteness*' of decision counts is a problem which occurs when it comes to the comparisons between operators, since values on a ratio scale would simply suggest a ranking between operators. This ranking between operators is obviously is not very meaningful cause it assumes *uniformity* of individual decision even between operators.[207] *Alternatively, comparisons with cumulated and relativized decision scores are recommended.*
- PROBLEM (2): The problem of *'uniformity over time'* suggest that the value of a decision does not change over time. In the notations from above, this means that

[207]Absolute values might not be a problem when compared across decision categories for one operator.

one decision in 1950 is equal to *one decision* in 2013. This view appears to be flawed. Just as costs and prices, decisions in different time periods may not be directly comparable and would have to be adjusted. For instance due to technological changes nowadays it might be "easier" or *cheaper* to take certain operational decisions than 50 years ago. Or today, due to better monitoring techniques simply more decisions would be reported in the annual reports. The comparison of decisions over time requires their adjustment to a common time period. *Thus, the effect of time on the "value" of a decision was corrected by so-called learning curves, which express past decisions scores in "values" of today.*

- PROBLEM (3): Absolute values might also be an issue when comparing decision sub- and main categories[208] of one operator. The resulting '*dominance problem*' essentially corresponds to the application of uniform count data to decision categories, which might be naturally heterogeneous in the way they "attract" decisions. In the initial decision classification, all *categories* were supposed as equally weighted and no assumptions about mutual relations or the distribution of counts were made. During operationalization then, *decisions* were treated unweighted and equal regardless of the category they were assigned to. Consequently, categories comprising a higher number of counts by nature - that is decisions that have been taken quiet frequently - automatically dominate the overall picture relative to other categories. This creates a biased, if not flawed, picture of strong or weak categories, suggesting that some decision categories are more important for the management than others are. Especially with reference to the dynamic comparison it is more realistic to initially uphold the assumption that decision-making in one category is consistently independent from other categories and that, in other words, every category should be equally important to the management. *Thus, the count induced category dominance was eliminated by standardizing each category to its maximum decision score.*
- PROBLEM (4): Weighting of decision categories might not be wrong in fact, if it was not achieved by skewed classification and counting issues but rather by expert opinion or other methods. The *weighting problem* thus concerns the introduction of properly weighted categories, in contrast to the count-induced category dominance. *Weights help to achieve a more realistic description of managerial decision over time, in which the operator management is in fact confronted with changes of the relative category importance (that relate to a category's nature).*

Table 5.12 below summarizes main data adjustment steps required to solve the four problems.

A step-wise procedure results in two approaches to decision analysis and interpretations:

(1) The simple static-cumulative approach is based on the cumulated decision counts of the decisions tableau.

(2) The *dynamic-relative* approach involves the standardization of decision data to offset dominant categories and the adjustment for temporal aspects.

Characteristics of both approaches are outlined synoptically in Table 5.13 below.[209]

[208]Referred to as "decision categories" hereinafter.

[209]It should be noted that the weighting problem was only "solved" by supposing weights for (sub-) categories with the goal to conduct a sensitivity analysis for several weight scenarios used during regression modelling in Chapter 6. As those adjustments do not contribute to any results or interpretations upon managerial decision in this section, they are not considered part of the decision analysis.

Table 5.12: Data adjustments, step-wise solved problems and approaches to decision analysis.

#	Data adjustment	Remaining problems	Approach to analysis	Relevance in study
1	*cumulation and relativization*	~~absoluteness~~, uniformity over time, dominance, lack of weighting	*static-cumulative*	interpretation
2	*learning*	~~absoluteness, uniformity over time~~, dominance, lack of weighting	*dynamic-relative*	high for regression
3	*standardization*	~~absoluteness, uniformity over time, dominance,~~ lack of weighting		
4	*weighting*	none	none	high for regression

Table 5.13: Comparison of approaches to data analysis.

Feature	static-cumulative approach	dynamic-relative approach
data nature	cross-sectional	time-series
data format	absolute, relative	relative
data origin	totalized counts	annual count ratio
data reference	sum of counts over all categories	maximum count per category
data range	unlimited, 0 to 1	0 to 1
decision uniformity	yes	yes
temporal adjustments	no	yes
category uniformity	no	yes
category weighting	no	no
output	overall category ranking per operator	decision Activity Levels (AL) over time
interpretation	relative importance of categories	relative importance of categories over time
sub-cat. comparison	yes	no
main-cat. comparison	yes	yes
operator comparison	limited	yes
usability	limited	high
subsequent use	none	yes
example	"STCP, 1950-2013, 681 network decisions=40% of all decisions"	"STCP, 1950-2013: network activity levels over time are decreasing, similar to Hochbahn"

STATIC-CUMULATIVE APPROACH: The cumulative approach tackles PROBLEM (1) and relies on cumulated count data to enable several simplified comparisons of the *column-sums* of the decision categories, which can be expressed in absolutes (counts) or in relative values (ratios, percentages). This practice is common standard in Content Analysis.[210] The resulting *ranking of categories* and relative *importance* of categories could be used to grossly assess differences and similarities of managerial foci between operators. Thus, the approach at most allows for comparing decision categories of one operator in absolute scores. Nevertheless, it should be avoided to compare absolute values of individual decision categories between operators (unless for methodological validation). As mentioned beforehand the static-cumulative approach violates the assumption of *uniform categories* and should thus be taken with caution. It further lacks the potential of comparing decision-making dynamics over time. Despite its straightforwardness, the approach can only provide initial summarizing and static information.

DYNAMIC-RELATIVE APPROACH 1 - LEARNING CURVES: In order to cope with the insufficient representation of temporal aspects as in PROBLEM (2), each decision count at year t has to be

[210]See also Srnka and Koeszegi (2007) p. 49, Krippendorff (2004) p. 193, Schreier (2012) p. 219.

adjusted by a "skill" factor $F(m)$. The factor is derived from of a so-called *learning curve* with exponential shape, which is specified for each operator. Learning curves originate from the field of psychology and relate *skill* to *time.* It is assumed that skills increase over time. In economics or with regard to organisations the effect of learning/experience/skill generally equates to decreasing costs over time as discussed by Henderson (1974). As per Costa et al. (2014) 'riding' the learning curve allows to reap benefits analogous to economies of scale. Two main concepts for skill development over time exist, namely *convex* or *concave learning curves* as depicted in Figure 5.6 below. In a *convex learning* scheme, skills increase only marginally in early stages but strongly in later ones. This suggests either a lack of practice or inhibiting conditions in the beginning or both. Contrary, in a *concave learning* scheme, skills evolve strongly in the beginning but rather stagnate in later stages as the curve comes out relatively flat. This situation is usually encountered when high level of practise in a field meet optimal conditions right from the start (Mangal, 2009). Both phenomena and corresponding adjustments can be expressed in the following exponential functions and its adjustment curves:[211,212,213]

convex learning curve	$L_x(m) = exp^{km}$	(13)
concave learning curve	$L_v(m) = 1 - exp^{k(t-m)} + L_v(t)$	(14)
count adjustment to convex learning	$c_{mn} = C_{mn} \times F_{xp}(m)$	(15)
count adjustment to concave learning	$c_{mn} = C_{mn} \times F_{vp}(m)$	(16)

Note that for clarification, complementary formulas, calculation notations, and charts about the incorporation of learning curves and derivations can be found in Appendix 6. With regard to the implementation of learning curve adjustment to the data, three choices have to be made.

- *First,* the question is which concept would better fit to which operator. With regard to Porto and Dresden, in particular political conditions might have "restricted" skill development on the operator side for several decades. However, after the radical political changes in 1974 and 1990, respectively, the operators might have been able to catch-up accordingly and to strongly increase skills in a relatively short stretch of time. This favours the application of a *convex learning curve* for Porto and Dresden. In contrast, Hamburg Hochbahn could develop under democratic conditions and free-market opportunities especially in the thrifting decades after WW2. Thus, it is reasonable to assume a *concave learning curve* for Hamburg with comparatively fast progress in early years.
- *Second*, an adequate functional form of the learning curve has to be chosen for each operator. Obviously, the shape of an exponential function is determined by the growth-parameter k: the higher k the flatter or steeper is the *skill improvement* over time, especially in the beginning or end. The parameter should thus be not too small to avoid approximations to linearity and not too large to avoid heavily skewed time-series. But since the "real" k was unknown and could not be estimated econometrically, it had to be defined based on the assumption

[211]Theoretically, a third approach is *linear learning* which assumes a constant increase over time.
[212]C_{mn} original count, n decision category, m year 0 to t, k growth parameter, $F_{xp}(m)$ adjustment factor to convex learning curve, $F_{vp}(m)$ adjustment factor to concave learning curve, skill factor or value.
[213]Adjustment curves could be also interpreted as equivalent cost reductions occurring with skill increase.

that the *first year* corresponds to 0% learning progress and the *last year* to 100%. Following this logic, intermediate periods would correspond to a *cumulated learning progress* at that time. Once again, with reference to the game-changing historical events described above, for convex learning curves k is chosen to match the assumption that Porto had achieved 20% of the total skill development in 1974 and Dresden 10% in 1990. Both thresholds appeared to be reasonable, considering the vast impact of the political system. In contrast, for Hamburg k is chosen to sum up to 70% of the skill potential by 1980, meaning that most of it had been achieved during the post-war boom, which is in accordance with the interpretation of a concave learning curve.[214]

- *Third*, concerning the approach to data adjustment, one could either express *recent decision counts* in corresponding *past skill factors* ($F_r(m) \leq 1$)[215] or *past counts* in *recent skill factors* ($F_p(m) \geq 1$).[216] However, it seems more likely that recent counts have a higher reliability/credibility than past ones. Further, a similar practice is applied in calculations of the *value of money* over time or *inflation*. Therefore, decision counts are adjusted to the most *recent* year 2013 (or year 64).

While preserving its original shape, a decision time-series is then simply tilted upwards in the past years while being fixed in its recent years as illustrated in Figure 5.7 and 5.8. The adjustment to learning curves is applied to all operators and decision categories, except of fare decisions.[217]

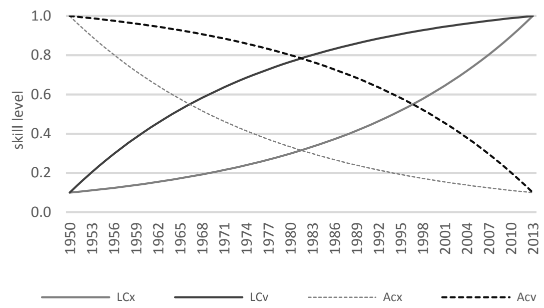


Figure 5.6: Learning curves: convex (LCx) and concave (LCv) and corresponding adjustment curves (AC).

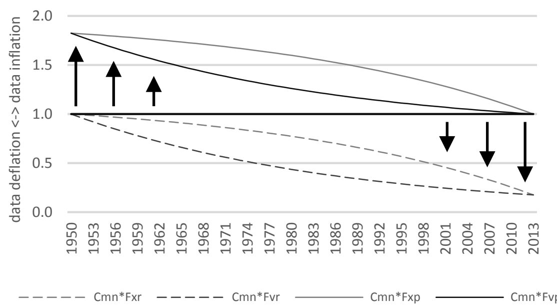


Figure 5.7: Data adjustment of *recent* (dotted) or *past* (solid) counts by factor $F(m)$. Example count of “1”.

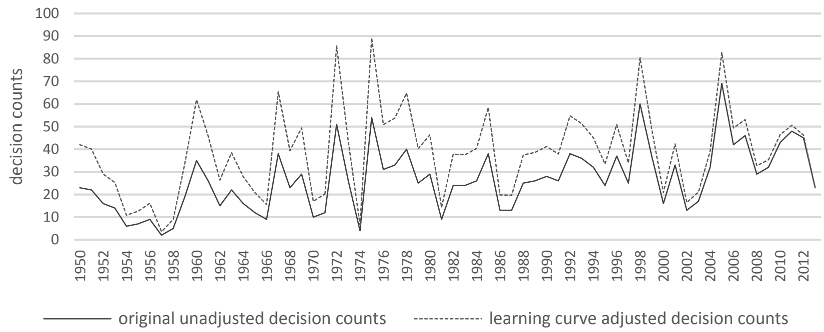


Figure 5.8: Overall effect of learning curve adjustment on the original count data. Upwards tilt for past counts. Example for STCP, annual decision count cumulated.

[214]k values for Hamburg, Porto, Dresden: 0.03015, 0.027650, 0.09855.
[215]Data deflation: adjusted recent values are smaller than originals.
[216]Data inflation: adjusted past values are higher than originals.
[217]Fare decisions predominantly captures monetary decisions (fare increases) which might have been taken anyway to correct for inflation. Thus a temporal double adjustment should be avoided by sparing them from LC adjustment.

DYNAMIC-RELATIVE APPROACH 2 - STANDARDIZATION: After the incorporation of temporal considerations, PROBLEM (3) - *category dominance* - needs to be solved to make the data more suitable for comparison and interpretation across operators and time. A standardization technique based on the transformation to ratios was proposed. The ratio $AL_{mn} = c_{mn}/c^*_{mn}$ is termed as *Activity Level (AL)* in year m in decision category n. The idea here is to use the inner structure of each individual category to establish a comparative balance among them and to remove the effects from "misleading" absolute values. The denominator c^*_{mn} is the *maximum decision count* in category n across all years m (see Table 5.11). Based on a time-series of absolute counts, c^*_{mn} precisely marks an operator´s all-time maximum ability to take decisions in a specific category. In production terms, this would be called input maximum.[218] The AL is then 1.0 or 100% in the specific year and all other years related to it. By expressing each annual decision count in a category *relative* to its maximum possible manifestation, all counts can be scaled to values between 0 and 1. The *Activity Level* notation comes with several advantages:

- The count-induced dominance across categories is eliminated at both, cumulative (column-sums) and at cross-sectional (row-sums) levels.
- The initial assumption of category uniformity was restored.
- The scores are highly accessible for interpretation and comparison, as for instance a score of 0.6 in the service category would suggest that management efforts towards service were about 60% in that year, compared to its maximum potential. This comparison also works between different categories, as AL scores are expressed in ratios as opposed to incomparable, absolute values. One could also suggest that *low activity* levels correspond to *minor importance/necessity* of a certain decision category for the management, and *vice versa*.
- All categories lie within the same numerical range, which increases their comparability immensely.
- The transformation is just a standardization measure. Decision curves and patterns over time do not change, nor does their interpretation: a high or low number of decisions corresponds to high or low score for AL.
- The transformation allows to draw preliminary and comparative conclusions about decision patterns over time, among individual categories, and across operators as indicated for instance by Krippendorff (2004), p. 194.
- The proposed data range corresponds to that of DEA.
- The approach leads to time-series data for managerial decisions, which is the main purpose of this chapter. This data can be used as key input for assessing the link between managerial decisions and performance as demonstrated in Chapter 7.

The resulting decision data time-series are analysed with both proposed approaches. Results are presented in the next section.

[218] As well other benchmarks would be reasonable, e.g. average or median figures. A low average activity level per year and category (e.g. AL<0.2) indicates that c^*_{mn} scores maybe outliers or that the decision data is dispersed with some extremely high activities and many low ones.

5.4 Results from Decision Analysis

This paragraph presents findings from the decision analysis of public transport operators in Hamburg, Porto and Dresden for up to 64 years between 1950 and 2013. The results have a rather descriptive character based on the approaches to decision analysis explained above. Relevant figures and visualizations were generated from the data to support qualitative findings. Key findings are numbered, e.g. **[25]**. Outcomes of the *static-cumulative approach* are summarized first, followed by those of the *dynamic-relative approach*.

R1: Static-Cumulative Approach

The decision analysis starts with an assessment of pure,[219] *cumulated absolute frequencies* of the decision categories and their corresponding *static relative importance*. Table 5.14, Figure 5.9 and 5.10 summarize results in different ways. As indicated, the static approach just produces a *decision category ranking* for each operator to compare *managerial foci* across operators.

Table 5.14: Overall static output of decision analysis in absolute and relative counts.

Decision category sub-category	**Hamburg**	**Porto**	**Dresden**	**Hamburg**	**Porto**	**Dresden**
	absolute counts			relative counts		
network	*611*	*681*	*764*	0.39	0.40	0.53
network management	542	614	731	0.89	0.90	0.96
network development	69	67	33	0.11	0.10	0.04
accessibility	39	26	22	0.57	0.39	0.67
(re)organization	9	19	7	0.13	0.28	0.21
other innovations	21	22	4	0.30	0.33	0.12
fleet	*71*	*33*	*47*	0.05	0.02	0.03
fleet upgrade	42	25	35	0.59	0.76	0.74
technology upgrade	29	8	12	0.41	0.24	0.26
personnel	*114*	*167*	*89*	0.07	0.10	0.06
incentives	43	60	25	0.38	0.36	0.28
training	16	25	18	0.14	0.15	0.20
other	55	82	46	0.48	0.49	0.52
schedule	*61*	*46*	*30*	0.04	0.03	0.02
frequency changes	44	25	16	0.72	0.54	0.53
other	17	21	14	0.28	0.46	0.47
fares	*60*	*70*	*23*	0.04	0.04	0.02
fare change	23	27	3	0.38	0.39	0.13
other	37	43	20	0.62	0.61	0.87
service	*340*	*243*	*196*	0.22	0.14	0.14
operations	106	52	50	0.31	0.21	0.26
customer	179	148	108	0.53	0.61	0.55
IT	55	43	38	0.16	0.18	0.19
management	*295*	*452*	*278*	0.19	0.27	0.19
optimization	157	226	186	0.53	0.50	0.67
development	76	51	49	0.26	0.11	0.18
R&D	62	175	43	0.21	0.39	0.15
total	*1552*	*1692*	*1427*			
years	64	64	57			
mean	24	26	25			

[219]In this approach, the data was **not** corrected for time or category dominance.

ABSOLUTE COUNTS ANALYSIS: Comparing decision categories across operators based on *absolute decision counts* might be limited for interpretational purposes. For the sake of clarity, however, the following findings could be derived, which are strictly bound to a methodological, output-oriented viewpoint: When cumulated, operators seem to be relatively homogenous in terms of total decisions taken (maximum 16% deviation from lowest to highest) as well as average decision per year (maximum deviation 8%). At individual category level, the deviation is very disperse in fares (67%), medium disperse in fleet (54%), schedule (51%), personnel (47%), service (42%), management (38%) and less disperse in network decisions (21%). With regard to the *"best performers"* per category, Hamburg had the overall highest count for fleet, schedule and service decisions, Porto for personnel, fares and management decisions and Dresden for network decisions. **[1]** For all operators, network, service and management categories yield significantly higher counts than fleet, personnel, schedule, and fare categories.[220] However, the interpretational shortcomings of the cumulative approach become obvious when one speculates about the meaning of a comparison of for instance 114 vs. 167 vs. 89 personnel decisions. Thus, it is recommended to use *relative counts.*

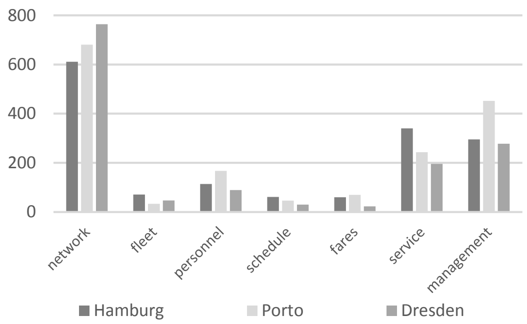


Figure 5.9: *Absolut* decision counts per category.

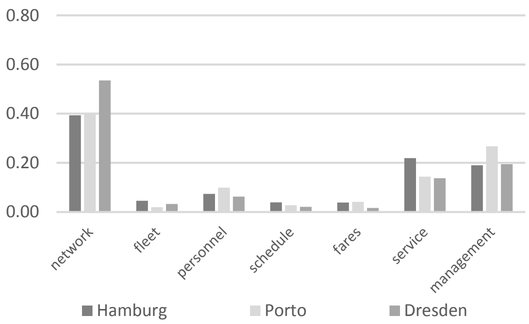


Figure 5.10: *Relative* importance of decision categories.

MANAGEMENT FOCUS (STATIC): The relative importance of a main category can be understood as a measure of *managerial focus*. Once the score is high, the category might be more important for the management than other categories: **[2]** Network decisions account for averagely 45% of all decision counts, followed by management (22%), service (17%). **[5]** The direct comparison of the most relevant decision categories shows that Hamburg is the most *service-oriented* operator Hamburg (+60% than other operators), Porto the most *management-* and *personnel-* oriented operator (+40%, +60%) and Dresden the most *network-oriented* operator (+36%). **[6]** Hamburg balances service and management decisions, whereas in Porto and Dresden *service* decisions play a much smaller role than *management* decision in general. **[7]** As for the remaining categories, there are no major differences in the relative importance for each operator. They

[220]This claim is supported by Figure 5.12 showing high correlation between the operators in absolute counts.

yield consistently lower values than the dominant ones (<10% of relative importance). **[8]** Interestingly, several, almost identical value pairs among the operators could be discovered, such as Porto and Hamburg in *network* decisions, Hamburg and Dresden in *management* and *personnel* decisions, as well as Porto and Dresden in *service decisions.*

category	Ham	Por	Dre
network	1	1	1
management	3	2	2
service	2	3	3
personnel	4	4	4
fleet	5	7	5
schedule	6	6	6
fares	7	5	7

Correlation p-value	DRESDEN	HAMBURG	PORTO
DRESDEN	1.0000 -----		
HAMBURG	0.9642 0.0005	1.0000 -----	
PORTO	0.8571 0.0137	0.8214 0.0234	1.0000 -----

Figure 5.11: Rank and rank correlation.

Correlation p-value	DRESDEN	HAMBURG	PORTO
DRESDEN	1.0000 -----		
HAMBURG	0.9606 0.0006	1.0000 -----	
PORTO	0.9542 0.0008	0.9453 0.0013	1.000 -----

Figure 5.12: Ordinary correlation.

The *main category ranking* sorts the relative importance of categories per operator as illustrated in Figure 511. These ranking can be compared across operators with the Spearman rank correlation: **[9]** The first, fourth and sixth rank (network, personnel, schedule) is fixed for all operators. **[10]** Hamburg and Dresden account for almost identical rankings except for the second and third rank, where management and service are swapped. **[11]** Porto shows more ranking similarities with Dresden than with Hamburg. Porto’s and Dresden´s ranks are identical in the first four spots. In summary, the ranking for the four most important categories shows only slight difference for the *service* category, which is ranked higher in Hamburg than in Porto and Dresden. As being similar to those from above these findings are particularly interesting when one considers the role of the individual car use in these cities. Public transport in Hamburg was continuously challenged by increasing car-ownership, which posed a competitive threat due to the prospering economy. Thus, the managerial focus in public transport needed to be rather service-oriented to not lose customers. In Porto and especially in Dresden however, due to the political framework cars were unaffordable for a long time and car ownership lagged behind. Thus, public transport was mostly the only means of mobility. From managerial perspective, customer and service-orientation could be ignored to certain degrees (seller´s market). Managerial attention then was shifted to infrastructural and network needs in order to fulfil the public obligation to provide transport - at any costs - for as many people as possible due to the lack of mobility alternatives in that time (effectiveness > efficiency).

Next, the role of *sub-categories* (as defined in Tables 5.3-5.10) is explored with regard to similarities and differences amongst the operators. In general, the introduction of sub-categories further refines managerial action to smaller groups, which then jointly form a main category. This generates additional information on the decision-making of the operators. Figure 5.13 below illustrates the relative importance of decision sub-categories in the corresponding main-category as named in the captions. *First*, *considerable similarities* between the operators could be observed. Among network decisions,[221] **[12]** network management obviously dominates all other network-related decisions. This confirms that regular adjustment of lines are a common pattern and sort of "daily business" for all operators. **[13]** A closer look into the three sub-categories of network development further reveals that accessibility measures are more frequently applied to the network than any other measures in this group. **[14]** Further, fleet upgrades appear to occur more often than individual technology upgrades, and **[15]** personnel incentivation seems easier/cheaper/more effective/more sustainable than training measures. With regard to schedule decisions, **[16]** frequency changes are the most commonly applied homogeneous sub-group in these decision categories, for all operators. **[17]** For all operators, fare decision seems to be dominated rather by fares innovation than by fare changes. **[18]** With reference to the sub-categories of service decision, the ranking is consistently one of customer-focus>operation-focus>IT-focus, clearly pointing at the importance of demand inducing service measures directly targeting (potential) users. **[19]** When it comes to management decisions, business optimization is the dominating sub-category, which suggests that streamlining and optimization measures are broadly considered important for the operator management. **[20]** Another similarity relates to the sub-categories labelled with "other", that could be considered as "measures of innovativeness" or "plurality of decision choices" in the associated category. In so far, the toolbox for personnel (and fare management) seems to offer comparatively more options than network management. This claim might be valid due to the limited flexibility rooted in the network nature. Concerning the few *differences* encountered, for instance the results for two sub-categories in the management category diverge. **[21]** Porto's

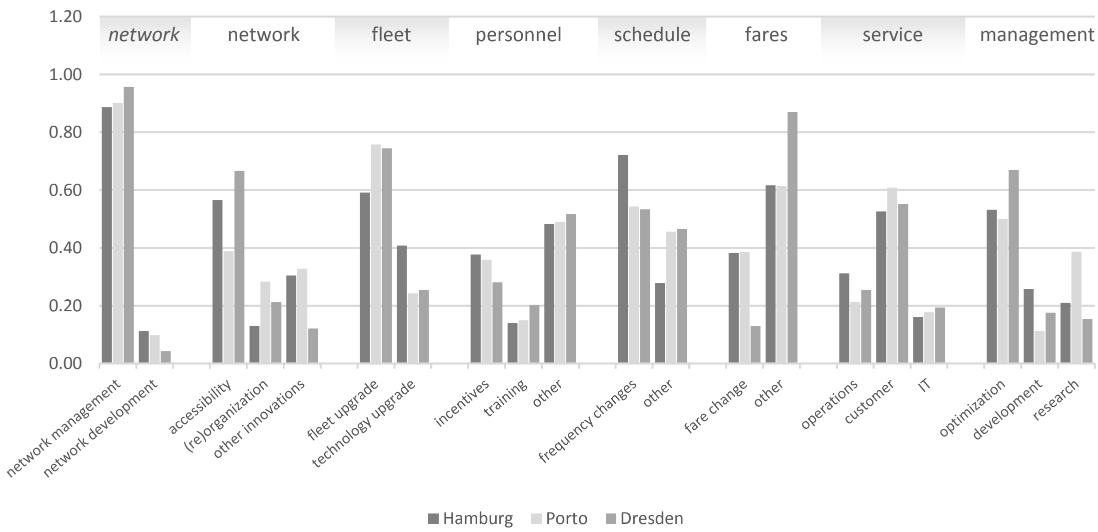


Figure 5.13: Relative importance of decision sub-categories in corresponding main-category.

[221]This main category is split in two sub-categories *network management* and *network development*, the former of which sums up short-termed regular line adjustments and the latter long-termed measures.

focus appears more on R&D than on business development, meaning that comparatively few decisions have been taken to explore new sources of revenues or businesses for the operator, in comparison to Hamburg and Dresden. Further, as to outliers, **[22]** Dresden apparently prefers to experiment with fare models and innovations rather than with fare changes, and ranks business optimization higher than business development (keywords*: fixed prices, controlled economy and resource scarcity*). Also, **[23]** Hamburg quiet often adjusted its operation parameters in terms of frequencies, compared to other available measures in that decision field.

SUMMARY: Figure 5.9 to 5.13 show the operationalized decision counts for Hamburg, Porto and Dresden at different category levels. Despite the discussed issues of the cumulative approach, it still yields two interesting results: *First*, outcomes are correlated between the operators, both in absolute counts and relative importance but also in ranking. The results seem to point at the existence of systematics in decision-making of public transport management, at least within the operator set assessed. In particular, the resemblances in the relative importance of pivotal decisions for service provision, such as network, service, management, personnel, should be stressed. *Second*, indications for the existence of different *managerial foci* could be found, especially concerning service orientation. This is supposedly an issue of locally varying effects from car ownership as a consequence of the prevalent political system.

R2: Dynamic-Relative approach

In this approach, the basic count data in the sub- and main categories is processed as proposed above. *First*, the entire data is first learning curve adjusted (PROBLEM 2). *Second,* sub-categories n were standardized and merged to main-categories N via summation. The resulting row-sums were again standardized to obtain AL_{mN} (PROBLEM 3). The *dynamic-relative approach* aims at comparing activity levels AL_{mN} of main decision categories over time to draw conclusions about their importance for the operator management. The comparison is based on two elements:

(1) *Qualitative and visual assessment* and description of peculiarities in course and form of time-series, inspired by chart analysis terminology.[222]

(2) *Descriptive measures* to compare average activity levels, volatility and variations, as well as similarity (Table 5.15 below).

In particularly the degree of *similarity* between the time-series was of key interest as resemblances in managerial decision-making could be identified. According to Ralanamahatana

[222]The following terms chart analysis terms are important: (1) *Trend:* movement of time-series in a certain direction. (1b) *Triangle:* ascending or descending formation that occur throughout a trend. (2) *Level-shift*: significant changes in the mean level of the time-series. (3) *Neckline or plateau*: support level or resistance line that is not crossed. (4) *Peaks or head-shoulder* pattern: increase to a peak and decline then increase above the former peak and declines and again increase to another peak and decline; (see Market Technicians Association (2015), Gilliland et al. (2016)).

Type	Formula	Interpretation
Mean	$\mu_n = \sum AL_{nm} / m$	average activity level
Coeff. of Var.	$C_{Vn} = \sigma / \mu$	standardize volatility (standard deviation)
FD	$FD = \frac{\lvert AL_{nm} - AL_{nm-1} \rvert}{\sum AL_n}$	standardized annual variation
Euclid. Dis.	$ED = \sum_{0}^{m} (t_{1m} - t_{2m})^2$	similarity of time-series t_1, t_2 of equal length m

Table 5.15: Descriptive measures for time-series comparison, sort by complexity.

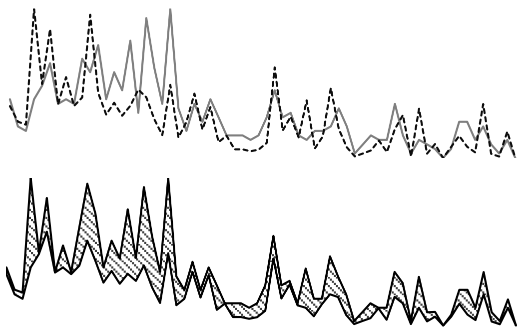


Figure 5.14: The intuition of the Euclidean distance. Upper curves: t_1, t_2. Lower curves: Distance $t_1 - t_2$.

et al. (2005) a widely used measure in this regard is the Euclidian Distance (ED) whose logic is displayed in Figure 5.14[223]. Further, the data is smoothed by a weighted-moving-average[224] to reduce the spikiness in curves and to facilitate meaningful visual comparison. *First*, the decision analysis starts with an extensive comparison of individual main-categories over time using elements (1) and (2)[225]. *Second*, the gathered information is operationalised to explore the manifestation of different *management characteristics* in public transport. *Third,* the evolution of the *dynamic managerial focus* is assessed via area charts. *Fourth,* so-called super-categories are introduced to gain insights from higher levels of decision aggregation.

MAIN-CATEGORY COMPARISON: Descriptive statistics for all categories are summarized in Figures 5.15 and 5.16. The data standardization significantly reduces the skewed ranking and the dominance of the network category. The average annual activity levels suggest that service, management, personnel and network decisions appear to be the most important categories. Further, the overall volatility seems to be similar across operators, except of the fact that less active decision categories are subject to higher volatility as indicated by a larger coefficient of variation. The subsequent figures illustrate the smoothed Activity Levels for each main-category from Hamburg, Porto and Dresden and their similarity[226] in overall view and per decade.

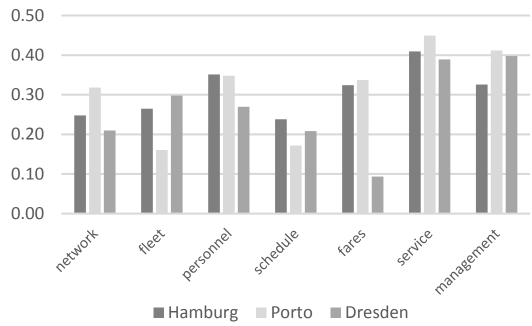


Figure 5.15: Average annual Activity Levels.

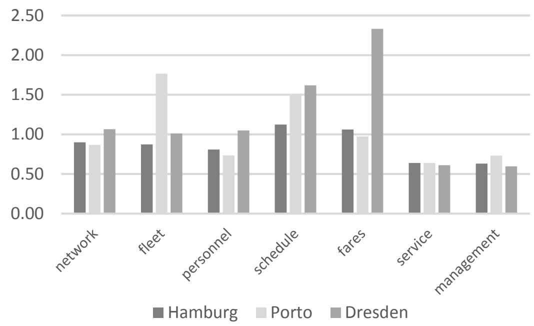


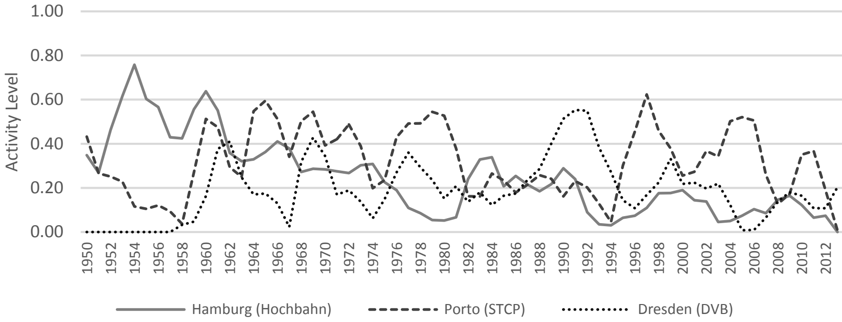
Figure 5.16: Standardized volatility per category.

223 There exist many more in-depth methods to compare time-series, such as Dynamic Time Warping (DTW) or Longest Common Subsequence Similarity (LCCS), which however could not be addressed here but might be in future research.

224 $c^{a}_{mn} = \sum_{m-1}^{m+1} w_m c_{mn} / \sum_{m-1}^{m+1} w_m$, centered around c_{mn} and window size 3.

225 Except for ED, the measures refer to unsmoothed data. As being average-based, this has no effect on the results.

226 Similarity $S = 1/(1 + ED)$ to return distance you values within 0 and 1. The higher S, the more similar.



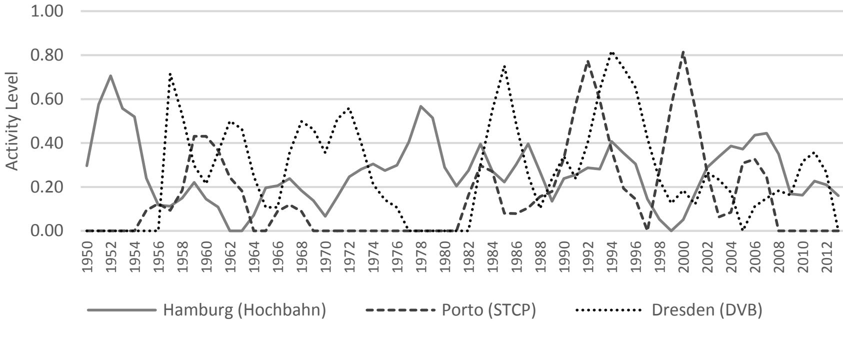
years	HH OPO	OPO DD	DD HH
overall	0.36	0.36	0.40
61-70	0.66	0.53	0.57
71-80	0.54	0.61	0.66
81-90	**0.62**	**0.68**	**0.71**
91-00	0.56	0.52	0.57
01-10	0.53	0.54	**0.80**

Similarity scores

Figure 5.17: Network decisions - Activity Levels. **Table 5.16:** Similarity NET

NETWORK**:** As to the *visual analysis*, Hamburg clearly shows no major level shifts, an overall decreasing trend with high activity scores in the beginning and lower values in the end of the interval. This suggests that the importance of network decision diminishes over time. From 1958 on, Porto shows two major activity plateaus,[227] the first one decreasing until 1982 and the second one starting in 1994, peaking in 1997 and declining until recently. The former of which had a remarkable phase after the Portuguese revolution; the latter shows reinforced network activities supposedly linked to the opening of Metro do Porto in the early 00s. Dresden in turn was rather constant in network activities, with a dominating head-shoulder formation around 1990 due to the impact of political changes. Interestingly, decision making in Dresden appears to be very cyclical and trended from 1960-1980, probably due to the socialist five-year plans. As to the *similarity scores* of Table 5.16 it can be concluded that the *overall* similarity between the decision time-series is weak compared to the decade perspective. Stronger similarity could be found during the 80s for all operators and individually between Dresden and Hamburg from 2001-2010, which might be caused by the "same" German regulatory environment (Beck, 2012).

FLEET: As to the *visual analysis*, in Hamburg fleet-related decisions occurred majorly from the mid-70s to the mid-90 and during the 00s, without any significant trend in the category importance over time. In addition, the long neckline and the few, but systematic peaks suggest a relative stability in fleet decision-making (or the lack of managerial flexibility to respond



years	HH OPO	OPO DD	DD HH
overall	0.33	0.30	0.32
61-70	0.63	0.54	0.53
71-80	0.48	0.51	0.48
81-90	**0.64**	0.54	0.55
91-00	0.51	0.46	0.54
01-10	0.49	0.52	**0.60**

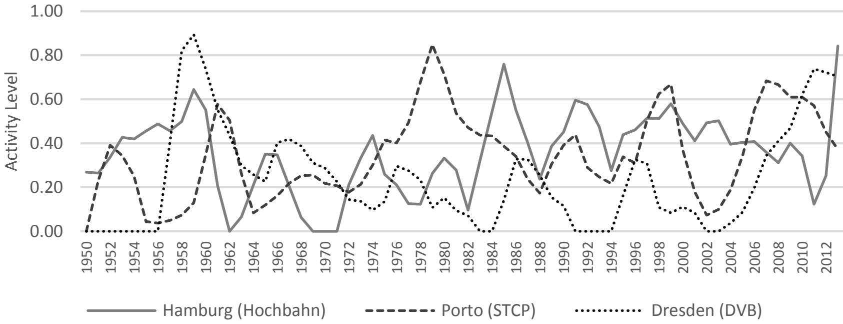
Similarity scores

Figure 5.18: Fleet decisions - Activity Levels. **Table 5.17:** Similarity FLE

[227]Plateau: no valley, peak around a comparatively high average.

situationally) and a constant managerial focus on the resource fleet. In contrast, Porto shows two distinct intervals of action with level-shifts and peak structures from the 50s and 60s and the 80s until 2008 (probably catching-up). A similar pattern - however less cyclical - can be observed in Dresden, with several high activity periods in the 50s and 60s and 80s and 90s. As illustrated, there are several years without any fleet decision activity in Porto and Dresden. This seems to indicate that the management *had to* take fleet decisions rather bundled and rather in responsive than proactive manner. This *ad-hoc* change from *do-nothing* to *do-anything* in relatively short time in fact requires high levels of managerial flexibility. One could also argue that the flexibility is the consequence for simply acting too late, but again, the delay can also be caused by political powers intervening in fleet planning or impeding access to technology or fleet upgrades or probably simply due to financing issues. Consequently, as Table 5.17 demonstrates, fleet decision-making patterns are overall not very similar across the operator pairs. However, the 80s in general (and in particular for Porto and Hamburg), as well as the 00s for Dresden and Hamburg suggest minor resemblances in decision-making.

PERSONNEL: As to the *visual analysis*, the operators seem to have similar patterns in staff decision-making, in that the curves have an early dominant stage (end 50s) followed by reduced activity (60s). While Hamburg and Porto then increased their AL again, Dresden kept it at low levels. Hamburg gradually climbed upwards showing a few peaks and cycles, but kept a high neckline/plateau until the mid-00. This clearly suggest that the resource staff was a constant managerial tool to make adjustments. In contrast Porto acted non-cyclical and applied major staff decision directly in the years after the revolution suggested by a clear head-shoulder pattern centred around the end of the 70s (head, enforced introduction of the single-man operation), which then decline to a minor plateau before peaking again in the end 90s (shoulder, effect competition of Metro do Porto). After a near halt in staff decisions around the year 2000, since the mid-00s the resource is again considered a crucial decision factor in Porto, as shown by the high neckline of that decision category. As to Dresden, after the peak in the 50s, staff decisions were considerably cyclical - however - at very low levels during the following decades



years	HH OPO	OPO DD	DD HH
overall	0.32	0.30	0.30
61-70	0.55	**0.64**	0.55
71-80	0.50	0.51	**0.62**
81-90	0.56	0.48	0.51
91-00	**0.68**	0.48	0.44
01-10	0.54	**0.58**	0.50

Similarity scores

Figure 5.19: Personnel decisions - Activity Levels. **Table 5.18:** Similarity PER

until the mid-00s, when, similar to Porto, the importance of staff management strongly increased again. This might be partially explained by the policy of full employment in the former GDR, which made most performance-oriented staff schemes largely redundant. However, when after 1990 staff was immediately reduced also qualitative staff decisions were stagnating. The recently enforced staff activities of all operators might be a sign of increased competiveness attempts resulting from EU Regulation (EC) n°1370/2007. The *similarity* of curves indicated by Table 5.18 seems to be very weak overall, with the highest one for Hamburg-Porto in the 90s, Porto-Dresden in the sixties and most recently, as well as Hamburg-Dresden in the 70s.

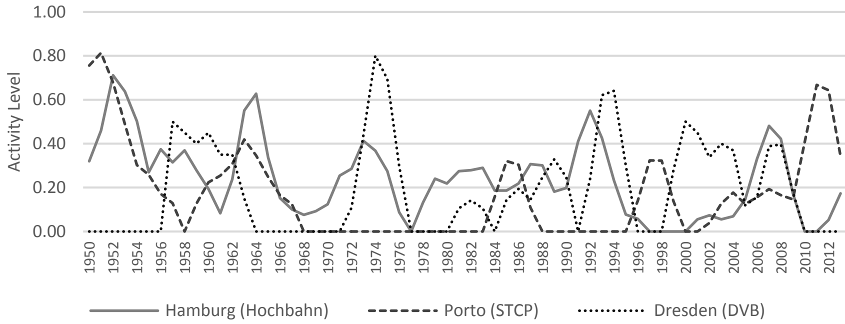


Figure 5.20: Schedule decisions - Activity Levels.

years	HH OPO	OPO DD	DD HH
overall	0.34	0.30	0.36
61-70	**0.72**	**0.63**	**0.52**
71-80	0.56	0.46	0.56
81-90	**0.59**	**0.65**	**0.68**
91-00	0.50	0.47	0.56
01-10	**0.69**	0.54	0.54

Similarity scores

Table 5.19: Similarity SCH

SCHEDULE: As to the *visual analysis*, Hamburg and Porto shows both a slight decrease in importance of schedule measures over time (contrary to Dresden). Hamburg’s curve has significant peak patterns with minor cycles from 1950 to 1998, followed by another strong increase in the most recent decade. Various necklines are visible, suggesting that the schedule was adjusted quiet frequently. Porto has a sort of u-shaped curve with two major peaks (one of which is in the last decade) and several intermediate small peaks. This suggest, that when schedule measures were applied at all than rather erratically, at least until 2000. After 2000, schedule activities increased until 2011. Dresden is in a middle-position, less disperse than Porto but also less coherent than Hamburg. In fact, the figure shows one plateau-like structure with a head-shoulder formation from the 80s until the 00s, indicating a frequent and increasing application of schedule measure, especially after the re-unification when the entire service provision as gradually remodelled and most recently. The *similarity* Table 5.19 indicates that overall similarity of the curves is very weak. An approximation can be observed in the 60s, 80s and 00s, in particular between Hamburg and Porto. However, it appears that schedule decision are taken rather infrequently and with different magnitude. Thus, they might only be of temporary managerial importance, e.g. for fine-tuning or complex remodelling of operations.

FARE: As to the *visual analysis*, overall, Hamburg displays a decreasing trend/importance in fare-related decisions. Despite being mostly balanced and cyclical in other categories, the curve yields

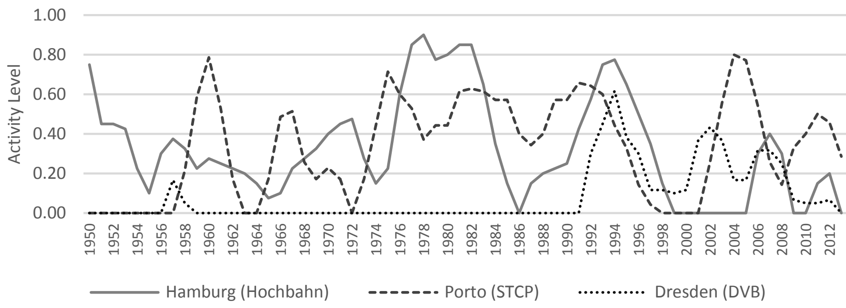


Figure 5.21: Fare decisions - Activity Levels.

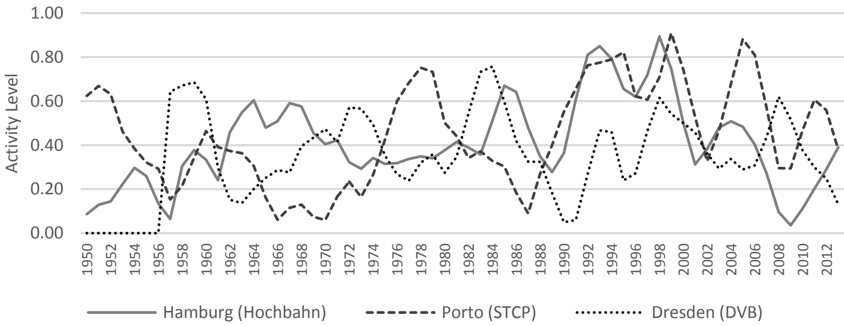
years	HH OPO	OPO DD	DD HH
overall	0.29	0.25	0.26
61-70	**0.55**	0.45	**0.59**
71-80	0.48	0.43	0.36
81-90	0.53	0.38	0.38
91-00	**0.56**	**0.50**	**0.56**
01-10	0.43	0.49	**0.58**

Similarity scores

Table 5.20: Similarity FAR

a strong head-shoulder structure with multiple level-shifts and no cyclical patterns. The activity level changed significantly in the mid-60s and peaked during around 1980 and the mid-90s. In recent years, the category is of minor importance for the management. Similarly, Porto shows a plateau with a continuously high activity shortly after the revolution and for the subsequent 20 years, marking fare measures as important management tool. Fares appeared to be then untouched in the late 90s only to be dealt with again in the beginning of the 00s, with the introduction of the intermodal fare system “Andante” the Metro do Porto. With regards to the presence of cycles, Porto´s curve seems to indicate a gap of up to 10 years duration between several peaks bin the 60s until 90s which suggests a planned and supervised fare setting in that time. However, there are also intervals with no action taken for both operators, which outlines the fact that fare adjustments and general changes might not be applicable annually. Dresden illustrates a distinctively different pattern for this type of decisions, since any managerial action only happens to occur after 1990. Fare policy was simply irrelevant before and prices rather a “symbolic act” mostly decoupled from the real system costs as usually in controlled economies, most likely also because public transport was the only means of mobility. Finally, the highest *similarity* between the curves is found during the 90s and in the 00s between Hamburg and Dresden (Table 5.20). In summary, it seems that once a fare system has reached a certain maturity and sophistication, it becomes less suitable for changes and thus plays a minor role for the management (adjustments only to keep up with rising costs inflation).

SERVICE: In contrast to Hamburg’s network decisions, service activities increase over time with a high neckline and a clear head-should pattern from the mid-80s to until the mid-00s. This considerable change suggests that the importance of service decision increased over time up to a point of saturation (probably due to capacity limits). Only after 2008, the operator had to reinforce its service activities (probably due to capacity shortfalls). In terms of trends, the overall pattern for Porto appears to be similar to Hamburg until the year 2000. However, Porto presents more cycles in its upward movement. A first landmark level shift happened after 1974 with a



years	HH OPO	OPO DD	DD HH
overall	0.35	0.29	0.33
61-70	0.49	0.60	0.54
71-80	0.54	0.48	0.70
81-90	**0.57**	**0.55**	**0.64**
91-00	**0.72**	0.44	0.46
01-10	0.55	0.50	0.55

Similarity scores

Figure 5.22: Service decisions - Activity Levels.

Table 5.21: Similarity SER

strong increase in service activities peaking at the late 70s and subsequently declining until 1987 hitting to pre-revolution levels (almost identical in form and duration with the peak/decline in personnel). Another strong activity plateau is observed from the late 80s until most recently, however with large fluctuations. As for Dresden, it can be concluded that the highest service activities were registered during the 50s and mid-80s, both followed by strong declines. After 1990, service activities increased accordingly and peak again at the late 90s (head) and late 00s (shoulder). However, Dresden´s approach to service decisions seems rather constant and exhibits various long neckline. Similarity between service decision-making seems to be strong in the 80s and the 00s. Especially in the 90s, Hamburg´s and Porto´s curves are very similar (0.72). In summary, it seems as if the late 80s marked a general starting point of enhanced service orientation in public transport, demonstrated by increasing importance of service related decisions, at least until the mid-00. Interestingly, when the global financial crises of 2007-08 and 2011 took effect, Hamburg´s and Porto´s hitherto declining activities mark a turning point. This could be interpreted as an adjustment of the offer to a higher unemployment rate that might have forced people to shift to cheaper means of transport. In contrast, Dresden´s service activities dropped immediately after 2008 and even more severely in 2011, similar to Porto.

MANAGEMENT: As to the *visual analysis*, at first glance all curves display an ascending trend over time with several considerable upwards level shifts, and comparatively high neckline. This suggests an increased and continuous importance of decisions in this category (Hamburg mid-70s, Porto mid-70s and massively end-80s, Dresden early 70s and early 90s). Hamburg´s shape is more cyclical (8-10 years) and with a much flatter neckline than Porto. Porto appears to have changed its management policy drastically by end of the 80s and kept a much higher level (than others) almost consistently until 2011. Dresden in turn seemed more active in the 70s-80s than in subsequent years, which suggests that in particular the resource shortages in socialism might have trigged several streamlining measures, which are a main sub-category in this decision group (not in order to be profitable, but rather to be capable to provide service at all). Again,

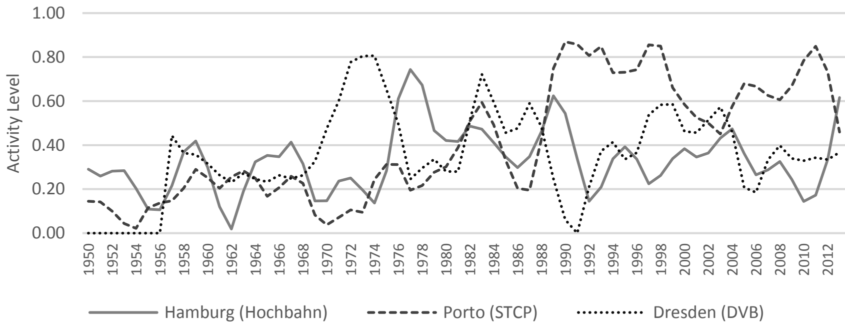


Figure 5.23: Management decisions - Activity Levels.

years	HH OPO	OPO DD	DD HH
overall	0.30	0.28	0.35
61-70	**0.71**	**0.78**	**0.71**
71-80	0.54	0.42	0.42
81-90	**0.77**	**0.58**	**0.62**
91-00	0.39	0.39	0.55
01-10	0.54	0.54	**0.75**

Similarity scores

Table 5.22 Similarity MAN

the financial crisis 2011 is a turning point for the operators, however with different directions. Hamburg increases, Porto decreases and Dresden keeps it activity level. The similarity scores indicate high resemblances in decision-making during the 60s and medium ones in the 80s across the operators. Pair-wise comparison further suggest a strong similarity between Hamburg and Dresden in the 00s. In summary, the curves seem to indicate increasing managerial efforts to optimize and streamline the process of service provision overtime. This might be directly linkable to regulatory changes, imposed competitive threats, changes in ownership, subsidy cuts or the positive trend of public transport as affordable, efficient means of transport in general.

MANAGEMENT CHARACTERISTICS: The previous explanations were rather qualitative and descriptive and thus hard to comprehend. Thus, the relevant information gained from the visual analyse of curves and from the corresponding measures of Table 5.15, is used to tentatively derive certain *management characteristics* for each operator, say *operator style*. In a line with the management focus of this work, nine measures and criteria related to chart analysis is given the interpretations displayed in Table 5.23. For instance, when a category displays strong long-term (strategic) and strong recent trends (tactical), in either direction, the management seems

Table 5.23: From time-series measures and criteria to Management Characteristics.

Measure/Criteria used	Assessment	Interpretation with regard to Activity Level	If…	…then…
mean	empirical	average AL	high	*'active'*
CoV	empirical	volatility of AL over time	low	*'positioned'*
FD sum	empirical	totalized annual variation over time	low	*'balanced'*
overall trend	empirical	long-term importance of category	strong	*'strategic'*
recent trend	visual	recent importance of category	strong	*'tactical'*
level-shift	visual	significant changes in category importance	no	*'resilient'*
necklines or plateaus	visual	AL safety net, lower bound	multiple	*'cautious'*
peaks or head-shoulders	counting	capability of increasing AC situationally	multiple	*'flexible'*
cycles	counting	repetitive AL schemes per category	long	*'systematic'*

to have a 'strategic' and 'tactical' vision of how to apply to decisions. Alternatively, the presence of cyclical patterns in a curve might indicate a rather 'systematic' management undertaking "seasonal" adjustments. Further, strong and sudden level-shifts might suggest a less 'resilient' management vulnerable to shocks. In contrast, flat curves might suggest a lack of 'flexibility' (or very good planning), and so forth. These measures and criteria were then coded with a 0 to 2 scale for each operator and category separately. They finally constitute *nine* managerial characteristics or attributes, which differ in their manifestations[228]: '*active', 'positioned', 'balanced', 'strategic', 'tactical', 'resilient', 'cautious',' flexible, systematic'.* The coding scheme and results can be found in Appendix 7. Table 5.24 outlines the final scores for each operator over all categories with a maximum possible score of 126 (9x7x2).

Characteristic	**Hamburg**	**Porto**	**Dresden**
"active"	7	9	7
"positioned"	8	9	8
"balanced"	7	8	9
"strategic"	9	11	7
"tactical"	8	**11**	**12**
"resilient"	7	4	5
"cautious"	**12**	8	9
"flexible"	**12**	**11**	9
"systematic"	7	6	6

Table 5.24: Final scores. Max = 14.

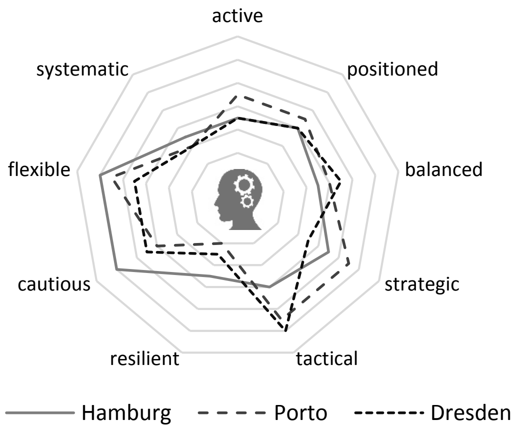


Figure 5.24: Management characterisitcs.

The so-called radar chart of Figure 5.24 displays the multivariate data and interrelations. Overall, the operators score are almost identically (77,77,76). Based on the two highest (and lowest) scores, the following conclusion upon management characteristics can be concluded: **[1]** Hamburg´s management is specifically more *cautious* and *flexible* but *less active* and *less systematic*. Porto´s management is *tactical* and *flexible* but much *less resilient* and *less systematic*. Dresden`s management is rather *tactical* but also *less resilient and less systematic.* **[2]** Obviously, none of the operators is specifically systematic, in that its activity peaks might recur at a certain frequency. Thus, from a general viewpoint it seems that decision-making in public transport might not generally follow repetitive patterns of *increase, decline, depression, improvement,* but rather be determined short- and middle-termed or situationally.

MANAGMENT FOCUS (DYNAMIC 1): Until now, categories were assessed individually to draw conclusion about their evolution over time. Any relation *across categories* had to be assumed irrelevant and was eliminated by standardization of the categories to their maximum score (see PROBLEM 3). However, when returning to the *row-sum* logic proposed in Table 5.11, one may intend to make inferences about *relative importance of categories over time.* Figure 5.25 shows

[228]Adapted from Daraio et al. (2016), Diana and Daraio (2014), Ceder (2007); van Egmond et al. (2003), Zatti (2012).

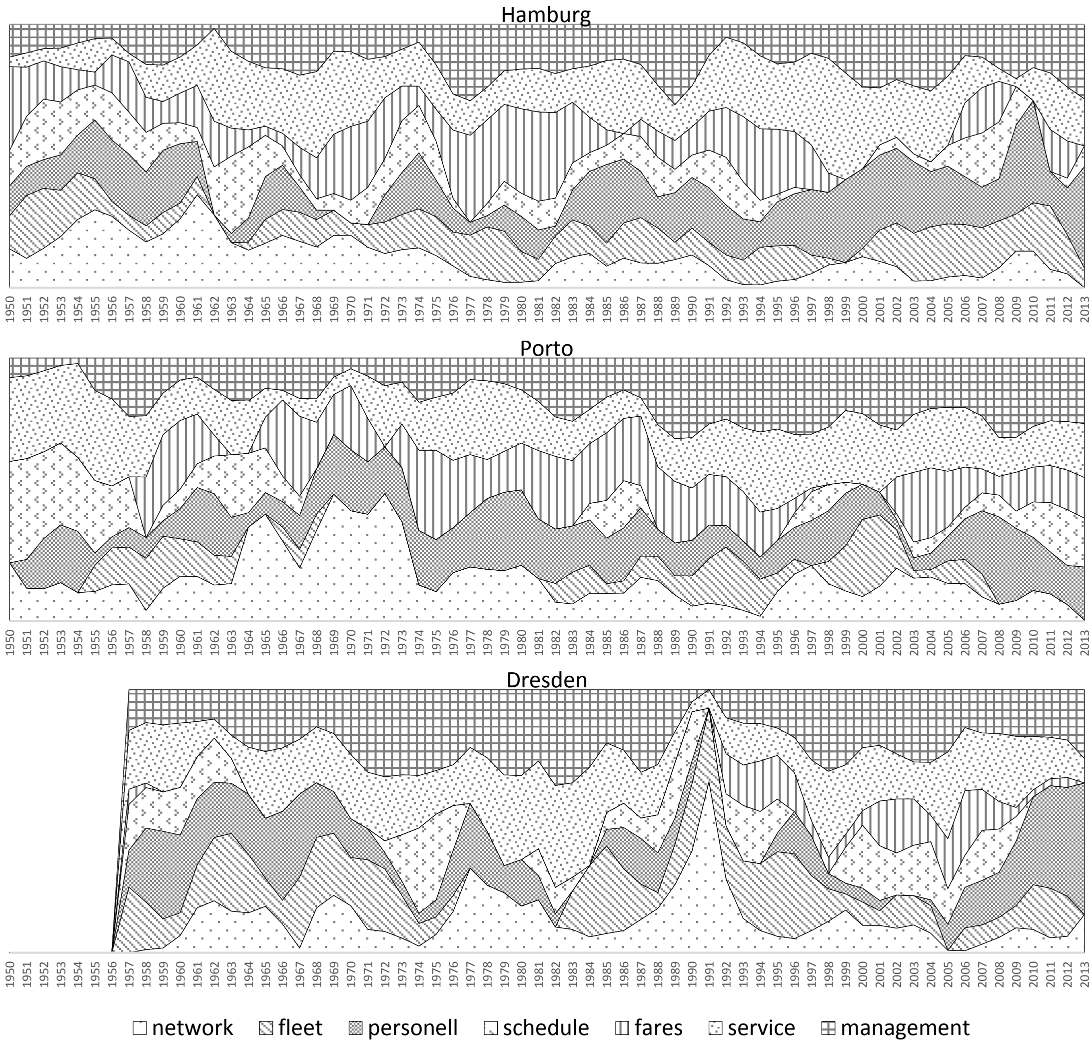


Figure 5.25: Relative importance of categories over time.

"100%-stacked area" charts that allow for assessing the trend of the relative contribution of each category to a totalized annual activity level over time. The wider a certain 'decision strand' the higher the relative share and thus the relative managerial importance/focus of a category. This representation gives additional information about the internal structures of decision-making.[229] As a by-product, operators would not be "penalized" for displaying comparatively low activity levels. In addition, this chart technique can demonstrate that even when activity in a category increases over time, its relative importance might be constant or even declining[230]. In summary, the standardization technique is built upon the following assumptions:

- With the measures at their disposal, managers do the best possible each year. *["Do the best you can until you know better. Then when you know better, do better."]*
- Managerial decision-making is somewhat "budgeted" per year (e.g. by financial means, commitment, available knowledge, etc.). Thus, it would have to be decided on which

[229]The visual tool essentially relates all AL_{mn} in a *row* to its corresponding *row sum*. Shares add up to 1 per year.
[230]Weaker decisions categories might gain higher importance simply due to the lack of activity in other categories.

> categories to set focus in particular, at the expenses of other categories. *["You can't to everything at once."]*.

As a result, the difference of activity levels over time is becomes relevant, but rather the relative importance of a category against other ones, observable in patterns/strands. Then a fixed pattern would suggest that managerial focus is distributed equally or in fixed proportions across the categories in a time-invariant manner. Also, decision categories might be correlated.[231]

With regard to the dynamic managerial focus expressed by the relative importance of a respective main category over time, the following key take-aways can be drawn: **[1]** From Figure 5.25 it can be concluded that managerial foci change over time for each operator differently. There is no common pattern. Overall, Porto appears to be show mostly fixed patterns especially since 1974 and 2005, similar to Dresden until the mid-70. Hamburg´s patterns, however, show such regularity only in the 50s. **[2]** This might confirm that Hamburg is the most flexible operator in the set, as a decision category becomes important, when required. **[3]** The overall ranking (service, management and personnel) remains relatively constant over time, which is in a line with the propositions of Figure 5.15. **[4]** Network decisions lose in relative importance in Hamburg during the entire period, and in Porto after 1974. In Dresden, they peak after reunification, probably caused by low activity levels in other categories and the intense reorganisation of the network. **[5]** Fleet decisions played a dominant role during the mid-70s until mid-90 in Hamburg and even more in Porto, with decreasing overall tendency until recently. However, in Dresden fleet decisions became only relevant after 1990. **[6]** The relative importance of personnel decisions was rather high for Hamburg and Porto and strongly increased for all operators over time, in particular since the early 2000s. When applied, the focus on personnel activity seems to suppress other activities, especially after 2000 and for all operators. **[7]** Schedule decisions are consistently important but at low levels for Hamburg, and only most recently also at low levels for Porto and Dresden. **[8]** Fare measures lose in relative importance in Hamburg overall and Dresden (only after 1990), but seem to be a highly relevant tool for Porto, especially in the 70s and 80s and most recently. **[9]** Service-related measures are highly relevant role for all operators, with increasing trend over time. Interestingly, Dresden was relatively more service-oriented before reunification than after, which contradicts some of the previous conclusions based on absolute numbers. **[10]** Management decisions are constantly high for all operators, especially for Porto (recently) and Dresden (past). This stresses the continuous overall importance of strategic management and administration. **[11]** When management decisions are a constant, it also appears that network (↓) and service decisions (↑)

[231]When complementary measures are applied, e.g. increased punctuality (service) *and* driver training (personnel).

as well as personnel (↑) and fleet decisions (↓) are partially antagonists over time in relative importance, whereas the other categories are used more situationally and contextual. However, it should be noted that the analysis is conducted visually, which leads to complications in pattern detection when seven main-categories are considered. One might achieve better results when a higher level of aggregation is considered, e.g. through super-categories.

SUPER-CATEGORY COMPARISON: Figure 5.16 above shows large outliers for fares and fleet in terms of the variation coefficient, which might be problematic when these variables were used in further analysis. In addition, these time-series have several years without any activity (=zero) and show generally low or erratic activity levels, which would even impede some sort of data inclusion. Also, several of the time-series are heavily trending, level-shifted and thus non-stationary per definition[232]. In order to create more stable decision time-series, so-called super-categories[233] were introduced. These are essentially mergers of main-categories with thematical proximity and/or to include weaker categories to those with substantively sufficient "mass". As a by-product, this allows for visual and empirical data assessment at higher aggregation levels, which eventually reduces model complexity in terms of number of variables and helps to better identify the managerial foci. Table 5.25 gives the super-categories proposed, originating from totalized AL_{mn} values from main-decision categories (see Table 5.11). Figures 5.26/5.27 show descriptive data. Figures 5.28 to 5.30 plot the smoothed time series for four super-categories. The *management* category is absent as it continues to be treated as a separated category.

Table 5.25: Super-categories, interpretations and aggregation level.

Interpretation	super-category *"SUM"*	main-category *"CATEGORY"*	super-categories *"CLUSTER"*	Interpretation
overall, unclassified, decision activity, managerial activeness, busyness	SUM	network	RESOURCES	all decisions that refer to key *inputs* required for service production
		fleet		
		personnel		
		schedule	SERVICE	all decisions that relate to intermediate or final *outputs* of service production or to customers
		fares		
		service		
		management	MANAGEMENT	all decision that affect the process of service production
Aggregation	high	low	middle	

Without going too much into detail, a few observations are outlined: **[1]** Hamburg and Porto appear to have a similar average activity levels in SUM and SERVICE, but diverge in RESOURCES and MANAGEMENT decision, where Porto is closer to Dresden. Dresden performs comparatively weak in SERVICE decisions (Figures 5.26). **[2]** According to Figure 5.27, the differences in volatility decrease through category merger. **[3]** As to super-category SUM, the overall activity

[232]The issue could be also termed as PROBLEM 3.1 according to the classification in section 5.3.
[233]Also labelled clusters or generic categories (Lowe et al. (2011), Elo and Kyngäs (2008), Srnka and Koeszegi (2007)).

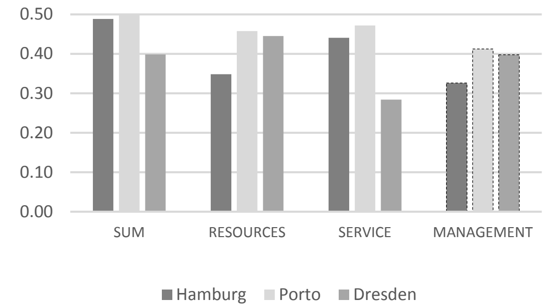


Figure 5.26: Average annual Activity Levels - SUPER

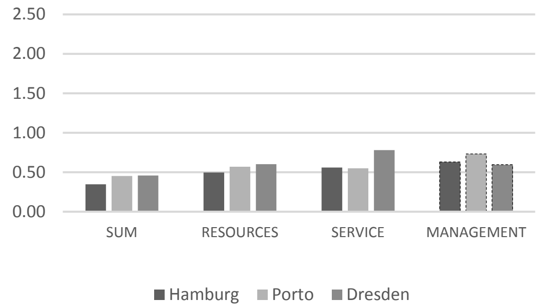


Figure 5.27: Standardized volatility - SUPER

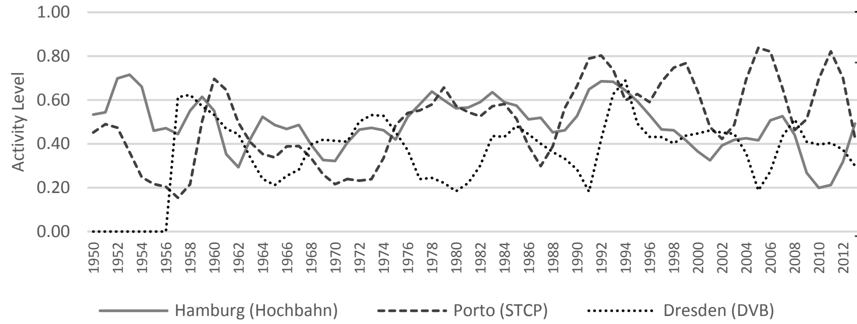


Figure 5.28: SUM - Activity Levels

years	HH OPO	OPO DD	DD HH
overall	0.40	0.33	0.42
61-70	**0.68**	**0.72**	**0.65**
71-80	0.70	0.55	0.60
81-90	**0.77**	**0.61**	**0.60**
91-00	0.64	0.50	0.62
01-10	0.58	0.51	**0.71**

Similarity scores

Table 5.26 Similarity SUM

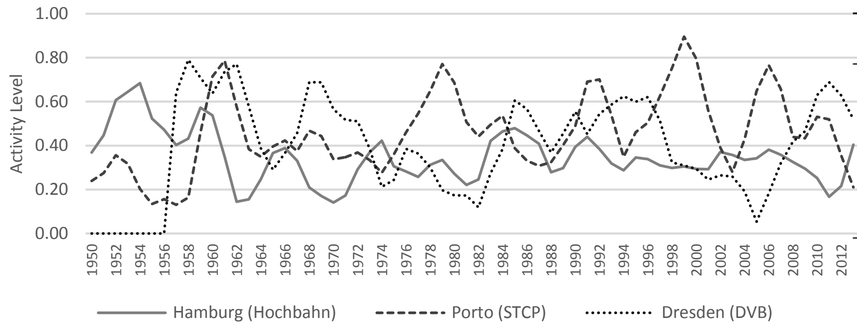


Figure 5.29: RESOURCES - Activity Levels

years	HH OPO	OPO DD	DD HH
overall	0.35	0.32	0.36
61-70	0.56	**0.68**	0.47
71-80	0.58	0.56	0.60
81-90	**0.63**	**0.55**	**0.74**
91-00	0.51	0.54	0.61
01-10	0.54	0.47	**0.69**

Similarity scores

Table 5.27 Similarity RES

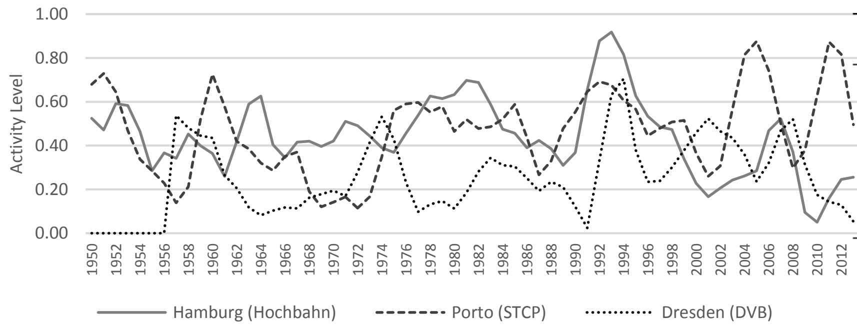


Figure 5.30: SERVICE - Activity Levels

years	HH OPO	OPO DD	DD HH
overall	0.34	0.30	0.32
61-70	0.58	**0.58**	0.51
71-80	0.59	0.52	0.51
81-90	**0.70**	**0.58**	**0.51**
91-00	0.68	0.51	0.49
01-10	0.51	0.50	**0.62**

Similarity scores

Table 5.28 Similarity SER

increases over time for all operators. This suggest that comparatively more decision are taken nowadays in public transport management. *Similarity* scores suggest the largest approximation between all operators in the 80s. **[4]** Hamburg´s RESOURCES decisions start cyclical but are rather flat in recent years. This indicated an internal coordination (peak meets valley) of input-related measures, supporting remark [11] from above. In contrast, Porto shows several cyclical peaks or head-shoulder formations (especially after 1974 and around 2000) indicating that input-related measures were applied rather simultaneously (peak meets peak). Likewise peaky, Dresden decisions might be divided in three main stages (until 1980,2004,2012). Overall, Porto´s and Dresden´s RESOURCE activities increase over time. The highest *similarity* across the operators is found in the 80s again. **[5]** As to SERVICE decisions, all three operators show a clearly increasing trend over time. Hamburg’s curve, however, shows a rather balanced approach until the end 80s with a massive intensification during the 90s. This suggest a clear managerial shift to customer focus, which seems decreasing recently. Porto exhibits stable decisions after 1974 with strongly increasing and more cyclical patterns, especially after the introduction of Metro do Porto. This indicates that increased competition also increases the need for higher service and customer-orientation. Dresden´s service activity is overall lower and only markedly increased after 1990. The *similarity* scores show resemblances in particular during the 80s.

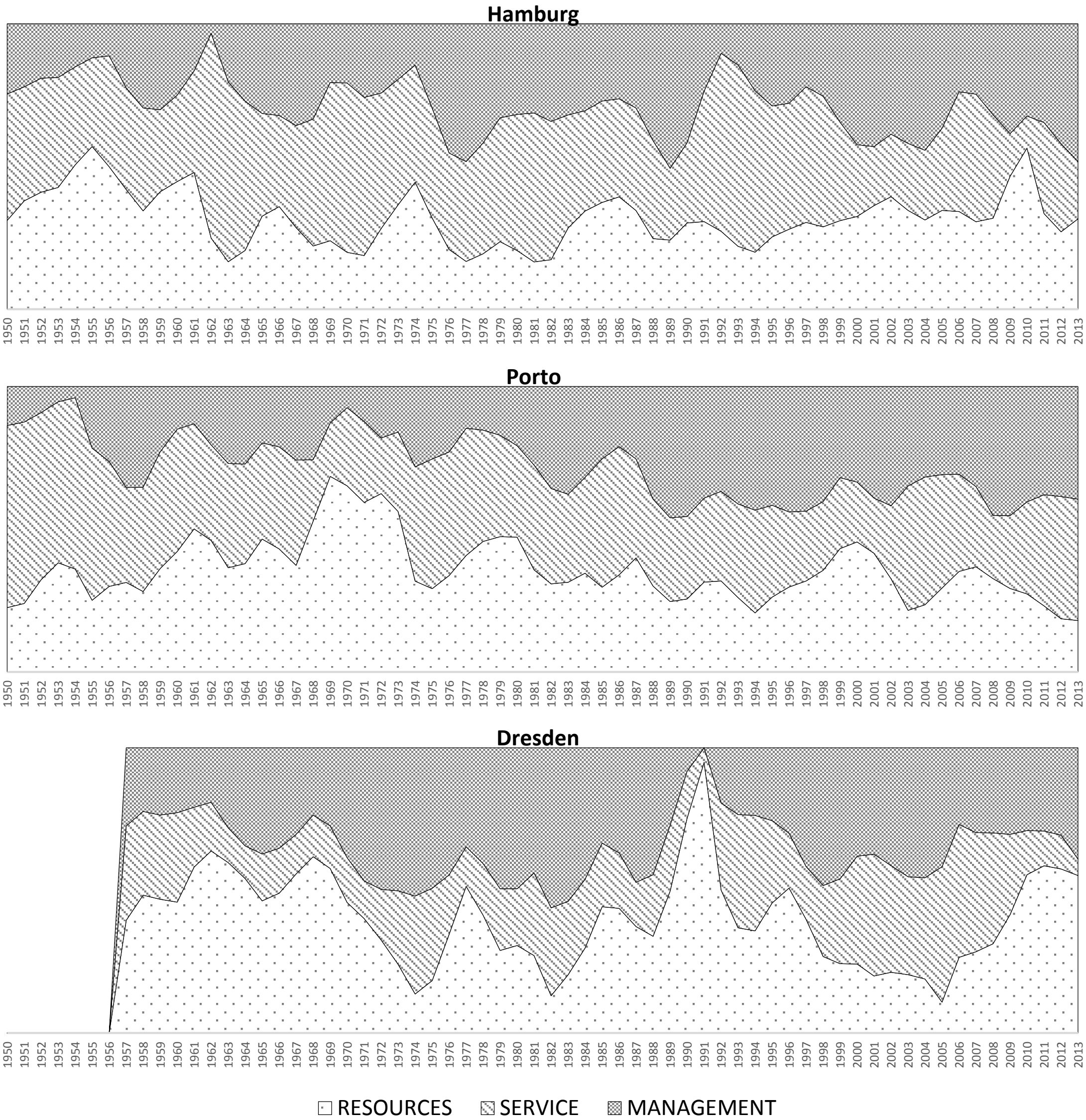


Figure 5.31: Relative importance of super-category over time.

MANAGEMENT FOCUS (DYNAMIC 2): Figure 5.31 above shows the relative importance of the super-categories over time. Resulting schematic patterns based on main trends of RESSOURCE, SERVICE and MANAGEMENT decisions are condensed in Table 5.29 below. Hamburg seems to focus on *service* and *management* decisions, which can also be interpreted as demand-oriented. Porto and Dresden focus rather on *resources* and *management* decisions, then supply-oriented. In general, service decisions are more of operational nature (short-termed). They aim at improving the operator's core product and account for strong customer-orientation. In contrast, resource and management decisions are primarily tactical or strategic (middle or long-termed) and deal with cost- and resource optimization, re-structuring and business development. Thus, it can be said that Hamburg is more concerned with the *"provision of transport services"* whereas Porto and Dresden are more concerned with the *"administration of transport services"*.

Table 5.29: Relative importance of super-categories over time. Rank and Pattern.

Operator/	**Hamburg**		**Porto**		**Dresden**	
Decisions	Rank	Pattern	Rank	Pattern	Rank	Pattern
RESOURCES	3	decreasing-increasing	1	decreasing	1	decreasing-increasing x2
SERVICE	1	constant	3	constant	3	constant
MANAGEMENT	2	increasing-decreasing	2	increasing	2	increasing-decreasing x2

R3: Contextual Aspects

Reported negative contextual aspects, events and disruptions were registered during the Content Analysis and operationalized in the same way as the regular managerial decisions. Figures 5.32 to 5.33 give an overview about the absolute and relative numbers of negative events and their evolution over time termed as 'severity level'. **[1]** The largest group of "complaints" refers to non-classified events ("other"), among them traffic or weather disturbances, free-riding or vandalism. **[2]** For classified effects, Hamburg´s management mostly complains about demand-related events as well as energy issue, whereas Porto and Dresden considered changes in the legal framework as obstructive for service production and provision. **[3]** Once bundled and standardized as in Figure 5.34, it can be concluded, that Hamburg was especially confronted with effects from outside during the 70s and 90s and in the 00s, Porto in the end 70s and mid-00s, and Dresden rather constantly over the course of time. Though the similarity scores show minor similarities between the curves during the 90s and 00s and though some effects from major incidents might have been mentioned alike in the reports (oil crisis, financial crises, and currency change) this category *per definition* is not suitable for comparison, as it clearly captures predominantly local effects and circumstances.

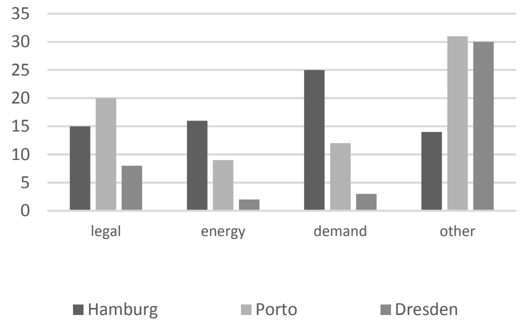


Figure 5.32: Absolute counts of negative events.

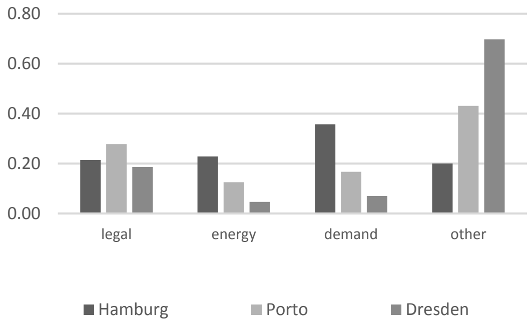


Figure 5.33: Relative count of negative events.

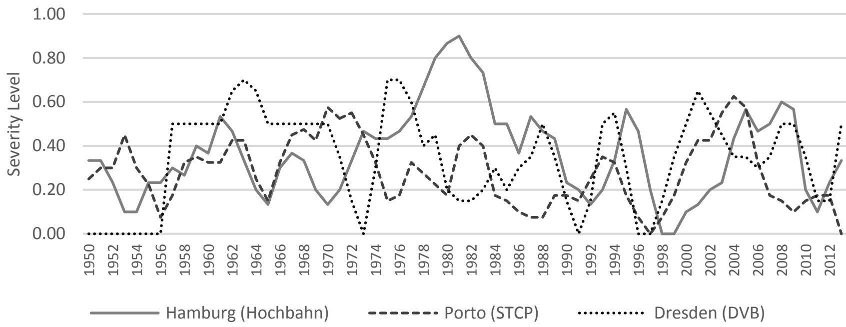


Figure 5.34: CONTEXT - Severity Level

years	**HH OPO**	**OPO DD**	**DD HH**
overall	0.32	0.35	0.31
61-70	**0.73**	**0.58**	0.54
71-80	0.49	0.49	0.54
81-90	0.43	0.58	0.42
91-00	**0.61**	**0.71**	**0.55**
01-10	**0.52**	**0.57**	**0.54**

Similarity scores

Table 5.30 Similarity SUM

5.5 Summary of Results and Interpretations

With regard the first research question - *How does managerial decision-making behave over time, e.g. with regard to the importance of certain decision categories and are there similarities across operators?* - the following inferences can be drawn. Note that results refer to *qualitative* decisions as defined in Table 5.2. These decisions target all *resources* and *outputs* in the public transport production process, but are not necessarily linked to their quantitative changes.

(1) Overall managerial activity increases over time for all operators. This suggests that comparatively more decision are taken nowadays in public transport management. From a general viewpoint the curves seem to indicate that decision-making in public transport might not generally follow repetitive patterns of *increase, decline, depression, improvement,* but rather be determined short- and middle-termed or situationally.

(2) Over the course of 64 years, the overall dominant categories are service, management, personnel and network for all operators and ordered by their importance.

(3) *Network* decisions consistently decrease over time and lose importance relative to other decision categories. They are positively affected by significant political changes or the increased competition. There are indications for weak similarities in network decision making between the operators in general. Further, stronger similarities can be observed when operators work under the same regulatory framework. For all operators, network management activities dominate all other network-related decisions. This confirms that regular line adjustment are a common pattern and sort of “daily business” for all operators. In addition, accessibility measures are quiet frequently applied.

(4) *Fleet* decisions and in particular fleet upgrades appear to be taken either well-dosed and planned or bulky and ad-hoc approach. For the latter case this seems to indicate that these decisions are taken rather in responsive than proactive manner. This again seems to point at shortcomings in steady service planning and forecasting, forcing the management to be highly flexible. Moreover, this could be a sign for political forces intervening in fleet planning, the lack of access to technology or fleet upgrades, delayed financial approval, public discussion, etc.

(5) *Personnel decisions* are a constantly used managerial tool with increasing absolute and relative importance. They strongly increased for all operators over time, in particular since the early 2000s. These recently enforced staff activities might be a sign of increased competiveness efforts because of the EU Regulation (EC) n°1370/2007. Surprisingly, incentivation seems more favourable than staff training measures.

(6) *Schedule decisions* tend to decrease in importance over time. However, it appears that they are taken rather infrequently and in different magnitudes. Thus, schedule decisions might only be of temporary managerial importance, e.g. for operations fine-tuning or, in contrast, complex remodelling of operations.

(7) *Fare decisions* also tend to be decreasing over time. However, the patterns over time suggest that they are an important management tool, which may to applied in a planned manner. Fare adjustments do not appear to be taken annually. In summary, it seems that once a fare system has reached a certain maturity and sophistication, it becomes less suitable for significant changes and thus overall plays a minor role for the management (adjustments only to keep up with rising costs inflation). Further, fare decision appear to be a local phenomenon since the curves show almost no similarity.

(8) *Service decisions* significantly increase over time, both in absolute and relative importance. The curves points at a paradigm shift in public transport to service orientation in the late 80s. However, service decision may increase only up to the point when the capacity limits of a system appear to be reached. In contrast, with overcapacity operators seem to reinforce service activities to attract customers. Further, increased competition from other public transport modes make the operator management increase their customer-orientation. In addition, in particular the financial crises might have affected service decisions (positively and negatively), which is supposedly related to higher unemployment rates. Directly addressing (potential) users seems to be preferred over service measures with operational or technical focus.

(9) *Management decisions* - which concern the administration and coordination of the operator in a rather strategic manner - are of increasing and continuous importance for all operators. Business optimization is the dominating sub-category, which suggests increasing managerial efforts to optimize and streamline the process of service provision overtime. This might be directly linkable to regulatory changes, imposed competitive threats, changes in ownership, subsidy cuts or the positive trend of public transport as affordable, efficient means of transport in general.

(10) As to the *similarity* question, the static approach shows surprisingly strong similarities between the operators. Similarity is high on main-category and in particular on sub-category level. However, the dynamic approach relativizes this claim. The temporal patterns show a weaker similarity between operators. Overall, one could conclude that the highest similarity occurs between Porto and Dresden, which might suggest that operator size affects decision-making. However, even if weak, the results seem to point at the existence of some systematics in decision-making of public transport management.

(11) *Management characteristics* or operator *management style* differ: Hamburg appears service-oriented, cautious, flexible but less active and systematic. Porto seems management-oriented, tactical, flexible but much less resilient and systematic. Dresden appears network oriented and tactical but less resilient and less systematic. Management actions in Hamburg are more controlled over time (less prone for outlier decisions or extreme actions) than in Porto and Dresden.

(12) In summary, Hamburg seems to focus on *service* and *management* decisions, which can also be interpreted as demand-oriented. In contrast, Porto and Dresden focus rather on *resources* and *management* decisions, then supply-oriented. It can be said that Hamburg is more concerned with the “provision of transport services” whereas Porto and Dresden are more concerned with the “administration of transport services”. These findings are particularly interesting when one considers the role of the individual car use. Public transport in Hamburg was continuously challenged by increasing car-ownership, which forced service-orientation. This force was absent in Porto and especially in Dresden, where due to the political and economic framework car ownership lagged behind.

(13) *Managerial focus,* that is the *relative importance of decision categories* against all other categories, changes over time and for each operator differently. However, the general trend and overall ranking of the categories persist, supporting the results of (2). In particular, network (↓) and service decisions (↑) as well as personnel (↑) and fleet decisions (↓) may be mutual substitutes, with shifting relative importance over time. However, relatively fixed relations between decision categories, sluggishly changing, might corresponds to lower managerial flexibility. In contrast, high flexibility could mean that a decision category becomes important, when required.

(14) *Changes in political and regulatory regime* affect decision activity significantly, at least for a while. Several structures indicate catch-up activities after severe changes.

(15) *External effects* and *disturbances* are heterogeneous in nature. Among them traffic or weather disturbances, free-riding or vandalism. Hamburg´s management mostly complains about demand-related events as well as energy issue, whereas Porto and Dresden consider changes in the legal framework obstructive for service provision.

(16) Under the socialist regime, Dresden showed some interesting peculiarities: network decisions appear cyclical, probably due to the socialist five-year plans. Fare policy was simply irrelevant, indicating that prices were rather a “symbolic act” decoupled from the real system costs as usually in controlled economies. Further, resource shortages might have specifically trigged the application of streamlining and cost-reduction measures.

6 Modelling Performance

6.1 Introduction

The previous section was concerned with *qualitative* decisions in public transport management. By applying Data Envelopment Analysis (DEA), this chapter rather focuses on *quantitative* decisions. DEA was given increasing attention in performance literature to better understand the economic functioning of public transport systems and the effects from regulatory and operational changes on operator performance. However, most studies rely on a *cross-sectional* research design. Only a minority of works touches on the huge potential of a *temporal* perspective on performance, i.e. assessing efficiency and effectiveness over a considerable large stretch of time for multiple operators. Thus, the main goals of the chapter are as follows:

- database development of long-term production data suitable for DEA
- application of time-series DEA to calculate performance curves suitable for regression
- assessment of performance curves through new approaches to DEA output

Within the overall outline of the work, this chapter represents the *first stage* of the two-stage DEA approach. The structure is the following. In the *first* section, the initial production data is extensively compared. The *second* section reviews methodological particularities of time-series DEA, the applied BCC-DEA model and its configurations. In the *third* section, key results of the DEA are presented in an innovative manner, namely the *performance scores, weights, lambdas, slacks and slacks over time*. Further, the scale efficiency over time is computed. The last section summarizes the key message of this chapter concerning the following research questions:

What can be learnt from the production data over time? How does operator performance behave over time? What is the relation of operator efficiency and effectiveness over time? Are there similarities across operators? Can one derive other meaningful measures or information from the production or performance time-series?

6.2 Production Data at a Glance and Analysis

While conducting Content Analysis to gain qualitative managerial *decision data*, another paramount task was to collect *production data* from the operators, and other complementary quantitative information of interest.[234] Relevant metrics are usually summarized in dedicated sections or comprehensive tables in the annual reports assessed. These kinds of data - usually given by the operator to public (user, regulators, transport associations) - is designed to highlight any quantitative aspects of the operator's service provision by means of inputs, outputs, and other indicators as evidence of managerial action. In addition, the reports often refer to socio-economic data that might be influential, which can be collected separately from publically available statistical databases. Table 6.1 gives an overview on the key data and other supporting information gathered, as well as definitions, units of measurement, dimensions and a note on general data availability. Data labelled as '*key data'* was highly available for all operators, and found to be in accordance with the extended public transport production model of Chapter 3.1, Figure 3.14. It therefore presents the key resource for the DEA applied herein. In contrast, data termed as '*auxiliary data*' was not homogenously available for all operators *or* not suitable to

Table 6.1: Key data, auxiliary data, and data availability.

Use	Nature	DA	Variable	Definition in research context	Unit
Key data (DEA and regression)	*Perf. inputs*	3	network length	total network of fixed and non-fixed infrastructure	km
		3	vehicles	number of vehicles in the fleet for all modes offered	count
		3	personnel	number of driving and non-driving employees	count
		2	energy costs	energy costs in service provision (fuels, electricity)	EUR
	Perf. outputs	3	vehicle-km	movement of a vehicle over one kilometre	km
		3	seat-km	movement of a seat in a vehicle over one kilometre	km
		3	passengers	realized customers that used service and paid for it	count
		3	passenger-km	distance travelled by passengers	km
	finance	3	revenues	fare-box revenues, revenues of core business	EUR
		3	investment	annual fleet or non-fleet investment	EUR
	socio-economic	3	GDP (x)	value of all final goods and services in an economy	EUR
		3	population (x)	number of inhabitants in urban area	count
		3	unemployment (x)	number of unemployed (or unemployment rate)	count
		3	motorization (x)	number of vehicles per 1000 inhabitants	count
Auxiliary data (Descriptive purpose)	*finance*	1	annual result	revenues minus costs minus subsidies	EUR
		1	subsidies	support by public to recover losses	EUR
		1	service costs (x)	costs per performance indicator	EUR
		1	total costs (x)	cumulated costs of service provision	EUR
		1	staff costs change	change of costs per worker over time	%
	mixed	1	training	number of employees trained and educated	count
		1	fleet age	average vehicle age for all modes	years
		1	ticket type	share of seasonal tickets	%
		2	system speed	average speed over all modes	km/h
		2	occupancy	pax-km/seat-km	%
		1	stops (x)	number of stops in network, all modes	count
		1	seats (x)	number of seats offered, all modes	count

Perf: Performance; DA: Data availability: 3=for all operators 2=two operators 1=one operator; (x) shown only in Appendix 9.

[234]In so far, a unique long-term database is constructed, to be used in academia to pursue related research questions.

contribute to the performance analysis. However, this data is an informative by-product of this work, collected the first time. Initially the “raw” performance data was transcribed to a spreadsheet during the data gathering process of Content Analysis. For further utilization, however, the data needed to be assessed in terms of *completeness*, *outliers*, *consistency* and *unusual level-shifts*, as well as general *comparability* and *usability* (Viegas, 2011).

- As to *data completeness or missingness* - which occurs in roughly 10% of the data strands - several options are at hand to handle these gaps. *First,* one might traditionally consider deleting the missing cases (years). This option is discarded as it would distort the data set and in particular the time-series validity. A s*econd* way is to impute data, for instance based on average values, values that simply are plausible in the context of the variable or derived values from those in close “proximity”. The latter approach could be applied conveniently since often the curves display some kind of local trends over a few years, which then is used to estimate the missing values at relatively low costs.[235]
- As to the issue of *outliers,* it can be concluded that none were not found in the performance data, supposedly due to the data nature and the crosschecking involved in the publication process of the operators. Outliers can be found by comparing basic input-output ratios.
- As to *level-shifts* of the curves, it was observed that operators occasionally changed the underlying measuring systems concerning the way passengers were counted or output performance was calculated. In these cases past years were adjusted accordingly to the new method proposed in the report, usually by a factor that could be simply derived from simultaneous publication of data in the old and the new measurement system over the course of some years. In so far the curve patterns were smoothed and measurement-induced level-shifts avoided.
- As to *data comparability* – in particular for visual analysis across operators - it was assured that units of the same variables are in the same power dimension. Further, monetary units had to be presented over time in correct form and were thus inflation-adjusted to values of 2013 and corrected for several currency reforms.[236]

Before entering the input and output analysis, it should be noted that in contrast to Chapter 5 - the framework for software/qualitative decisions - the focal point of interest in this section are *hardware decision*/*quantitative* decisions. That are precisely adjustments of the stock of resources and corresponding changes in the *input mix* (see Table 5.2). However, it is assumed that in particular the quantitative changes of *outputs* are strongly related to the former decision group, regardless of being supply or demand. Table 6.2 displays the descriptive statistics for performance inputs and outputs and financial data. The complete data is accessible in Appendix 8. The plots of Figure 6.1 visualize the cleansed data as time-series for all operators in comparative manner. Important inferences are summarized below. Socio-economic data, however, is only presented in Appendix 10 since the focus here is on operators.

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[235]For instance by curve fitting tools in SPSS or OriginPro that rely on linear or polynomial regression, and “fit” the data according to an “observed“ structure.

[236]1990 and 1999 (Hamburg “DM to EUR”; Porto “Escudo to EUR”, Dresden (“OM to DM”, “DM to EUR).

Table 6.2: Descriptive statistics for performance inputs and outputs and financial data.

city/variable	statistics	NET LENGTH	VEHIC-LES	PERSON-NEL	EN-ERGY	VEH-KM	SEAT-KM	PAX	PAX-KM	INVEST SUM	INVEST VEH	INVEST INFRA	REVEN-UE
		km	#	#	EUR	x10^3	x10^6	#	x10^6	EUR	EUR	EUR	EUR
HAMBURG	A	752	1,655	5,816	24,382,958	103,032	8,525	387,094,720	1,979	63,489,154	24,693,210	38,795,945	280,957,271
	B	155	136	1,363	5,677,449	13,813	1,731	24,260,610	296	26,460,264	15,502,709	19,285,801	46,622,700
	C	337	1,422	4,340	14,003,773	72,645	3,779	344,158,867	1,572	18,049,050	819,333	10,058,918	169,852,537
	D	871	1,899	8,999	32,907,071	133,992	11,877	440,570,840	2,520	131,369,739	71,397,059	88,440,447	387,876,293
PORTO	A	351	505	3,045	9,601,895	26,533	2,108	119,409,990	522	10,107,513	4,948,050	5,159,463	62,269,740
	B	123	139	811	3,399,520	6,557	882	45,670,359	183	8,193,949	5,703,620	4,999,816	12,246,011
	C	120	268	1,247	5,104,700	13,236	615	56,010,054	293	67,000	0	67,000	46,202,000
	D	552	707	4,217	19,009,712	36,223	3,356	198,935,000	971	35,066,461	26,662,608	30,157,156	93,620,280
DRESDEN	A	359	605	3,394		29,672	4,927	261,875,614	1,413	32,280,154	14,549,859	17,730,295	39,841,074
	B	38	158	1,218		3,616	1,580	100,102,606	587	36,111,849	17,271,899	22,136,053	27,627,955
	C	290	342	1,673		24,000	3,289	133,000,000	642	982,942	0	660,936	6,305,201
	D	436	865	5,879		37,287	8,499	403,846,800	2,241	117,478,261	69,541,412	69,547,826	99,335,000

A: mean B: standard deviation C: min D: max

Figure 6.1: Plots inputs and output performance data.

INPUT DATA: As to the production inputs of Figure 6.1, **[1]** *network length* expands over time. Hamburg`s network has roughly the double size than the other operators and shows a typical growth curve shape with a saturation stage since the mid-70s. Porto`s one developed rather linear until 2008. Dresden`s network was cut drastically around 1990. **[2]** *Vehicles:* All operators at some point start to decrease fleet size: Hamburg already in the early 70s; Porto and Dresden 20 years later. **[3]** The development of the *personnel stock* clearly indicates massive downward staff adjustments, however at different stages: Hamburg in the 60s, Porto only after in the early 80s and Dresden in the early 90s. Considering operator size and output, until the mid-90s the two latter operators appear heavily overstaffed compared to Hamburg. **[4]** Data on *Energy Costs* is only available for Hamburg and Porto. It suggests a massive drop after soaring prices in the 80s. Obviously fleet reduction correlates with energy costs and output curves. However, the similarity of the shapes across operators indicates that they do not seem to have any resilience (strategy) against rising energy prices except of fleet modernization. **[5]** For all operators changes in inputs appear to happen rather planned and gradually than erratic and volatile. This might point at the existence of some sort of commonly applied managerial planning scheme but also at contractual commitments, for instance externally with the public/regulators (e.g. service obligations) and internally with staff (e.g. work contracts).

OUTPUT DATA: As to the *supply side outputs - vehicle-km* and *seat-km,* assumed largely under control of the management it can be observed that **[6]** Hamburg and Porto increase the produced vehicle-km until the year 2000. Later, Hamburg further increases, while Porto decreased its offer. In particular, for Hamburg the inverse relationship between the *number of vehicles* and *seat-km* offered, demonstrates that vehicles simply get larger over time, yielding a higher capacity per vehicle. Dresden´s long-term trend is decreasing and with a considerable drop in seat-km in production after 1990. The decline relates to the fact that supply capacity was regulated but simply reducing the number of carriages per tram then led to different effects in vehicle-km (smoother) than in seat-km (steeper). With regard to the demand-side outputs - *pax* and *pax-km*, usually under control of the management - four suggestion can be made: **[7]** *First*, Hamburg pax curve over time is relatively stable, which suggests that effects from motorization could be mitigated. *Second*, Porto’s curves especially rise after 1974 but decline rather steadily since the mid-80s back to the levels of 1970, supposedly due to increasing car ownership. *Third,* in the 60s Hamburg and Dresden had roughly the same number of passenger despite the differences in city size. This stresses the importance of public transport in the former GDR. But especially after 1990, Dresden´s curve is in “freefall”, which is when cars were suddenly affordable. Notably, since 2000, a slight improvement is observable. *Forth*, for all operators the ratio pax-km/pax suggest that journeys might get shorter over time (or people travel less but longer). Overall, the curves suggest that - metaphorically speaking - Porto *"did not survive the car and was finished off by Metro do Porto"*, Dresden *"bled dry, had a near death experience, but recovered"* and Hamburg *"fought back".*[237]

FINANCIAL DATA: A closer look at the financial data indicates **[8]** rising fare-box *revenues* for Hamburg and Dresden, and contrarily, decreasing revenues for STCP, which is in accordance with the demand-loss. Interestingly, in Dresden, the introduction of the market economy in 1990 and "privatization" might have induced a market- and cost-oriented fare stetting, since the operator managed to increase revenues significantly despite a declining demand. This suggest again that socialist fares before 1990 were rather pointless, at least in terms of cost-recovery or profit-maximization aspects. **[9]** The *investment* charts demonstrate different types of investment policies: a constantly high investment with infrastructure focus (Hamburg), a comparatively low investment with a balance between vehicles and infrastructure spending (Porto) and a mixed-policy in Dresden. Porto and Dresden appear to be similar in shape and magnitude until 1990. After 1990 however, the annual investment in Dresden increases roughly to Hamburg´s level. This proves (a) that infrastructure investment in Dresden was probably neglected before 1990 and (b) that rail-based operators need vast amounts of money for maintenance and expansion as opposed to the "cheaper" bus network in Porto. For instance, Hamburg´s average investment

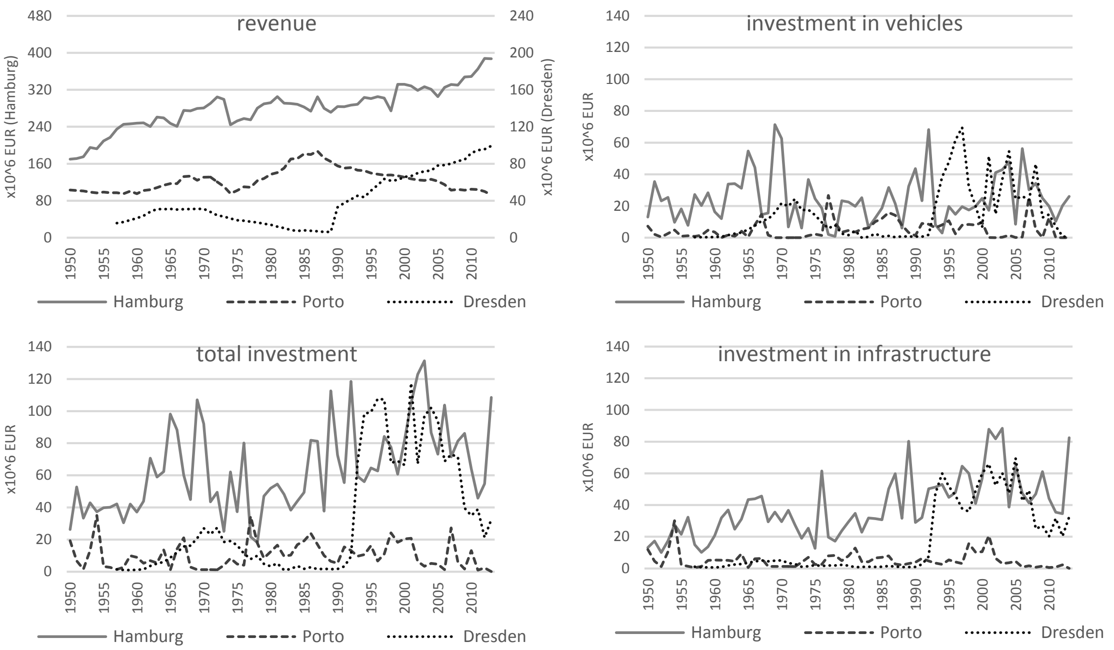


Figure 6.2: Plots financial data.

[237]Future research: *Do city size and mode-mix function as barriers against car-use (or other interferences, probably in combination with economies of scale and density)? A partially rail-based service guarantees higher operational speeds (see below) which might prevent people to switch to the car (Hamburg) or it will enable PT to be considered as a real alternative (Dresden). Pure bus system are be vulnerable. Is the answer to improve the ROW situation for buses?*

in infrastructure is eight times higher than Porto´s and twice as high as Dresden´s. However, the charts also suggest that the recent investments in Dresden might have contributed to halt passenger decline and be thus considered a long-term investment with rather future than sooner benefit. This tempts to conclude that especially the lack of infrastructure investment (speed measures, separate lanes, etc.) has worsened passenger downturn in Porto.[238]

AUXILIARY DATA PORTO: Finally, Figure 6.3 below illustrates interesting information with a particular focus on Porto, since the operator´s annual reports account for the highest data variability. **[10]** The *annual results* and *subsidies* display soaring losses over time for Porto, that could be "stopped" only briefly in the mid-90s and mid-00s, however, externally, by subsidy increase. Once interpreted jointly with the supply and demand curves it appears that a lagged adaptation of supply to decreasing demand might have cause this gap. The operator seems obliged to keep a certain supply-level despite losing customers regularly. This creates a situation with reduced fare-box revenues but constant or even increasing costs. **[11]** *Subsidies* decrease over time and bounce back only a few years after the introduction of Metro do Porto. Paradoxically, the appearance of the competitor seems to have strengthen STCP´s position in terms of subsidy bargaining or the claim for some sort "compensation" for demand "damages" caused by the Metro.[239] **[12]** The dynamics of the annual change of costs per workers (costs for labour, remunerations, etc.) suggest a strong decline since the early 80s, which corresponds to a more smoothed approach salary increases, in particular since the mid-90s. Significant peaks in this curve can be considered as new wage agreements concluded with the unions (or the government), with an increasingly better position for the operator. **[13]** As to the *resources*, the charts indicate that staff dismals schemes were largely accompanied by increased *training and education*[240] and that the bus *fleet age* was tapered considerably after 2000, supposedly as part of the "forced" repositioning induced by competition from the metro. **[14]** The *share of seasonal tickets* over time suggests that the operator's business/fare models changed remarkably in the mid-70s with figures climbing up to about 80% of seasonal ticket sales most recently. In general, seasonal tickets allow for high levels of revenue predictability, steady cash-influx, and down payments and in this respect might affect the operator´s spending and investment policies from managerial perspectives. The last two figures reveal two striking operational aspects of public

[238]Probably this is rather a political problem than a managerial one. Investments might be limited due to the lack of flexibility to apply changes to road network in Porto. In addition, one could argue that the swift loss of passengers in Dresden literally "forced" the operator to entirely remodel its service, as in contrast Porto's decline happens rather gradually which does not "force" massive managerial/political shifts in short time.

[239]Surely, this is an interesting issue for a CBA study with temporal aspects. The gains for the public offered by a "new" mode appear to be offset (initially) by the costs to compensate the "old" mode.

[240]This is in accordance with the decision curves for personnel, which indicates the validity of CA (Appendix 12).

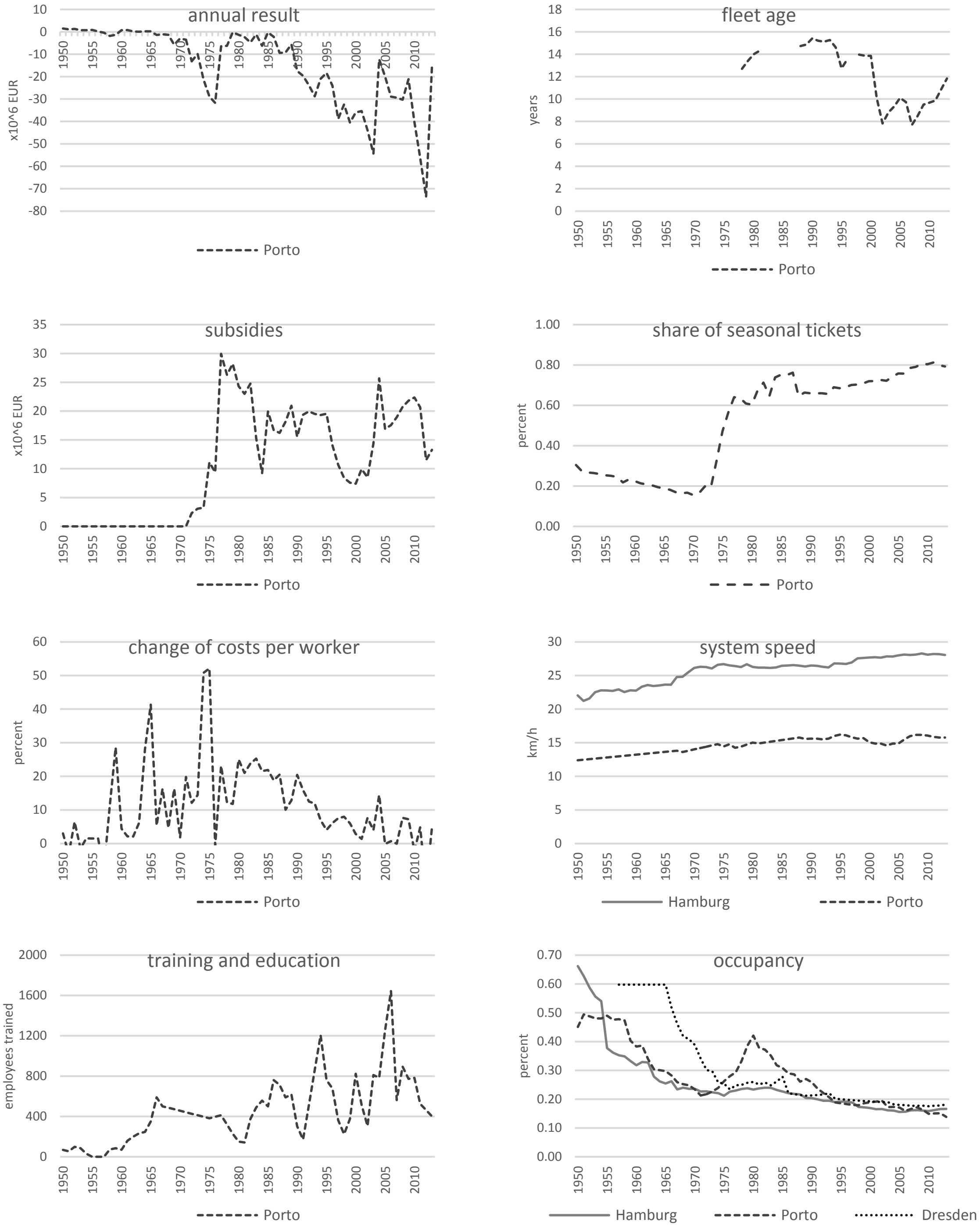


Figure 6.3: Plot auxiliary data Porto.

transport: *First*, **[15]** *system speeds* are much higher for operators with a higher share of rail-based infrastructure (factor 1.7). *System speeds* tend to increase over time (keyword: technology) but appear to be capped at some point, either by technical regulations (rail) or congestion in the road network (bus). Hamburg appears capable to increase speed again from the early 90s on after a long stagnant phase. Porto´s curve clearly indicates a rather stationary stage since the mid-90s, even with phases of speed deterioration. However, slight improvements are observed since the early 00s (keyword: competition). It appears that in particular the rising interaction with regular car traffic limits Porto´s capacity for further speed increases. This might eventually constitute a vicious cycle of service deterioration, further demand losses, and consequently more individual car traffic. This scenario could only be solved by strong political commitment but might be a tricky undertaking if more and more *voters* became *car users*. **[16]** For all operators, *occupancy rates*[241] (ratio pax-km/seat-km) decline to a steady baseline of about 17%, observed since the mid-90s. This implies that a relatively stable relation between demand and supply had developed over time, regardless of the mode-mix, city size, structure etc. One could also extend this logic to the concept of quality standards in public transport, in that these scores might express some aggregated quality equilibrium over space "negotiated" between provider and customer over time (averaged between peak and off-peak).

6.3 Data Envelopment Analysis (DEA)

Methodological Departure: Time-Series DEA

Approaches to performance measurement were discussed in Chapter 3. In particular, the basic idea of DEA - as a non-parametric frontier approach relying on the construction of a virtual-output-to-virtual-input-ratio per DMU to derive a score between 0 and 1 - was elaborated, in addition to its different models, orientations, and most recent research directions. It was then outlined why Data Envelopment Analysis was chosen preferably to Stochastic Frontier Analysis. In this regard, Table 3.17 recapitulates the methods' major features and points at the following key advantages of DEA in the context of this study:

(1) Consistency with economic theory regarding the inefficiency location as per Pareto-Koopmans. No need for arbitrary cut-off points to classify efficient and inefficient units.
(2) Straightforwardness of results with strong outreach beyond academics as DEA directs management attention toward potential improvement.
(3) No need to specify a parametric functional form.
(4) Simultaneous consideration of multiple inputs and multiple outputs without the need for weighting them and regardless of the units measured in.
(5) High flexibility through various models and configurations.

As to the last point, it was further learnt from that (a) DEA might be used in a *two-staged* process linking DEA and regression and (b) that the widely applied *cross-sectional approach* in the first stage might be altered to a *time-series approach* to account for temporal aspects of performance. It was also mentioned that the so-called *time-series DEA* is a special configuration of the rarely applied *window DEA* introduced by Charnes et al. (1985). The relevant parameters

[241]Occupancy rate is affected by fleet mix and vehicle size. For partially rail-based operators as Hamburg (16%) and Dresden (17%) occupancy figures are averagely lower than in Porto (18%) since they operate with a higher share of high-capacity vehicles (trains and trams) more likely for to be less utilized than medium-capacity vehicles (buses).

and further references were presented in Chapter 4. As displayed in Table 6.3 the basic idea of a window DEA for multiple DMUs n over time periods k is to select a *"window"* of size p and treat e.g. years as additional DMUs to the problem. Then the window is moved by one year and the analysis repeated for all DMUs in the window, which creates multiple sub-matrices with efficiency scores. Overlaps between windows are then simply averaged which makes the method similar to a moving average-based technique (Cook and Seiford, 2009). In this fashion, window DEA could be applied to assess and compare the performance of Hamburg, Porto and Dresden over the stretch of time *and* cross-sectionally in one DEA model[242]. However, due to the research issues elaborated in Chapter 4 the analysis will evaluate each operator separately by "manipulating" window DEA to its "bare essentials" as show in Table 6.3, right hand side. This so-called time-series DEA is simply an extreme case of window DEA with a corresponding *window width* of all years m of the time-span and only one sample item/operator. Formally this equates to a conventional DEA using *years* as *DMUs* instead of operators. This allows for a straightforward observation of *performance over time* for one operator.

Table 6.3: Schematic representation: window DEA and time-series DEA, 3 DMUs, 64 years.

		window DEA (multiple operators, moving window, 62 windows)					
		years = additional DMUs					
		1	2	3	i	63	k
operators	1	$\theta_{11,64}$	$\theta_{12,64}$	…	…	…	$\theta_{164,64}$
	n	…	…	…	…	…	…
	3	$\theta_{31,64}$	$\theta_{32,64}$	…	…	…	$\theta_{364,64}$
		$k = 64$			window size p=2		

	time-series DEA (one operator, fixed window, one window)					
	years = DMUs					
	1	2	3	i	63	k
1	$\theta_{11,64}$	$\theta_{12,64}$	…	…	…	$\theta_{164,64}$
~~n~~						
~~3~~						
			window size p=64			

The approach is also termed *"modified window analysis DEA"* (Yang and Chang, 2009) or "*intertemporal analysis"* (Tulkens and Eeckaut, 1995). The link between window DEA, window width and time-series DEA is further explored and formalized by Tulkens and van den Eeckaut (1995), Cullinane and Wang (2006) and Asmild et al. (2004).[243] An in-depth reading on efficiency over time is provided by Cooper et al. (2007) pp. 323 ff.

Regardless of its methodological terminology, the following section uses the basic logic of DEA to calculate performance of the same operator in different years in order to draw comparative conclusions about the evolution of efficiency and effectiveness over time.

[242]Asmild et al. (2004):*"In doing so, the performance of a unit in a particular period is contrasted with its own performance in other periods in addition to the performance of other units."*

[243]The authors also elaborate on different temporal scenarios such as *sequential*, *contemporaneous*, *locally intertemporal* and *intertemporal* analyses.

Model Choice: Input-Oriented BCC

Before modelling performance three decisions need to be taken concerning **(1)** the *type of efficiency* assessed, **(2)** the *DEA model type* and **(3)** the *model orientation*. As to **(1)** it might be considered to assess allocative or technical efficiency as shown in Table 3.4. Allocative efficiency needs to involve price data for inputs and outputs; technical efficiency requires just physical inputs and output. Since the former data type is simply not available, the focus was set on the concept of *technical efficiency*. With regard to **(2)** it is suggested in Chapter 3 that the most widely used conventional DEA models are CCR and BCC. The former of which *produces technical efficiency* scores related to a *linear* frontier and the latter *pure technical efficiency* related to a *convex* frontier (Jarboui et al., 2012). Formally, the models differ in their assumptions about the nature of *economies of scale*. With constant returns to scale (CRS) in the CCR model, it is assumed that the observed production combinations can be proportionally altered without affecting efficiency and that the scale is optimal. In contrast, with variable returns of scale (VRS), it is assumed that efficiency may vary with different input-output configurations due to the presence of scale economies. This allows to account for specific technology characteristics (Graham, 2008). In this regard, this research follows Coelli (2005) who outlines the appropriateness to assume VRS, in particular when imperfect competition, government regulations, constraints on finance, or other effects might cause an operator to deviate from its optimal scale. This brings together the notions of efficiency and modern production theory, applied at a public sector service. Hence, the BCC model is used, which incorporates VRS. Finally, as to **(3)** - the question of input- or output orientation - it needs to be decided whether to minimise inputs and fix outputs or *vice versa*. This can be done by paying attention to the nature and surroundings of public transport. As suggested by Link (2016) public transport often reflects situations where the outputs are rather fixed by exogenous factors. Costa (1998) concludes that outputs in public transport are more prone to stochastic influences and reporting problems. This is in accordance with Odeck (2008) who claim that the level of outputs might be determine e.g. by subsidisers and that in particular *“policy-makers are expected to be more concerned about input saving potentials and less about output increasing”.* Similarly, but rather referring to the objectives of public transport as a public service, Santos et al. (2014) and Margari et al. (2007) consider the minimization of inputs more important than profit or output expansion. In addition, the review of other relevant performance literature in this field clearly suggested input-orientation.[244] Thus, a BCC model with *input-orientation* is chosen.

[244]It should be noted that output- and input-oriented models estimate precisely the same frontier and identify the same set of efficient units and ranking, but the scores themselves vary in magnitude. See Coelli (2005).

The end goal of the DEA model is to calculate an efficiency score θ for each year p in the set for each operator individually. The relevant mathematical formulations of the final linear programs (LP) as well as corresponding models[245] are given below as a follow-up on the introductory remarks of Chapter 3. Since the formulations derive from the CCR model, additional notations, definitions, and deduction steps are presented more thoroughly in Appendix 2.

Table 6.4: Notations for BCC model.

Symbol	Definition	Symbol	Definition
x	input	v	input weight vector
y	output	w	output weight vector
p	DMU (year)	e	row vector with all elements unity
θ	efficiency score $[0,1] = \{\theta \in \mathbb{R} \mid 0 \leq \theta \leq 1\}$	λ	semipositive vector in R^{n}
X, Y	matrices	w_p	scalar, free variable

ENVELOPMENT FORM

$$\min_{\theta_{BCC},\lambda} \quad \theta_{BCC} \tag{17}$$
$$s.t. \quad \theta_{BCC} x_p - X\lambda \geq 0 \tag{18}$$
$$Y\lambda \geq y_p \tag{19}$$
$$e\lambda = 1 \tag{20}$$
$$\lambda \geq 0 \tag{21}$$

MULTIPLIER FORM

$$\max_{v,w,w_p} z \quad w y_p - w_p \tag{22}$$
$$s.t. \quad v x_p = 1 \tag{23}$$
$$wY - vX - w_p e \leq 0 \tag{24}$$
$$v, w \geq 0, w_p \; free \; in \; sign \tag{25}$$

FRACTIONAL FORM

$$\max_{v,w,w_p} z \quad \frac{w y_p - w_p}{v x_p} \tag{26}$$
$$s.t. \quad \frac{w y_j - w_p}{v x_j} \leq 1 \; (j=1,...,n) \tag{27}$$

$$v, w \geq 0, w_p \; free \; in \; sign \tag{282}$$

The BCC model is almost equal to the originally proposed CCR model of Appendix 1. It can be demonstrated that a CCR model can be easily modified to a BCC model by simply introducing the convexity condition $\sum_{j=1}^{n} \lambda_j = 1$ or $e\lambda = 1$, which ensures that DMUs are only benchmarked against DMUs of similar scale. In that, the BCC frontier envelops the data more closely than a CCR frontier and efficiency scores are greater than or equal to CCR efficiency scores, because in CCR models DMUs might be compared that substantially differ in size (Graham, 2008). Similar to the CCR, the primal problem PLP_p^B is solved in two stages[246] where first, the scalar θ_{BCC} is minimized and then slack sums are maximized, while keeping $\theta_{BCC} = \theta^*_{BCC}$. The optimal solution

[245]Based on Cooper et al. (2007) pp. 89ff and Coelli (2005) pp. 162ff.
[246]As shown in the Appendix 1 it can be solved either simultaneously.

for PLP_p^B - which in fact is the optimal solution for each year assessed - is denoted as $\theta^*_{BCC}, \lambda^*, s^{-*}, s^{+*}$ with the maximal input excesses and outputs shortfalls.

Model Configuration: Kinds and Number of Inputs and Outputs

The intention of modelling should be to represent reality in the best possible way. Considering the "supreme rule" of empirical economics quoted by Liebert and Niemeier (2010) - "*garbage in = garbage out"* - the selection of inputs and outputs should essentially *"characterize the dynamics of the industry"* (Ermagun and Levinson, 2015; Santos et al., 2014) and capture the underlying production process appropriately and in consensus with research. The first step of clearing a model - identification of relevant inputs and outputs of operator - was concluded and discussed in Chapter 3. The gathered data was introduced, processed and descriptively analysed accordingly. However, the final selection for DEA is still constraint by two factors: (1) practically, by data availability across operators and (2) theoretically, by methodological issues:

(1) A key task in this research is the comparisons of intertemporal performance patterns across three operators. Thus, performance should be calculated for all operators in the same way, based on the same number and type of inputs and outputs, respectively. Therefore, the highest common number of available variables determines the database for the DEA analysis (see Table 6.1, key data, column 3). For instance, the input variable energy costs is obviously not consistently available for all operators. As to the rather complete supply and demand-sided output variables in Table 6.1, the choice will based on their type, interpretation and the frequent use in literature.

(2) Odeck (2008) claims that the number of inputs and outputs should be kept at a reasonable level in order to preserve the DEA´s discriminatory power. Otherwise DEA tends to create a comparably higher number of efficient units located on the frontier when a large number of inputs are entered, a fact described by Borger and Kerstens (2006) as the "curse of dimensionality". Especially in time-series DEA, too many inputs would simply flatten the curves as shown in Figure 6.4 below. To create a useful frontier, a rule of thumb[247] advices that the number of inputs m and outputs s should be limited to less than *one-third* of the number of units n: $n \geq 3(\mathrm{m}+\mathrm{s})$ or $n \geq 2(\mathrm{m}+\mathrm{s})$. As per Table 6.1, at best, three inputs and two outputs can be used over a period of maximum 64 years. This is still largely below the proposed threshold. Thus, the discriminatory power of DEA could be maintained.

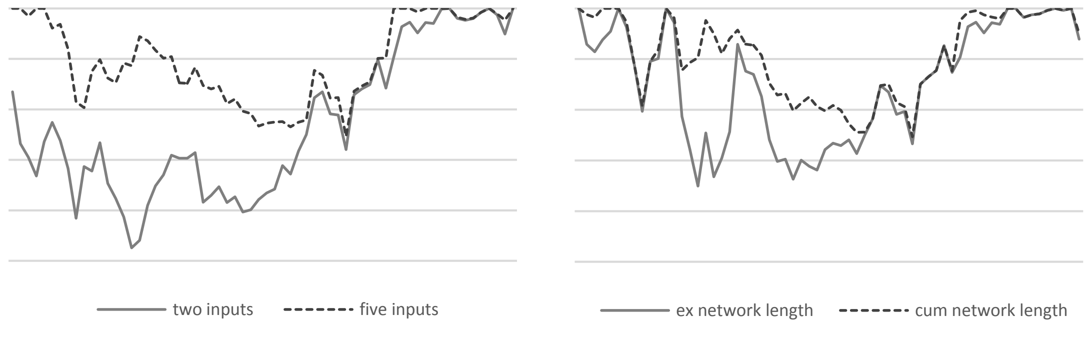


Figure 6.4: Curve flattening effect of a large number of inputs in the model and inclusion of network length.

[247]Yang and Chang (2009), Movahedi et al. (2007).

Table 6.5: Final DEA models.

Configuration	DEA Model		
	Effectiveness (I)	**Efficiency (II)**	**Mixed Performance (III)**
inputs	network length vehicles personnel	network length vehicles personnel	network length vehicles personnel
outputs	pax-km	seat-km	pax-km seat-km
performance perspective	demand-side	supply-side	comprehensive

In summary, the methodological pitfalls do not apply in this case. Inputs and outputs are therefore selected to allow for a consistent comparison across all operator and to ensure that they contribute to the analyses with the most suitable interpretation. The final variable selection is outlined in Table 6.5 jointly with the corresponding DEA models. As indicated in Table 4.2 to 4.3 of Chapter 4, there is consensus in research concerning the choice of most of these variables.[248,249] The majority of studies, uses similar if not equal capital and labour variables. Network length, vehicles and personnel (termed "staff" occasionally) are together considered as the operator´s inputs. Pax-km and seat-km have been considered key outputs. The alternated application of outputs determines three performances models, namely (I) *effectiveness*, (II) *efficiency* and (III) *mixed performance* as applied by Costa (1998) and Karlaftis (2004). The former two are so-called '*3-input-1-output'* cases. The latter one - also termed "combined" in literature[250] - is a '*3-input-2-output* case' and rather serves as a control model. By capturing demand *and* supply, public transport provision is apparently considered a multi-output product.

Inspired by the work of Daraio et al. (2016), effectiveness is ranked first in this order[251] because service provision with a focus on demand appears to be the primary task of the three operators. All of them operate under imperfect competition, which makes them less likely to focus predominantly on efficiency. Further, it has been demonstrated that the supply-sided output might be considered as intermediate "product", whereas the demand-side output is a final one (Graham, 2008). A few concerns are raised by several authors about *vehicles* as a variable, that

[248]Except for *network length* as lengthy discussed.
[249]Using the network variable follows the reasoning of Cullmann (2012):*"In transport networks we might face different network structures or complexities, not observed, but influencing the production process. The unobserved factors are typically modelled as separable factors. […] We argue that the entire production process is organized around different network structures. [..] They are inevitably non-separable from the observed inputs and outputs."* The term 'separable' would suggest to use network as an explanatory variable. However, 'non-separable' suggests that the network is rather part of the production process and has to be considered. A big advantage of the time-series DEA approach is that the issue of network heterogeneities is strictly circumvented, since only one operator is assessed. This allows including the network length variable, which already is a big surplus in comparison to cross-sectional DEA, where, due to heterogeneities, the network variable is often omitted. As per Coelli (2003) in the logic of DEA, denser network have *"a favourable effect upon efficiency"* because less network required to serve a particular number of customers.
[250]Karlaftis and Tsamboulas (2012): "combined'' or ''overall'' performance measure.
[251]This has no effect other than stressing the importance of this concept, which is often neglected in research. In fact, effectiveness is equally calculated as efficiency but with a different output.

usually does not account for the heterogeneity in number of seats or standing room per vehicle (Daraio et al., 2016; Odeck, 2008). This shortcoming cannot be solved - due to lack of data - but was partially alleviated by using seat-km instead of vehicle-km on the output side. The former of which then captures the vehicle-size, at least for efficiency. Also the claim of Costa (1998) that for ridership passenger-km are a more accurate measure than pax was taken into account.

Before entering the DEA tool all data was *mean-normalized* to have the continuous values for inputs and outputs in the similar magnitude[252] , to reduce processing time for the software and to facilitate visual interpretation (Avkiran, 2006; Holvad, 2010). Mean-normalisation is obtained by finding the mean for each variable and dividing each individual observation by the mean (Appendix 8). Other common data corrections for DEA, such as non-negative numbers and the omission zero values were not needed. In practical terms, the analysis using a BCC model was performed with OSDEA, or Open Source DEA[253], that, in essence is a *"free […] open source code which can be used and modified by anyone"*. The tool was developed, as most available DEA software programs are either not comprehensive enough or too costly. OSDEA covers the most commonly applied DEA models and their specifications. The software delivers outputs to Excel.

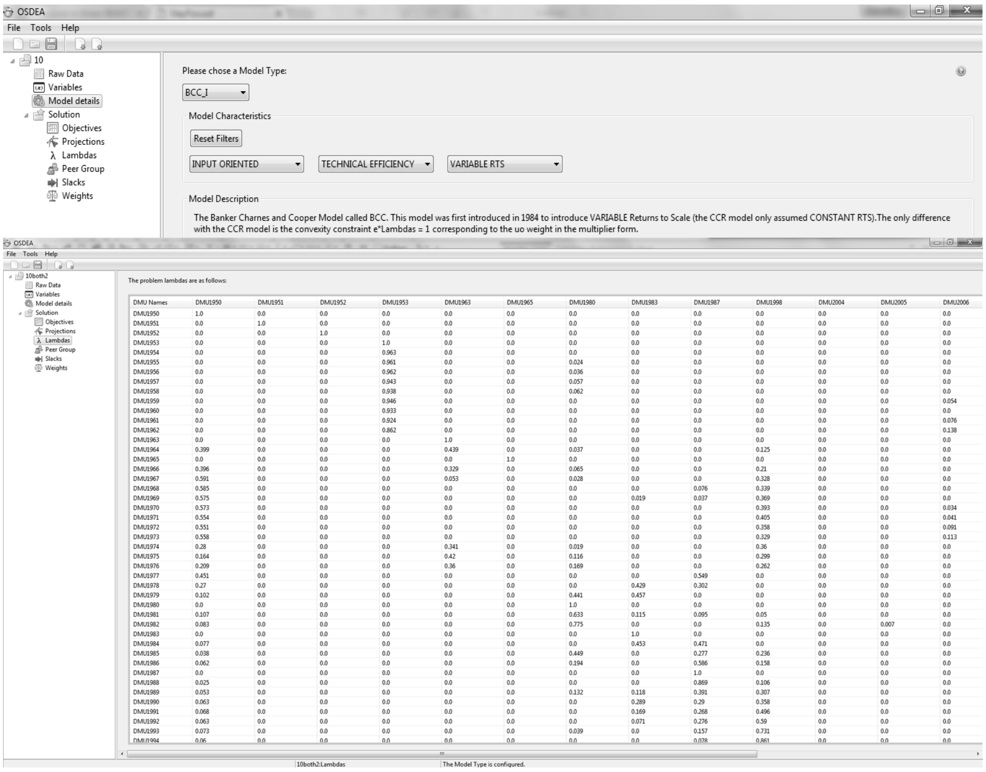


Figure 6.5: Screenshot OSDEA software.

[252]Cooper et al. (2007): DEA is in fact unit invariant, thus, the normalization could also be skipped, but mean-normalization allows plotting curves in one chart conveniently.

[253]Open Source DEA (OSDEA) is an open source project providing a Java library to solve Data Envelopment Analysis (DEA) problems. The library was written because of the lack free tools in an open source language, which people could easily understand, use and modify. The library solves many different types of DEA problems and provides detailed solutions: www.opensourcedea.org.

6.4 Results of DEA and Interpretations

The key results of this DEA are (R1) the efficiency scores *thetas,* (R2) *weights*, (R3) *lambdas and,* (R4) *slacks*. Further, one could calculate (R5) *scale efficiency.* Table 6.6 summarizes information on how to interpret results meaningfully, in the light of the managerial context of this research.

Table 6.6: Interpretation and explanation of DEA outputs. Adapted from Cooper et al. (2007) pp.23-80.

Output Interpretation	**Definition**
(R1) Theta over time *'PERFORMANCE EVOLUTION'*	Managerial efficiency: efficiency or effectiveness score between 0 and 1. When smaller than 1 the score indicates inadequate exploitation of the input-output relation in a year in comparison to the operator´s most efficient years. The evolution of the score over time displays how the management addressed to adjust the input-output relation quantitatively, qualitatively and in temporal manner.
(R2) Weights over time *'PERFORMANCE INITIATORS'*	The relative magnitudes of optimal weights for a specific year indicate which inputs have a comparatively higher effect/contribution in the calculation of the efficiency/effectiveness score. Then the evolution over time gives the relative importance of inputs over time, thus indicating the efficiency triggers. It further allows estimating the average input or output changes required, given a performance improvement goal.
(R3) Lambdas over time *'PERFORMANCE STARS/BEST YEARS'*	For a given year with performance *theta* its lambdas show, which efficient peer-years (benchmarks) contribute to its evaluation and to which extent. Thus, the most exemplary/influential/pivotal years for the operator can be identified among the efficient years, which might indicate the peak of management capabilities.
(R4) Slacks over time *'RESOURCE DISSIPATION'*	Slacks are unnecessary use of inputs (excess) that could be have been avoided in a specific year without sacrificing output and without the need to adjust the input mix by input substitution. Once inputs would be slack adjusted, the operator would not be efficient, but better off than before. In managerial terms, slacks over time thus show to which extent the simplest way of improving performance had been missed out: to reduce inputs without harming service provision.
(R5) Scale over time *'OPERATOR SIZE'*	When the size of operations is optimal, an operator is scale efficient. Any adjustment in either direction would then decrease overall efficiency.

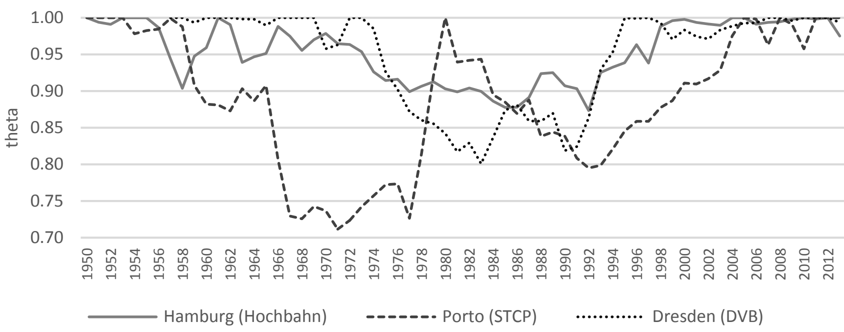
Table 6.7 displays the descriptive statistics of the DEA indicating the following: **[1]** The average overall performance in the three models appears to be at least around 90%. This is above many of the results presented in Table 3.19. **[2]** Interestingly, average scores across operators are almost identical, except for Porto, which has a lower effectiveness score. **[3]** Only for Porto and Dresden, average mixed performance is higher than average efficiency, which again is higher than effectiveness. This suggest that the operators - on average - were more concerned with

Table 6.7: Descriptive Statistics of DEA models.

Statistics	**Effectiveness (I)**			**Efficiency (II)**			**Mixed Performance (III)**		
	Hamburg	*Porto*	*Dresden*	*Hamburg*	*Porto*	*Dresden*	*Hamburg*	*Porto*	*Dresden*
time span	50-2013	50-2013	57-2013	50-2013	50-2013	57-2013	50-2013	50-2013	57-2013
DMUs (years)	64	64	57	64	64	57	64	64	57
mean	0.95	0.89	0.95	0.94	0.94	0.96	0.96	0.95	0.97
SD	0.04	0.09	0.07	0.05	0.05	0.05	0.04	0.05	0.05
min	0.87	0.71	0.80	0.87	0.84	0.84	0.87	0.84	0.85
max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
year of min	1992	1971	1983	1981	1967	1985	1992	1967	1983
year of last max	2012	2013	2012	2013	2013	2012	2013	2013	2012

efficiency than effectiveness, as opposed to Hamburg. **[4]** As to the performance range, Porto and Dresden present lower minimum performance levels than Hamburg. The lowest observed score is 0.71 in 1971 in Porto. **[5]** The year with the latest maximum is one of the most recent years, which trivially confirms that performance increased over time.

In the following, results for the three performance models are presented in the familiar chart visualizations style[254] on basis of the five DEA outputs described above. Key findings are briefly discussed with focus on the *effectiveness (I)* and *efficiency (II)* model. Results from the mixed performance model will be elaborated only in case of particularities. Further, for any time-series the Euclidian distance-based measure of similarity is given in order to identify resemblances

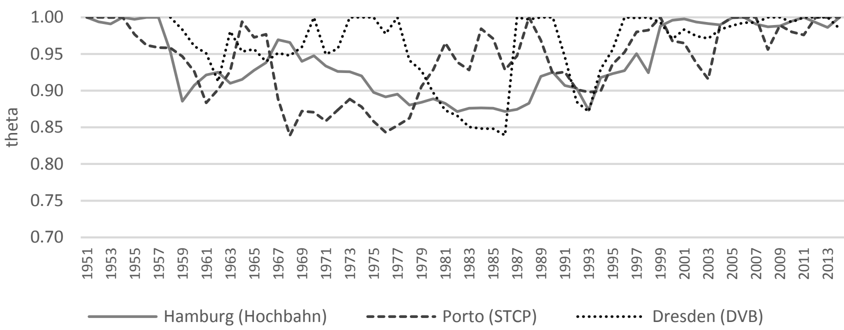


years	HH OPO	OPO DD	DD HH
overall	0.54	0.51	0.76
61-70	0.67	0.64	0.90
71-80	0.63	0.62	0.89
81-90	**0.86**	**0.78**	**0.84**
91-00	0.76	0.74	0.87
01-10	**0.86**	**0.88**	**0.97**

Similarity scores

Figure 6.6: Effectiveness over time.

Table 6.10 Similarity Es

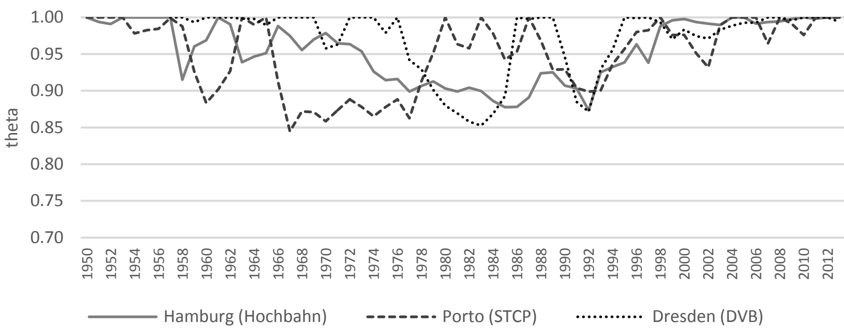


years	HH OPO	OPO DD	DD HH
overall	0.72	0.67	0.73
61-70	**0.82**	**0.82**	**0.90**
71-80	0.88	0.75	0.82
81-90	0.80	0.79	0.83
91-00	**0.92**	**0.93**	**0.88**
01-10	**0.90**	**0.92**	**0.96**

Similarity scores

Figure 6.7: Efficiency over time.

Table 6.11 Similarity Ey



years	HH OPO	OPO DD	DD HH
overall	0.70	0.65	0.76
61-70	0.79	0.77	0.90
71-80	0.83	0.76	0.87
81-90	0.80	0.78	0.83
91-00	0.93	0.93	0.90
01-10	0.92	0.94	0.97

Similarity scores

Figure 6.8: Mixed Performance over time.

Table 6.12 Similarity Mix

[254]For a comparative multi-level visualization using similar charts see also Pjevčević et al. (2012) in the case ports.

across operators. In contrast to the decision curves of Chapter 5, however, performance curves are not subject to the typical formations found in chart analysis. They are less volatile and less cyclical. This indicates that taking hardware/quantitative decisions is less flexible than taking software/qualitative decisions. For instance, the management might be able to change the schedule relatively swiftly but cannot simply dismiss 5% of its staff.

(R1.1) EFFECTIVENESS OVER TIME – 'PERFORMANCE EVOLUTION': Effectiveness curves refer to the demand side of public transport provision by using pax-km as output. This implies that the performance type might be particularly sensitive to changes in the demand behaviour. Figure 6.6 shows that **[1]** all three curves are approximately *u-shaped* with high effectiveness in early and recent years and an intermediate rather long phase of declining, low and then recovering performance. The finding of a *u-shaped* curve interestingly is in accordance with Costa (1998) and Movahedi et al. (2007) and suggest indications for a common pattern of performance evolution (also *"performance lifecycle"*) probably valid for all operators (which might have to be explored in future for theory construction). The first stage might be dominated by high demand levels, the later stage rather by appropriate input adjustments in combination with slight demand recovery (at least in Hamburg, Dresden). The downturn phase suggests that managerial adjustments were lagged, or could not keep pace with the decline of demand, or both. **[2]** The corresponding turning points for Hamburg and Dresden - which are the minimal performance scores per series - happened to occur in the 80s when the inputs adjustment eventually reached a break-even point offsetting the decreasing overall demand. Interestingly, an immediate input adjustment to demand (in combination with anyway deterioration material) appears to be the reason why Dresden coped quiet modestly with the severe passenger loss after reunification. However, this was an extraordinary one-off event. Under "normal" operating conditions, such a massive input decrease in staff (40% in five years from 1989 on) would be practically infeasible (keyword: unions). Porto again, displays two turning points, the first in the mid-70s (demand induced performance through social ticket introduction) and the later in the early 90s (resource induced performance). The decline after the demand increase in the late 70s until the second turning point could be seen as adjustment to the "normal" downward trend of public transport ridership at these times. One might also conclude that a sudden demand increase without proper resource and service adjustments might have led to capacity issues that worsened service quality to an extent that the upsurge was eventually annihilated, especially as the car was an omnipresent alternative. **[3]** Hamburg's curve movement is rather smooth in contrast to Porto´s and Dresden´s, which suggests less severe and sudden changes of external or internal nature in the service provision process than in Porto and Dresden. **[4]** As to the similarity scores

- which are much higher than those from decision modelling are - Dresden and Hamburg happened to be very similar overall (0.76). Specifically in the last decade, both operators are almost identical, which could be an indication for effects from the same regulatory environment. Porto shows high similarities with both operators in the 80s and most recently. Overall, the curves of all operators approximate towards full effectiveness in the last 20 years.

(R1.2) EFFICIENCY OVER TIME – 'PERFORMANCE EVOLUTION': Efficiency curves refer to service supply by using seat-km as output. Since this performance type is not directly affected by the demand side, it can be considered to be largely under *managerial control.* **[4]** Also the efficiency evolution for three operators is averagely *u-shaped*, when one considers the overall trend (a rather smoothed curve). There are several indications for intermediate episodes where performance "deteriorates" and "recovers". The partial volatility of these curves might essentially be taken as evidence of *managerial control*, i.e. the management´s actions/attempts to fix the production process through input or output adjustments at different times and different reasons. In so far, at least Porto and Dresden show several of these volatile, iterative adjustment phases, whereas Hamburg appears comparatively smooth. **[5]** The similarities scores demonstrate that in the 70s and in the last two decades efficiency patterns across the operators are very homogenous with a strong tendency to full efficiency in recent years.

(R1.3) MIXED PERFORMANCE OVER TIME – 'PERFORMANCE EVOLUTION': The 'mixed' or 'combined' performance model uses two outputs at once, namely seat-km and pax-km as the closest to real-life performance scenario. One might expect that the thetas scores lie somewhere between those of effectiveness and efficiency. However, plotting the curves of the 'one-output models' individually against those of the 'two-output model' reveals that **[6]** the latter corresponds largely to the *effectiveness model* in Hamburg and, contrarily, largely to the *efficiency model* in Porto and Dresden. This phenomenon is also produced by Costa (1998) over time or even cross-sectionally by Karlaftis and Tsamboulas (2012). It suggests that when one chooses two outputs simultaneously in DEA the demand-side output dominates the supply-side one in Hamburg and *vice versa* in Porto and Dresden. This may allow drawing conclusions about the management's orientation in terms of efficiency or effectiveness as discussed below. Due to the mixed performance model´s proximity to either of the other models, the interpretational focus herein will be limited to effectiveness and efficiency only.

(R1.4) EFFECTIVENESS VS. EFFICIENCY OVER TIME – 'PERFORMANCE ORIENTATION': The supposed relation of both scores as opposing objectives in public transport has been intensively discussed in Chapter 3 and 4. **[7]** However, the significant correlation statistics show consistently

positive and rather strong relations for all operators: Hamburg ($r = 0.92$), Porto ($r = 0.83$), Dresden ($r = 0.67$). This implies that for the larger share both indicators move in the same direction, slightly more in Hamburg and Porto, than in Dresden. To further assess the relation for each operator visually, the effectiveness curve was subtracted from efficiency curve in order to achieve a *balance score*, which in fact is the unsquared distance between the two curves per year.[255] Accordingly, three outcomes are observable: *First,* a positive score (efficiency is located "above" effectiveness) suggest that the operator appears to value efficiency over effectiveness. *Second,* in case of a negative balance, (efficiency is located "below" effectiveness), the operator would be managed in favour of effectiveness. *Third,* a score of zero (or close) would indicate that the two objectives are *balanced* as both objective have (roughly) the same theta value.

Figure 6.9 below displays the development of the balance score over time for the three operators, leading to the following findings: **[8]** There are in fact significant differences between the operators concerning the tendency to one of the objectives over time. *Hamburg* is slightly

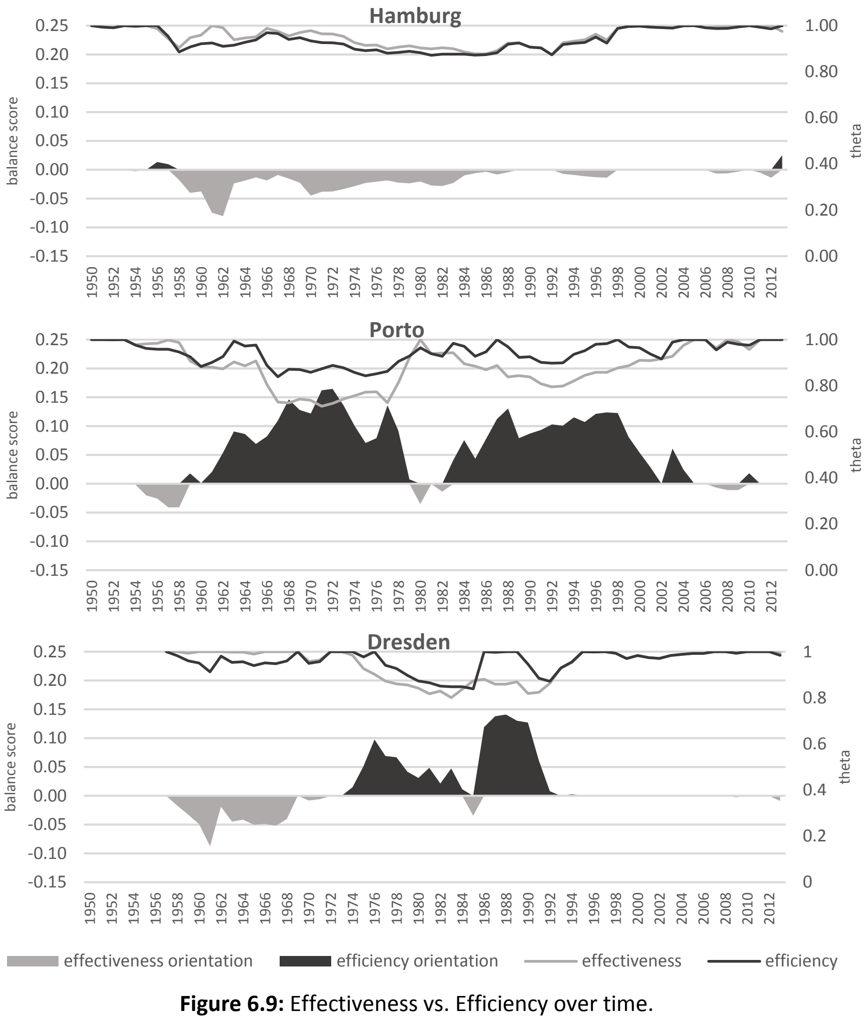


Figure 6.9: Effectiveness vs. Efficiency over time.

255 With reference to the Efficiency-Effectiveness Matrix (EEM) proposed by Costa (1998) the annual distance is used instead of a ratio. First, it is unclear how to interpret a ratio meaningful as it suggests that objectives are in a proportional relation. Second, the information from the EEM would be hardly recognizable when capturing 64 years.

more effectiveness- than efficiency-oriented in the early years, but practically balanced since the mid-80s. Only in 2012 - probably due to the crisis - the operator focuses more on efficiency. *Porto* is clearly efficiency-oriented until the mid-70s when objectives approximate and even slightly change position in the early 80s. However, with the loss of passengers as described above, the operator re-establishes efficiency policy until the end-90. Notably, the appearance of Metro do Porto briefly triggers a last relapse to efficiency orientation, displayed in the isolated peak around 2003. *Dresden* illustrates a good mixture of the former approaches by being first effectiveness-oriented until the early 70s, and then efficiency-oriented, peaking in the intense restructuring around the 1990, which is followed by a balanced phase until most recently. **[9]** That operators keep their performance orientation for a while points at the existence of a consistent, corporate management culture in that time. **[10]** It can be said that over the long run, efficiency and effectiveness are balanced for all operators (long term balance score equals zero). This implies that in recent years effective operators also tend to be efficient. However, the balance is achieved rather abruptly in Porto and Dresden and gradually in Hamburg. In addition, one could speculate, which role regulation or governance play, as Dresden achieves balance only when starting to operate under similar regulatory and economic condition as Hamburg. **[11]** The initial assumption that the effectiveness-efficiency relation can be understood as an iterative, oscillating process swinging from one objective to the other can only be partially confirmed: The curves show several peaky structures.[256] This suggest that the management changed performance-orientation. However, many of the peaks are just fractions of a larger trend in one direction. In so far, negative correlations indicated by other studies could in fact simply express temporary states.

Overall, Hamburg appears to be a rather *effectiveness-oriented* operator (which equates to service- and customer-orientation) whereas Porto and Dresden are *efficiency-oriented* operators (which equates to resource-orientation). Interestingly, these findings can be supported by the results in the decision-modelling chapter (see findings (11) and (12) in 5.5).

(R2.1) WEIGHTS OVER TIME – 'PERFORMANCE INITIATORS': Weights[257] in DEA have two functions. *First*, they show to which extent an input (net length, vehicles, staff) or output variable (pax-km, seat-km) contributes to the calculation of the final performance scores in the respective performance model. Similar to the concept of elasticity (see Chapter 7), this can be expressed as quantification of the unit change of performance caused by the change of a variable by one unit. *Second*, when weights are compared they can be treated as a measure of

[256]Peak structure: multiple occurrences of increasing (decreasing) then decreasing (increasing) *balance scores*.
[257]Also termed multipliers or shadow price. See Fried et al. (2008) p.59 and Førsund (2015).

the *relative importance of variables* in the DEA model (as mentioned above, the real weights are unknown, thus the model creates them in the optimization process).[258] In so far, one might be able draw conclusions upon when, which variable “causes” performance (positively or negatively) as well as related comparative dynamics over time. For example the larger a strand in one of the area charts below is, the more the variables contributes to the performance score.[259] Findings from Figure 6.10 are given in the following. The two most dominant variables are briefly outlined, when needed in stages.

HAMBURG: As to *effectiveness*, the data suggest that **[12]** all variables play crucial roles, but at different times: ‘early’ (*pax-km, vehicles*), ‘middle1’ (*net length, staff*), ‘middle2’ (*vehicles, net length*), ‘recent’ (*staff, pax-km*). **[13]** Effectiveness originating from *pax-km*[260] in Hamburg’s early years can be considered a ‘demand-risk’. In contrast, it could be seen rather as a ‘demand-

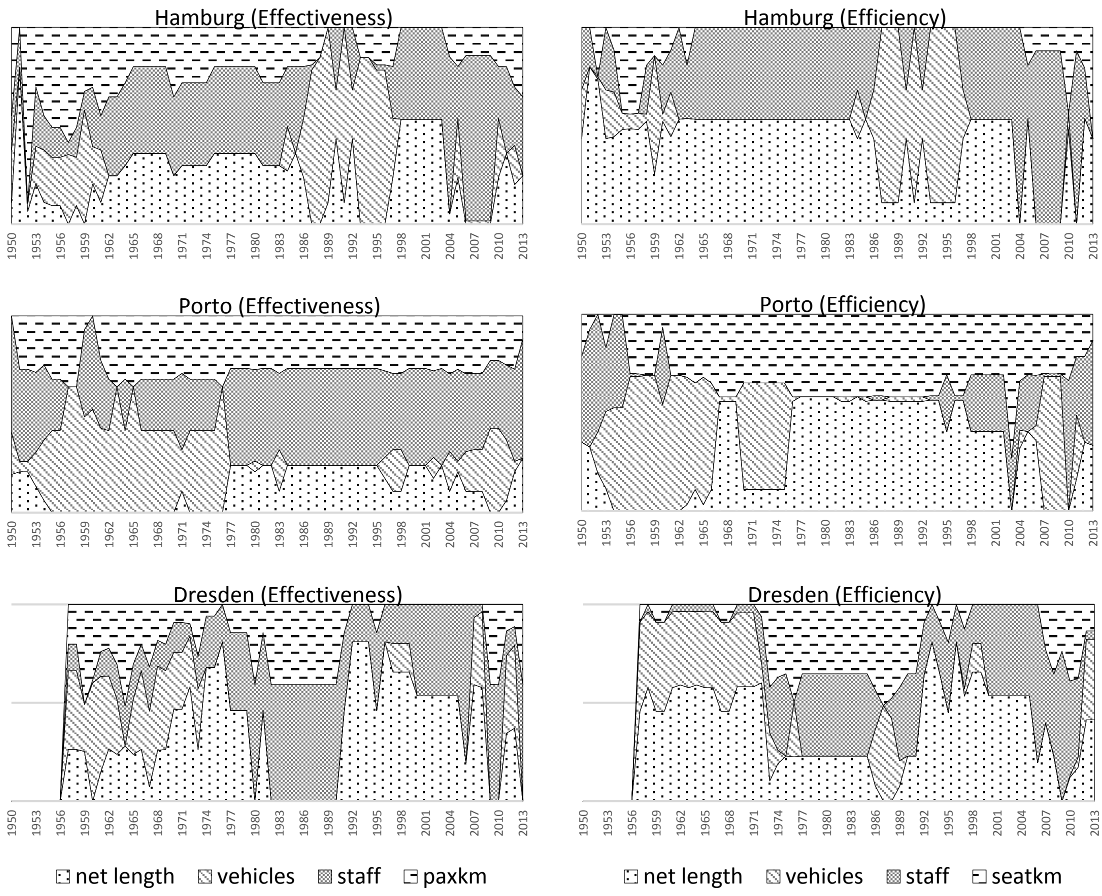


Figure 6.10: DEA weights over time.

[258]Inspired by Nacif et al. (2009), one might also *a priori* assume a relationship among variables expressed as a ratio between the weights assigned to the related variables.

[259]In further research, one could establish a link by relating the share of contribution of a variable to the performance score with the level of performance. This then precisely quantifies the importance of a variable conditional to a performance level, as the results indicated that the importance of variables changes over time.

[260]To explain the role of *pax-km* one might have to refer to the concept of *managerial control*. When performance comes from variables under control of the management, the operator appears less exposed to external effects. In the case of demand, these effects can be positive (‘demand-opportunity’ = increase/stable ridership) and negative (‘demand-risk’ = decreased ridership). To make inferences in this regard one has to look at the raw passenger data.

opportunity' most recently. **[14]** Hamburg's *efficiency* chart shows that the main causes of performance are *net length* and *staff*, the latter of which is partly replaced by *vehicles* from the mid-80s until the mid-90s. The result is consistent with DEA theory, as mostly inputs create efficiency, over with the management has full control.

PORTO: **[15]** For *effectiveness* two stages can be defined: 'early' (*vehicles*, *pax-km*), 'recent' (*staff*, *net length/pax-km*). Interestingly, the latter stage shows relatively stable, balanced proportions of input contributions. However, in both stages a considerable contribution to performance comes from *pax-km* (about 1/3). This suggests that Porto is more vulnerable to negative demand effects once demand declines. **[16]** Porto´s *efficiency* is built on three stages. The performance distinctly stems from *seat-km* in combination with *vehicles* ('early') or *net length* ('middle') or *staff* ('recent'). Since this output type is assumed largely under control of the management, it can be concluded that managerial skills and capabilities in operations/service supply are pivotal for Porto´s performance outcome.

DRESDEN: **[17]** The effectiveness chart of Dresden shows three stages: 'early' (*pax-km*, *vehicles/net length*), 'middle' (*staff, pax-km*), 'recent' (*net length, staff*). Similar to Hamburg this implies that 'demand-risk' is "reduced" over time and transforms to 'demand-opportunity' most recently. **[18]** The *efficiency* chart of Dresden also marks three stages demonstrating that, except for the 70s and 80s, the key resources in the hand of the operator affect performance: 'early' (*net length*, *vehicles*), 'middle' (*seat-km*, *staff/vehicles*), 'recent' (*net length/staff*). Most recently, service supply appears to return an as important factor for performance.

With regard to the performance initiators, three key findings are made in summary.

- *Effectiveness* appears rather controllable in Hamburg and Dresden since it is majorly caused by controllable input variables. When caused by the uncontrollable output variable it might then be more a positive than a negative considering the recent demand development in both cities. Effectiveness in Porto however seem only in parts controllable with conventional inputs; a large share of performance stems from the demand side, which poses a continuous risk for the operator in times of falling ridership.
- *Efficiency* in Hamburg is clearly determined by inputs, as it is largely in Dresden. This suggest high levels of managerial control. In contrast, Porto´ efficiency appears to be rather determined by the output, which might be also a sign of high managerial control in case the operator really has a hold over supply.
- The overall ranked importance of inputs across the two models for each operator are as follows: Hamburg (1. net length, 2. staff, 3.vehicles), Porto (1. net length, 2. staff/vehicles), and Dresden (1. staff, 2. net length, 3. vehicles). The findings suggest that network exploration coupled with staff adjustment might have been important hardware management decisions.

(R2.2) WEIGHTS OVER TIME – 'AVERAGE CHANGES TO ACHIEVE PERFORMANCE TARGET': DEA weights allow for estimating what average input or output changes an operator would need to achieve a given performance improvement target. This innovative proposal is inspired by Cooper et al. (2007) p. 79/80 and should be understood as a gross estimation based on the marriage of average variable weights and average variable input levels of Appendix 8.[261] Table 6.13 exhibits the average absolute and relative changes per input or output variable required for a performance change of 0.01 points.[262] **[19]** *For instance*, if Porto´s operator was efficiency-oriented, it would have to dismiss circa 70 workers (-2.3%), sell seven vehicles (-1.4%) or cut the network by 6 km (-1.6%) to achieve 0.01 points of efficiency increase with input measures (while keeping outputs constant). Alternatively, the same efficiency growth could be achieved by increasing seat-km (+1.6%) while keeping the inputs constant.

Table 6.13: Changes of inputs or output to achieve 0.01 points performance increase ($\approx 1\%$).

Operator / Variable		net length (km)	vehicles (#)	staff (#)	output (km)	net length (%)	vehicles (%)	staff (%)	output (%)
Hamburg	eff-ness	-19	-31	-113	+138*	-2.5	-1.9	-1.9	+1.6
Porto	eff-ness	-13	-9	-52	+48*	-3.8	-1.7	-1.7	+2.3
Dresden	eff-ness	-7	-14	-68	+108*	-1.8	-2.3	-2.0	+2.2
Hamburg	eff-cy	-13	-36	-111	+186**	-1.8	-2.2	-1.9	+2.2
Porto	eff-cy	-6	-7	-70	+33**	-1.6	-1.4	-2.3	+1.6
Dresden	eff-cy	-7	-16	-75	+110**	-1.9	-2.6	-2.2	+2.2

*x10^6 pax-km, ** x10^6 seat-km

(R3) LAMBDAS OVER TIME – 'PERFORMANCE STARS/BEST YEARS': Methodologically, DEA creates a number of *efficient peer-years* or benchmarks $p = 1 \dots n$ that constitute the performance frontier. The model then calculates so-called *lambdas* λ_{mp} for each inefficient year $m = 1 \dots k,\ k < n$. Lambdas indicate which of the *efficient peer-years* p contribute to the efficiency evaluation of m and to which proportion. Consequently, each lambda λ_{mp} establishes a link between an inefficient year m and an efficient year p. Obviously, the year m can have multiple peers p and thus multiple lambdas λ_{mp} that sum up to unity for each year m. For a year m to become efficient, theoretically, its lambdas λ_{mp} could be used to calculate the required input or output changes based on the inputs and outputs of the corresponding efficient peer-years p (see an example Cooper et al. (2007) p. 54). Here a slightly different approach is proposed. All lambdas λ_{mp} that refer to one specific peer-year p are summed up. The resulting score is then compared to the sums of lambdas of other peer-years with regard to their relative referencing magnitude P_{rel}.[263] This allows to rank and assess peer-years and to identify the most

[261]As the weight tables in Appendix 13 show, *the unit change of performance per one unit change of a variable* in mean-normalized data had to re-transformed to original units in order to achieve meaningful results.
[262]Considering the average performance scores, this is a bit more than 1%.
[263]$P_{rel} = \sum_{m=1} \lambda_{mp} / \sum_{p=1} \sum_{m=1} \lambda_{mp}$ with $\sum_{p=1} \sum_{m=1} \lambda_{mp}$ = Number of years(DMUs). Appendix 13 "lambda tables".

extensively referenced benchmarks *("the best of the best" or "performance stars")*.[264] The results may indicate peaking management capabilities and practical advice for managers to potentially readjust their operations to these specific years or key benchmarks. Note that the "more recent" the exemplary years are, the more feasible would an analogous adjustment of the input-output relation be from managerial perspective. Table 6.14 displays the findings in terms of ranking and referencing magnitude per model. For instance a score of 0.33 for 2005 says that around 1/3 of the overall effectiveness evaluation in the model referenced to year 2005. When defining a key benchmark as $P_{rel} > 0.1$ to occur within the last 10 years, **[19]** at least one can be found for almost all operators. For Hamburg, its 2005. In Porto, the most recent benchmark is 2005 for effectiveness; however, none could be found for *efficiency* (the closest important efficiency benchmark is 1998). For Dresden, the most recent benchmark for both indicators is 2007. To which extent which benchmark-year evaluates other years is visualized more detailed in Appendix 14 for each operator separately in the style of Figure 6.11.[265]

Table 6.14: Ranking of benchmark years by relative referencing magnitude. Grey=most recent benchmark.

Hamburg				Porto				Dresden				Dresden (cont.)			
effectiveness		efficiency		effectiveness		efficiency		effectiveness		efficiency		effectiveness		efficiency	
2005	0.33	2005	0.67	1953	0.32	1998	0.22	1973	0.28	1974	0.16	1957	0.02	2011	0.02
2010	0.24	1953	0.13	1980	0.25	1950	0.19	1997	0.15	1957	0.13	1958	0.02	2010	0.02
2012	0.10	2010	0.06	**2005**	0.15	1987	0.18	**2007**	0.14	**2007**	0.12	2012	0.02	1976	0.02
1953	0.10	1950	0.06	1951	0.07	1953	0.17	1972	0.07	1997	0.11	1968	0.02	1986	0.02
1950	0.06	1955	0.05	2008	0.06	2011	0.06	2010	0.05	2008	0.10	1967	0.02		
1961	0.06	1956	0.02	2012	0.05	2006	0.05	2008	0.05	1972	0.07				
1955	0.04	2013	0.02	2011	0.04	2005	0.04	1962	0.04	1969	0.06				
2004	0.03			1952	0.02	2004	0.03	1961	0.03	1989	0.06				
1954	0.03			2013	0.02	1951	0.02	2011	0.03	1988	0.03				
				1950	0.02	2013	0.02	1969	0.03	1973	0.03				
						2012	0.02	1960	0.03	1995	0.03				
								1966	0.03	2012	0.02				

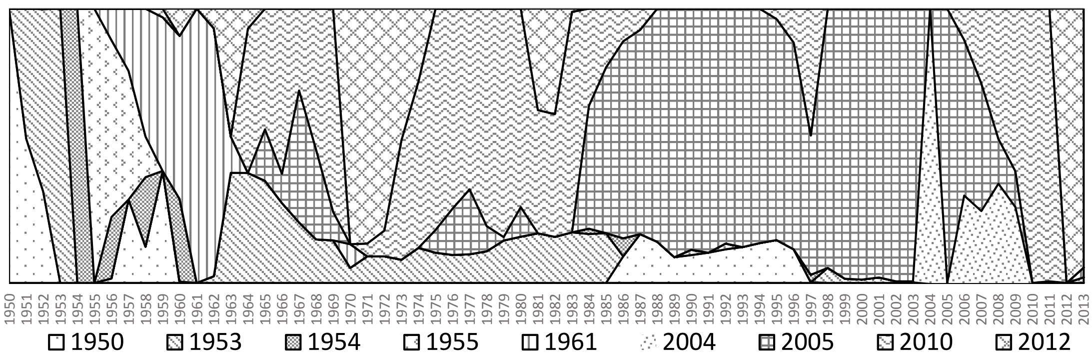


Figure 6.11: Lambdas over time. Example Hamburg.

(R4) SLACKS OVER TIME – 'RESOURCE DISSIPATION AND MANAGERIAL RESPONSE': Finally, one could use the slacks calculated in DEA to estimate the average resource dissipation and see how the management responded in terms of adjustments. Slacks are unnecessary use of inputs (so-

[264]Using a ranking is inspired by Movahedi et al. (2007) p. 1576, who simply rank the by highest efficiency score.
[265]The chart clearly shows the power of the BCC - VRS model that just compares similar DMUs.

called excess)[266] that could be have been avoided in a specific year without sacrificing output and without the need to adjust the input mix by input substitution (see example in Cooper et al. (2007) p. 80/81, Cooper et al. (1995) p. 107, Chen et al. (2012)).[267] Reducing inputs without harming service provision is the simplest way for managers to improve performance. Then slacks over time essentially capture to which extent this option was forfeit by the management. Figure 6.12 gives the differently grey-shaded slack shares of the input variables in percentages[268] in area charts (='input dissipation per input level in a specific year') plotted against the analogously coloured corresponding input curves in line charts (='managerial reaction'). An adequate managerial response to input dissipation would be a somewhat lagged downward adjustment of inputs. This would indicate the existence of a managerial "sensitivity" towards the state of input productivity. However, it should be stressed that public transport networks (net length) cannot simply be dismantled from one year to the next, especially when composed of a large share of physical infrastructure (metro, tram). Thus, a net length excess in combination with a constant network expansion might also be considered a concession for future demand

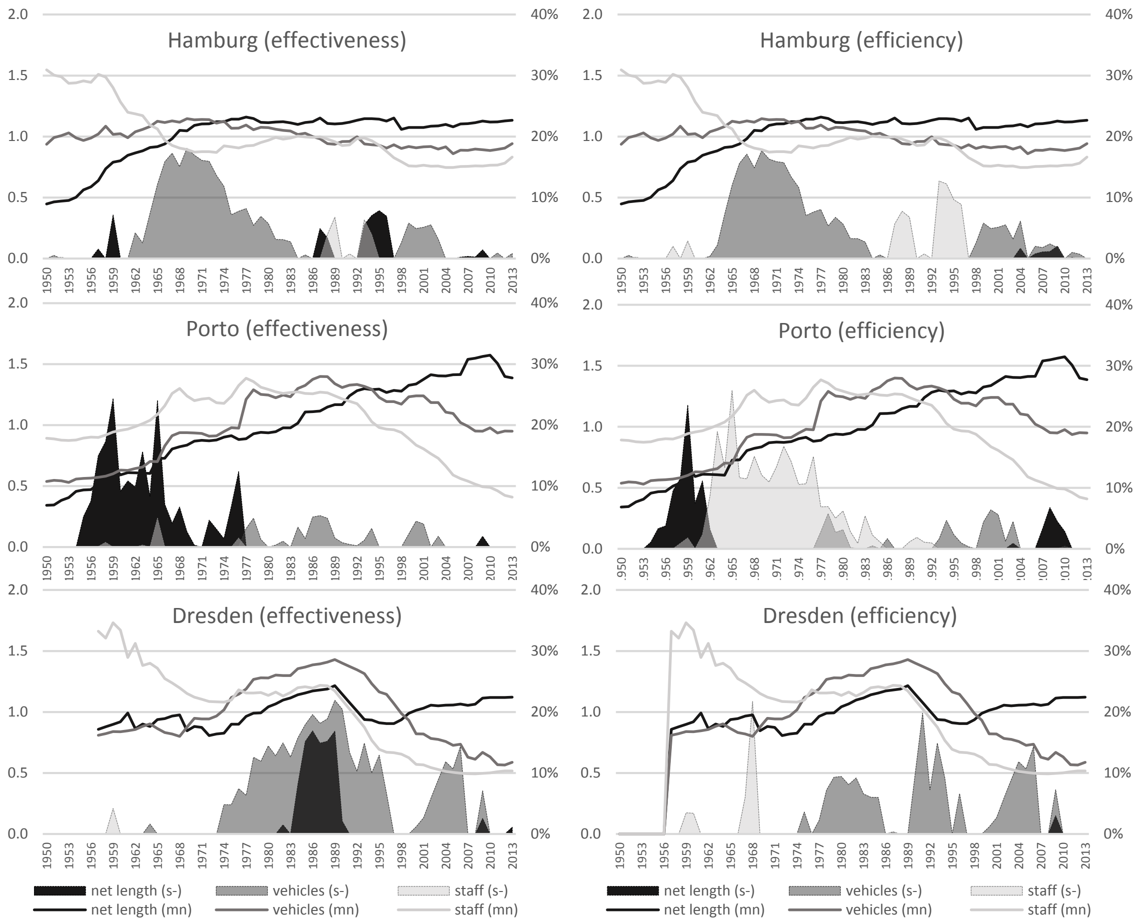


Figure 6.12: Input excess over time.

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[266]As mentioned slack can also be refereed to outputs which is are not discussed here but shown in Appendix 15.
[267]With regard to the contribution-to-performance issue discussed above it should be outlined that years with slacks do not contribute to the performance score, as they receive a weight of zero in the model.
[268]The slack share per year is the ratio of slack (Appendix 13) to mean-normalize raw data score (Appendix 8).

(anticipation) and not necessarily managerial failure or a negative response. For instance, **[20]** *Hamburg´s* performance curves display a large excess of vehicles from the 60s to 70s, which subsequently reduces since the input curve shows that new acquisitions were comparably modest as a consequence. In addition, the slight net length excess in the mid-90s seems to be cut rather swiftly, probably in the more flexible bus network. The efficiency curve further shows that the operator is overstaffed from the mid-80s to the mid-90s, which appears to be resolved through immediate staff dismal by the end-90s. *Porto´s* effectiveness curve shows **[21]** net length excess until the mid-70s, which is exactly reduced in the subsequent demand surge. The slight excess of vehicles is answered with a constant fleet adjustment during since the mid-80s on. The efficiency curve additionally demonstrates that Porto is massively overstaffed during the 60s and mid-70s, which appears to be adjusted accordingly until the mid-90s. *Dresden´s* slack charts are different from the previous ones. Concerning effectiveness and efficiency, the charts clearly exhibit management failure, peaking in the late 80s. By that time, inputs were constantly increased, however over-proportionally to the rather weak demand growth, which led to a significant excess in vehicles and net length. This was probably due to economic five-year plans, which had to be fulfilled at all costs, based on supposedly flawed forecasts. The corrective action was then taken after 1990 by cutting the inputs drastically as discussed. Probably a large bus and tram order in the early 00s created another vehicle excess, which is later corrected when aligning with the slightly stabilizing demand and further scraping of older vehicles. Excessive overstaffing was only an issue in the late 60s in Dresden.

(R5) SCALE EFFICIENCY OVER TIME – 'OPERATOR SCALE/SIZE': Scale efficiency relates to the question whether "*bigger is better*", i.e. if the scaling up of operations creates additional performance gains besides technical efficiency. An operator might be technically efficient and located on the frontier, but still could increase factor productivity by adjustment of its scale (see Figure 3.2 in Chapter 3). The scale - also "size" - is a measure for the magnitude of operations, usually the output.[269] The higher the scale efficiency, the closer the operator is at its optimal scale, which is given by a scale efficiency of 1 (see Cooper et al. (2007) p. 158 and Coelli (2005) p. 172 for further read).[270] Performance effects from the scale of operations is of interest for the regulator, particularly when it comes to mergers. To assess the evolution of operator size over time one might simple observe scale efficiency over time. Scale efficiency is defined by the ratio of the technical efficiency scores from CCR and BCC model. Thus, for the effectiveness and efficiency models, first the performance scores of a DEA-CCR model assuming CRS are calculated

[269]Termed scale economies, when the output increases and scale efficiency does equally (vice versa).
[270]It should be explicitly stressed that one might also be scale efficient but technically inefficient simultaneously.

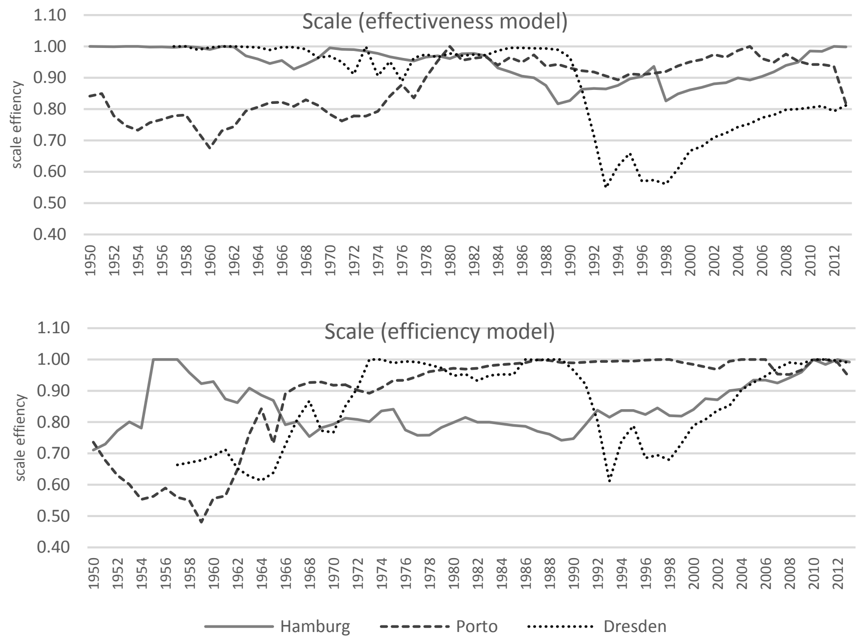


Figure 6.13: Scale efficiency over time.

for each model and then divided by those of the DEA-BCC with VRS (see Appendix 16). The result are displayed in Figure 6.13. As to the effectiveness model, *Hamburg* shows **[21]** almost optimal size until the mid-80s, then a declining one with decreasing returns to scale and most recently aiming at optimal size again (kind of u-shaped). This suggests that the operator was too small[271] in the intermediate phase (higher output levels would have been better) and that the "involuntary" downward trend in pax-km damaged productivity gains from scale. In contrast, in the efficiency model, Hamburg appears to be about 20% too big from the mid-50s on until 2000, but is recently approaching optimal size.[272] *Porto´*s effectiveness and efficiency model exhibit that **[22]** the operator works near optimal size already since the early 80s (maybe 10% too big in effectiveness), as opposed to the phase before (up to 30% too small). The conclusion here is that a gradual approach to downsizing avoids losing performance gains from optimal size. However, it seems that in particular the financial crisis of 2011 reduced scale efficiency in Porto significantly. **[23]** The effectiveness model of *Dresden,* however, illustrates a mirror image to Porto. It is relatively close to optimal size until 1990 and then about 40% too small and 20% most recently. The efficiency model of Dresden illustrates that the operator was too small until the early 70s, then operating on optimal size until 1990 and, again, too small until the end 90s. This suggests that the restructuring measures after 1990 eliminated any performance gains from size (but obviously increased technical efficiency tremendously as shown above). Dresden has most

[271]*"Too big"*=opposite direction of output and scale efficiency: output increases→scale efficiency declines (diseconomies of scale); *"too small"*=same direction of output and scale efficiency: output increases→scale efficiency increases (economies of scale). Dimensions refer to the optimal size with the highest productivity achieved.

[272]These points at a dilemma between efficiency and effectiveness in public transport. Sometime the supply has to be kept high at an "inappropriate scale" while facing pax-decline, also on an "inappropriate scale".

recently returned to optimal size. Table 6.15 summarizes the descriptive statistics for the scale efficiencies of each operator.

Table 6.15: Descriptive statistic scale efficiency.

operator	Hamburg		Porto		Dresden	
model	Effectiveness	Efficiency	Effectiveness	Efficiency	Effectiveness	Efficiency
mean	0.94	0.85	0.87	0.88	0.87	0.86
SD	0.05	0.08	0.09	0.16	0.14	0.13
min	0.82	0.71	0.68	0.48	0.55	0.61
max	1.00	1.00	1.00	1.00	1.00	1.00

When compared to Table 6.7 it can be concluded that **[23]** the average scale efficiency is considerably lower than average technical efficiency for all operators and models. This suggests that operating on the appropriate scale appears much harder to achieve than becoming technically efficient. **[24]** The larger operator Hamburg displays a higher scale efficiency in the effectiveness model than Porto and Dresden. Those in turn account for higher scale efficiency with regard to the efficiency model. This confirms the managerial orientation of either effectiveness or efficiency and might suggest that larger operator are less likely to find the optimal scale for efficient production than smaller operators. **[25]** However, over the long run all operators produce close to technical efficiency *and* scale efficiency in the efficiency models.

6.5 Summary of Results and Interpretation

"What can be learnt from production data of operators over time?"

(1) *Changes in inputs and outputs* seem to occur rather gradually than erratic and volatile. *First*, this suggest that operator management might rely on substantial levels of planning. *Second,* contractual commitments might constrain managerial flexibility with regard to ad hoc input and output adjustments. *Third*, with reference to the terminology of this research, it can be said that taking hardware/quantitative decisions seems less flexible than taking software/qualitative decisions.

(2) *Network size:* Net lengths expand over time up to a saturation stage. However this happens in different shapes for each operator (growth-curve-like or linear).

(3) *Fleet size:* At some point fleet size decreased for all operators. However, vehicles simply get larger over time, offering a higher capacity per vehicle.

(4) *Personnel:* Over time, the number of employees is massively reduced in this sector, however, at different stages of the operators. In general, Porto and Dresden appear heavily overstaffed in comparison to Hamburg.

(5) *Energy costs:* Operators do not seem to have any resilience (strategy) against rising energy prices except of fleet modernization.

(6) *Demand effects*: Hamburg mitigated and even reversed the negative effects from private motorization over time. Porto and Dresden are seriously affected overall. This might show that smaller operators are less resilient against demand shocks.

(7) *Investment:* Different types of investment policies are identified: a constantly high investment with infrastructure focus (Hamburg), a comparatively low investment with

a balance between vehicles and infrastructure spending (Porto) and a mixed-policy in Dresden. Rail-based operators Hamburg and Dresden need vast amounts of money for maintenance and expansion as opposed to the “cheaper” bus network in Porto. Massive post-reunification investments in Dresden might have reversed car-induced passenger decline. In contrast, the lack of infrastructure investment in Porto may have worsened/accelerated overall passenger downturn in the sector.

(8) As to operational and technical features, the data suggest the following: (a) *journeys* get shorter over time (or people travel less but longer). (b) *System speeds* tend to increase over time but appear capped recently, supposedly due to technical regulations (rail) or congestion in the road network (bus). Speed is much higher for operators with a higher share of rail-based infrastructure. (c) Across all operators, o*ccupancy rates* decline to a steady baseline of about 17% regardless of the mode-mix, city size, or structure.

“How does operator performance behave over time? Are there similarities across operators?”

(9) Performance increases over time; inefficiencies in public transport decrease.[273]

(10) The average overall performance is around 90%. This means that in 64 years the operators deviated averagely 10% from the performance frontier.

(11) Performance curves are less volatile or cyclical than decision curves, due to (1). The long-term plots seems to indicate some degree of managerial control over input and output quantities since the partial volatility of the curves appears to show managerial attempts to fix the production process by input or output adjustments (Porto, Dresden).

(12) Performance curves over time are approximately *u-shaped* with high scores in early and recent years and an intermediate rather long phase of declining, low and then recovering performance. In accordance with previous studies, this point at the existence of a common pattern of performance evolution (termed *“performance lifecycle”*) for public transport operators, as well as consistent managerial ambitions towards performance improvement over the long run, regardless of the measures taken.

(13) Performance appears sensitive to political and regulatory changes in the short- and middle term, which take effect mostly through demand shocks. Over the long-term, however, performance appears to be rather affected by major trends in the local transport market (such as car use) and the corresponding managerial responsiveness and flexibility (which might be linked of political flexibility either). Therefore, the performance downturn of all operators suggests that managerial adjustments were lagged and/or could not keep pace with declining demand.

(14) The same regulatory environment seems to produce similar performance curves (Dresden and Hamburg since 1990).

(15) High similarity scores (much higher than those from decision modelling) confirm the large similarity between operators. Specifically in the last decade, operators are almost identical for all performance models.

“What is the relation of operator efficiency and effectiveness over time? Are there similarities across operators?”

(16) The correlations between the two dimensions say that both indicators tend to move in the same direction over time. Thus, they cannot be regarded as opposing objectives over

[273]Notably, the average annual inefficiency/ineffectiveness decrease for operators is roughly the 30% from Margari et al. (2007). They can reduce the performance gap by maximum 1/3 per year. On average, the annual “productivity” change rate (growth) is in a range of 0.24-0.70%. The magnitude seems in lines with results from Atkinson et al. (2003) p.293 and Borger and Kerstens (2006): *“productivity growth is […] at best mildly positive”*.

time in general. The negative correlations reported in other studies could in fact simply express temporary states.

(17) There might exist some form of effectiveness- or efficiency-orientation of operators, i.e. one of these scores is consistently higher. Hamburg appears to be an effectiveness-oriented operator; Porto and Dresden are rather efficiency-oriented.

(18) Over the long run, efficiency and effectiveness become balanced objectives for all operators. This implies that in recent years effective operators also tend to be efficient.

"Can one derive other meaningful measures from the performance time-series?"

(19) *Performance initiators:* performance seem to be controllable in Hamburg and Dresden as performance contributions mostly come from inputs. Porto seems more exposed to output obligations or demand shocks, as large performance contributions come from seat-km or pax-km. Overall, network exploration coupled with staff adjustment appear to be the most important quantitative input measures.

(20) *Performance changes:* the average changes per input variable for an envisaged performance target differ between operators. For instance Porto would have to dismiss around 70 workers (-2.3%), or sell seven vehicles (-1.4%) or cut the network 6 km (-1.6%) to achieve 0.01 points of efficiency increase with input measures, *ceteris paribus*.

(21) *Key benchmarks, best years:* Influential benchmarks in both models occur in recent years and indicate peaking management capabilities: Hamburg 2005,2005; Porto 2005,1998 Dresden 2007,2007. Managers could readjust their operations to these specific years.

(22) *Resource dissipation and sensing*: 'Overfleeting', 'overstaffing', 'overinfrastructuring' are common problems of the operators. However, the results indicate some form of managerial intuition about the state of (in)productivity indicated by taking responsive actions or at least anticipating the market development correctly in Hamburg or Porto. Dresden shows that management failure leads to harmful vehicle and network excess.

(23) *Scale efficiency:* The relation to the optimal scale over time shows different patterns per operator and performance type. Similarity can only be found in Dresden´s and Porto's linear or growth-curve-like behavior. In the long term, all operators produce close to technical *and* scale efficiency at least in the efficiency model. Overall, the results indicate three conclusions: (a) A gradual approach to downsizing avoids losing performance gains from optimal size. (b) Operating on the appropriate scale appears much harder to achieve than becoming technically efficient. (c) Smaller operators (Dresden and Porto) may be more suitable to produce service on optimal scale and technically efficient than larger operators (Hamburg).

"Can one derive further information from the time-series?"

(24) *Porto* shows soaring fare-box losses over time, supposedly because the operator is "obliged" to keep a certain supply-level despite constantly losing customers.

(25) *Porto´s* operational speed curve over time indicates a rather stationary stage since the mid-90s. Porto´s capacity for further speed increases seems limited by regular traffic.

(26) *Porto´s* subsidies increased and the bus fleet age reduced considerably after 2000 with the appearance of Metro do Porto, which indicates positive effects from competition.

(27) *Economic system*: (a) The importance of public transport in the GDR (caused by the absence of affordable cars) is underlined by the fact that the much smaller Dresden had roughly the same number of passenger in the 60s as Hamburg. (b) Unrealistic five-year plans might have led to high resource dissipation in the GDR. (c) In 90s, the introduction of market economy with cost-oriented fare setting increased revenues significantly.

7 Decisions *and* Performance

7.1 Introduction

Conventional performance analysis in public transport is usually only concerned with modelling effectiveness or efficiency levels. Most recently, however, the role of discretionary or non-discretionary factors as potential sources of performance are being assessed more often, particularly in non-parametric set-ups. A common practice is to run DEA and then regress the emerging performance scores on the supposed explanatory data, labelled a *two-stage DEA*. The core idea of this method is that an explanatory factor of whatever nature might explain the distance to the efficiency frontier. Despite some theoretical draw-backs[274], *two-stage DEA* offers a good experimental design to test for effects from a wide range of explanatory variables, especially in combination with a self-referencing DEA framework over time (Avkiran, 2006; Coelli, 2005). As demonstrated before, the incorporation of *managerial decisions* in a two-stage DEA has yet rarely been studied. Thus, the basic assumption of this chapter is that sets of independent *managerial decision* and *external variables* (from Chapter 3 and 4) determine the dependent *performance* variable (from Chapter 5). The holistic research questions are: *To which extent do managerial decisions affect operator performance over time? Are there similarities across operators?* One way to model this *'decision-performance link'* is the OLS technique, which becomes time-series regression when longitudinal data is involved. Time-series regression offers new opportunities (assessment of lagged effects), but also poses methodological challenges (correction for correlated error terms). This chapter contains four sections. *First,* the scope of

[274]Daraio et al. (2016) claim that in a cross-sectional set-up, two-stage DEAs are often misused and questionable as to their statistical framework and validity (e.g. *truncated data*) and strong assumptions (e.g. '*separability condition'*). For instance, the 'separability condition' requires that explanatory factors of performance do not influence the performance frontier itself, but only the distances of an observation to the frontier. It should be stressed that in a time-series, self-referencing DEA framework this assumption appears less strong, especially when efficiency gains are assumed "catch-up" effects rather than shifts of the efficiency frontier.

analysis and the key outputs are explained. *Second,* the theoretical foundations of time-series regression are assessed, such basic statistical assumptions, methodological issues and the model building procedure. The *third* part focuses on modelling, its main objectives, data enhancement and transformation measures as well as the representation of the holistic modelling framework. Further, the *excursus section* introduces the software package used and shows the modelling steps exemplarily. In the *fourth* section, results are presented and discussed extensively.

7.2 Scope of Analysis and Key Outputs

In spite of recent efforts to deepen the understanding of the link between managerial decision-making and performance, it seems that much of the supposed inter-relation remains rather fuzzy and complex. The following section sets the scope and limitations of the present research and the underlying decision framework in accordance with Costa et al. (2014). Inferences about effect sizes of managerial decisions and their temporal dimensions are the centrepiece of this analysis. Thus, this section further highlights the key output goals of this chapter. Table 7.1 below summarizes the expected functioning between, resources, decisions and performance.

SCOPE/LIMITATIONS

(1) *MICRO-LEVEL SCALE*: In contrast to a macro-level perspective, i.e. effects of policy or public spending programs on governmental entities, herein effects of aggregated managerial decisions of an *operator* on its performance are analysed and quantified.

(2) *MULTIPLE DECISION LEVELS*: Several authors argue that the value of decisions is realized through a chain of relationships within the organizational structure of a company/operator. Multilevel models evaluate how factors or variables measured at one level might interact with variables at another level with regard to global operator performance[275]. This is covered by the different decision levels displayed in Figure 5.3.

(3) *UNI-DIRECTIONAL EFFECTS:* The analysis of the decision-performance link assumes merely unidirectional, causal effects in which managerial decisions are taken with the primary intention to improve (or stabilize) operator performance (as opposed to a multi-directional effects where performance causes managerial behaviour[276]).

(4) *LINEARITY OF EFFECTS*: Despite beeing rather of theoretical nature, the relationship between managerial decisions and operator performance is assumed a simple linear one. This may simplify the logic and predictability of managerial action, best in the sense that measure 'A' leads to effect 'Q' in a fixed proportion. Linearity further facilitates results interpretation and contributes to model straightforwardness.

(5) *NON-MONETARY EFFECTS*: Due to a lack of data, direct and indirect costs associated with managerial decisions have to be neglected. Decision and performance data is thus neutral in units. Consequently, the analysis cannot show whether cost-increases through decisions may exceed productivity/performance gains in monetary values.[277]

[275]Wu and Chen (2006), Heinrich and J. (1999), Donahue et al. (2000).
[276]Nicholson-Crotty (2005).
[277]Sels et al. (2006).

KEY OUTCOMES

(1) *EFFECT SIZES (OVER TIME):* Though some studies report a positive relationship between managerial decisions and performance, there remains considerable uncertainty about the magnitude of the impact. While some studies found the existence of high impacts, others indicate that the magnitude of those impacts seems to be quite low or non-existing. Further, one may suspect that the magnitude of how decisions effect performance might change over time, supposedly in decreasing fashion.[278]

(2) *TIME-LAGS*: The diversity of effect sizes found in the literature might be simply explained by neglectance and/or misspecification of lagged effects and their structure.[279] Theoretical and empirical studies recently recognize that the values of particular decisions may only be realized over an extended period of time[280]. For instance in the context of IT decisions *"firms and individual users of IT may require some experience before becoming proficient"*. It is assumed that time-lags occur because of complementary organizational adjustments to the decisions taken (e.g. retraining of the employees, re-distribution of tasks, re-design of decision-making processes).[281]

Table 7.1: Multiple decision levels, expected uni-directional relation with performance and lags.

Decision Level	Aggregation	Decision Variable	Expected Relation*		and	Lags
			Input (-)	*Output (+)*	*Performance (+)*	
Operator *(holistic)*	high	KSUM	+	-/+	+	no
Planning *(tactical)*	middle	LRESOURCES	+	-/+	+	yes
Operations *(operational)*	middle	MSERVICE	+	-/+	+	no
Administration *(strategic)*	middle	NMANAGEMENT	+	-/+	+	yes

*E.g. if inputs in production *decrease (-)* the decision variable LRESOURCES and Performance *increase (+)*.

7.3 Theory: Time-Series Regression

Time-series are sequences of observations of multiple variables at successive, discrete points of time. The basic idea of time-series regression is to assess the relation between sequences of an *independent variable Y* and sequences of one or more *dependent variables X*[282]. In other words, the former data is *"regressed"* on the latter one using for instance the OLS technique. At first sight, this logic appears similar to that of conventional *multivariate regression analysis* except for the difference that 'time' gives the data some structure. Conventional regression was originally developed for cross-sectional data. However, the method has also widely emerged into assessing longitudinal and chronological data. In economics, this is done rather often with little consideration to the fact that temporal fixation of data - since ruling out the option of random sampling - might cause interferences with some of the principle Gauss-Markov

[278]Costa et al. (2014), Leverty and Grace (2012).
[279]Kim and McMillin (2003).
[280]Appendix 17 summarizes findings from a literature review on time-lags in Costa et al. (2014). The lag lengths of effects from decisions on performance vary across studies and the type of the decisions considered. While effects from IT usage suggest a lag length less than six months, lags from effects of large-scale IT and ICT investments appear to be 2-3 years, 4-9 years for R&D investment and 1-3 years for HR management practices.
[281]Bryjnjolfsson (1993), Matteucci and Sterlacchini (2004).
[282]That is the collection of data at fixed points in time, e.g. $t = \{0,1,2,3 \dots\}$.

assumptions for regression, particularly with reference to the error terms. Thus, on one hand, regression analysis with time-series data enables revealing dynamic effects between X and Y. On the other hand, the method requires to correct for issues such as *ubiquitous autocorrelation* of the error terms or *non-stationarity* due to trending data. The following section briefly introduces these issues based on inputs from Coelli (2005), Brooks (2008), Wooldridge (2009), IHSEviews (2014a) and Enders (2015)[283]. However, in-depth statistical details should not be as important as the general understanding of these issues and their role in the underlying regression analysis.

Basic Assumptions

This section recapitulates on important assumptions[284] concerning the statistical properties of 'OLS regression'[285] and their relevance for time-series regression.

- A *static* time-series regression model as in equation (1) uses the terminology of cross-sectional regression but with observations bound to the same time t.[286] Then Y_t is the dependent variable, or 'regressand' at time t, X_t^n are the independent variables, or 'regressors' at time t. The coefficient β_n is the elasticity or effect size. Further, ε_t is the sequence of error terms or disturbances (sometimes also termed 'shock' or 'innovation'). Error terms are commonly used to capture the uncertainty in the model.
- The *lagged* model of equation (2) is a slight variation of the static version. The dependent variable at time period t is regressed on independent variables from previous time-periods $t-k$. As such, the model allows for assessing time-lags.

Table 7.2: Pivotal assumptions for OSL validity in time-series regression.

Model/Assumption	Formulation		
Basic model (static)	$Y_t = \beta_0 + \beta_1 X_t^1 + \beta_2 X_t^2 \ldots + \beta_n X_t^n + \varepsilon_t = \beta_0 + \sum_{j=1}^{n} \beta_j X_t^j + \varepsilon_t$		(29)
Basic model (lagged)	$Y_t = \beta_0 + \beta_1 X_{t-k}^1 + +\beta_2 X_{t-k}^2 \ldots + \beta_n X_{t-k}^n + \varepsilon_t = \beta_0 + \sum_{j=1}^{n} \beta_j X_{t-k}^j + \varepsilon_t$		(30)
(A3) Zero mean	$E(\varepsilon_t \vert X) = 0,$	t =1,2,…,n	(31)
(A4) Homoscedasticity	$Var(\varepsilon_t \vert X) = Var(\varepsilon_t) = \sigma^2,$	t =1,2,…,n	(32)
(A5) No autocorrelation	$Corr(\varepsilon_t, \varepsilon_s) = 0,$	$\forall\, t \neq s, s = t-1, t-2 \ldots$	(33)
(A6) Normality	$\varepsilon_t \sim N(0, \sigma^2)$		(34)
(A7) Stationarity	$E(X_t) \approx \mu \,\forall \wedge Var(X_t) \approx \sigma^2 \wedge Corr(\varepsilon_t, \varepsilon_s) = c, \quad \forall\, t$		(35)

With particular concern about the error terms, Table 7.2 shows the requirements to proceed with OLS techniques, unbiased estimators and other accompanying features such as standard errors, t-statistics, and F-statistics[287]. In the following, each assumption is described in brevity.

[283]A thematical classification of time-series modelling within the variety of empirical methods in transport economics can be found in Kockelman et al. (2013), pp. 240ff.
[284]So called 'finite sample', or 'small sample' properties.
[285]Truncated at 0 and 1, regressions of DEA scores at *levels* would require to handle negatively skewed data trough Tobit regression as proposed by Greene (2005). However, OLS regression is appropriate when one intents to regress non-truncated performance change rates. This applies herein. Change rates are a by-product of stationarization.
[286]For the sake of simplicity, the subscript t is employed to denote time instead of m as done above.
[287]Further assumptions for a multivariate time-series case are the same as in cross-sectional regression: (A1) linear in parameters, (A2) no multi-collinearity $Corr(X_t^n, X_t^k) = 0$.

- **(A3)** The expected value of the error term[288] ε_t is zero for each t, given the explanatory variables for all time periods. This means that averagely the errors are still zero (they mutually cancel out on average), but may conditionally deviate from zero. Further the assumptions implies that the error at time t, is uncorrelated with each explanatory variable in every time period, i.e. also their past (termed *exogeneity*) and future (termed strict *exogeneity*) values.
- **(A4)** This assumption says that the variance of errors cannot depend on X and that it must be constant over time, otherwise the errors are termed heteroscedastic. The idea here is that the deviation of residuals from the estimated regression line stays stable over time.
- **(A5)** Autocorrelation - as a special case of correlation - refers to the relationship between consecutive or further apart error terms. As error terms in cross-sectional regression must not be correlated this also accounts for time-series regression. No error term is allowed to be correlated with error terms from past observations ($Corr(\varepsilon_t, \varepsilon_s) = 0$), at least when one intends to achieve meaningful results in OLS fashion.
- **(A6)** The errors ε_t are independent from X and *i.i.d.* ('independently, identically distributed following normal distribution').

In summary, the classical linear model (CLM) assumptions (A1) to (A6) are slightly more constraining for time-series data than for cross-sectional data. Especially the assumption of strict exogeneity and no serial correlation might be unrealistic in some cases, in particular in social science as pointed out by Wooldridge (2009).[289] However, with (A7) an additional assumption is given that is only valid in the time-series context: *Stationarity* requires the mean and variance of each underlying time-series in the regression to be approximately constant over time, as well as the inherent pattern of autocorrelation, if chosen to be untreated. The relevance of *autocorrelation* and *stationarity* are further explained in the next sections.

Issue 1: Autocorrelation

AC FUNCTIONING: In the following, the focus lies on assumption (A5) - the issue of autocorrelation[290] (AC) - which is most likely to be encountered when using time series data. Nearly all time-series regressions are prone to produce correlated error terms. Violating the assumption would render the elements of a sequence of error terms ε_t as 'not mutually independent', i.e. subject to related adjacent/subsequent error terms. Error terms are said to

[288] *Errors*: deviation from true regression line, as opposed to *residuals*: deviation from the estimated regression line.
[289] Wooldridge (2009) on (A3): *"But something like the amount of labor input might not be strictly exogenous, as it is chosen by the farmer, and the farmer may adjust the amount of labor based on last year's yield. Policy variables, such as growth in the money supply, expenditures on welfare, and highway speed limits, are often influenced by what has happened to the outcome variable in the past. In the social sciences, many explanatory variables may very well violate the strict exogeneity assumption."* On (A4): *"Since policy regime changes are known to affect the variability of interest rates, this assumption might very well be false. Further, it could be that the variability in interest rates depends on the level of inflation or relative size of the deficit. This would also violate the homoscedasticity assumption."*
[290] 'Autocorrelation' and 'serial correlation' are used interchangeably herein, similar to 'series' and 'time-series'.

be correlated, when residual plots display large residuals followed by large residuals and *vice versa*. This means that a dependent variable, which is rather unexpectedly high in period t, is also likely to be above average for the next period $t+1$. Once there are unobservable factors increasing the observation at some point in time, then it is appropriate to assume that those factors bias the error term upwards in the next period. This appears to be a reasonable characterization of the underlying data in this research. For instance, the performance level of one period is obviously linked to the level before and after and so might be the error terms. In general, untreated autocorrelation leads to reliability issues with R^2 and the usual t- and F-tests in addition to an underestimation of variance of the error term.

Table 7.3: Types of autocorrelation of error term ε_t.

Process	Regression Formulation	
AR(1)	$\varepsilon_t = \rho_0 + \rho\varepsilon_{t-1} + v_t$	(36)
MA(1)	$\varepsilon_t = v_t + \theta v_{t-1}$	(37)
AR(p)	$\varepsilon_t = \rho_0 + \rho_1\varepsilon_{t-1} + \cdots + \rho_n\varepsilon_{t-k} + v_t$	(38)
MA(q)	$\varepsilon_t = v_t + \theta_1 v_{t-1} + \cdots + \theta_q v_{t-q}$	(39)
ARMA(p,q)	$\varepsilon_t = \rho_0 + \rho_1\varepsilon_{t-1} + \cdots + \rho_n\varepsilon_{t-k} + v_t + \theta_1 v_{t-1} + \cdots + \theta_q v_{t-q}$	(40)

AC MODELS: The most common and simplest type of autocorrelation is termed first-order autoregressive-process AR(1). In general, the term 'autoregressive' is used to describe models that regress observations on their own previous values. In an AR(1) process of error terms, the errors at one prior time period are correlated with errors at the subsequent time period: $Corr(\varepsilon_t, \varepsilon_{t-1}) \neq 0$. The error terms ε_t and ε_{t-1} are essentially related via a linear function in the form of equation (8), which includes another disturbance term[291] v_t, and the autocorrelation coefficient ρ, which is bound to $|\rho| \leq 1$. The formula suggests that the following. *Firstly*, auto-correlation can be positive, negative or zero. *Secondly*, when $p = 0$ no auto-correlation occurs and the model reverts to equation (1). *Thirdly,* in the case of auto-correlation each error ε_t is composed mainly of a fraction of the preceding error and consequently of all the previous errors (in theory infinitely). The latter feature is also called *long memory effect*. *Any* past error term is still present in *all* future periods, however with diminishing magnitudes over time.

Another type of auto-correlation is the first-order Moving-Average[292]-Process MA(1) where the error term is formed as in equation (9) with coefficient θ, normalized to unity. In an MA(1) process each error term ε_t is a function of the weighted average of the random disturbances v_t and v_{t-1}. Effects are only temporally, unlike in AR(1). Any disturbance v_{t-1} could be considered a *one-off event* whose effect dies out quickly after the next period and may be

[291]Has to fulfil Classical Linear Model (CLM) assumptions.
[292]The term moving average is slightly misleading but a convention for this model in research. It should not be confused with the moving average used in data smoothing, averaging or the one mentioned in window DEA.

labelled as a *short memory effect*. Following Table 7.3, also higher-ordered serial correlation may occur (correlation with residuals further apart), termed AR(p) MA(q). Both processes can be combined to an 'autoregressive-moving average process' or ARMA(p,q).

AC DETECTION: The basic idea here is to look vicariously for autocorrelation in the residuals[293] to draw conclusions about autocorrelation in the errors. There are two main ways to detect auto-correlation in time-series regression: visually and empirically. The *first option* is rather informally achieved by plots and graphs: *residual plots* help to identify whether long runs of positive residuals and long runs of negative residuals can be observed, thus giving a first glance about serial correlation. One might also create scatter plots of current against past residuals values that would then be perfectly correlated in case of auto-correlation. The *second option* is to provide statistical support of the visual impression through several tests to detect autocorrelation, namely Durbin-Watson-, Breusch-Godfrey-, and Ljung-Box Q-statistic. The Durbin-Watson statistic is the traditional test and centred around values of 2 when serial correlation of residuals is non-existent. The Breusch-Godfrey statistic (null: no serial autocorrelation in residuals) overcomes the limitation of the traditional tests and allows to test for autocorrelation at higher lags, thus for higher-ordered processes. The Ljung-Box Q-statistics - also called *correlogram* - is a more sophisticated tool of empirical-visual nature and usually part of most econometric software packages. It allows for direct assessment of correlations patterns between residual ε_t and all past values ε_{t-k}. It computes (a) the so-called autocorrelation-function (ACF) which is derived from the autocorrelation coefficients ρ and θ from above[294] and (b) the so called Q-statistic, which essentially tests the hypothesis for a certain lag $t-k$ that the

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	3.581566	Prob. F(4,53)	0.0117
Obs*R-squared	13.19290	Prob. Chi-Square(4)	0.0104

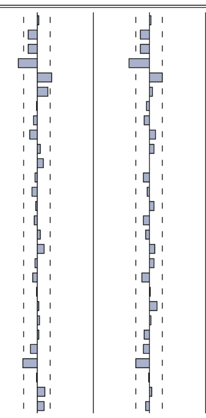
Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 06/08/16 Time: 15:49
Sample: 1952 2013
Included observations: 62
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.006876	0.023223	0.296083	0.7683
KSUM	-0.000672	0.006150	-0.109280	0.9134
QCON	-0.001430	0.001517	-0.942197	0.3504
QGDP_FDDT	0.023009	0.085291	0.269770	0.7884
QPOP_FDFD	0.042596	0.134103	0.317635	0.7520
RESID(-1)	-0.045575	0.132197	-0.344753	0.7316
RESID(-2)	-0.230006	0.131115	-1.754234	0.0852
RESID(-3)	-0.179521	0.126684	-1.417078	0.1623
RESID(-4)	-0.434456	0.134720	-3.224870	0.0022

R-squared	0.212789	Mean dependent var	-2.80E-18
Adjusted R-squared	0.093964	S.D. dependent var	0.020475
S.E. of regression	0.019490	Akaike info criterion	-4.904390
Sum squared resid	0.020132	Schwarz criterion	-4.595612
Log likelihood	161.0361	Hannan-Quinn criter.	-4.783156
F-statistic	1.790783	Durbin-Watson stat	1.781791
Prob(F-statistic)	0.099629		

Date: 06/08/16 Time: 15:51
Sample: 1950 2013
Included observations: 62

Autocorrelation / Partial Correlation



	AC	PAC	Q-Stat	Prob
1	0.027	0.027	0.0488	0.825
2	-0.159	-0.160	1.7253	0.422
3	-0.171	-0.166	3.7027	0.295
4	-0.338	-0.377	11.496	0.022
5	0.277	0.253	16.839	0.005
6	0.207	0.073	19.879	0.003
7	-0.011	-0.042	19.889	0.006
8	-0.069	-0.097	20.241	0.009
9	-0.126	0.115	21.429	0.011
10	0.067	0.096	21.773	0.016
11	0.117	0.003	22.842	0.019
12	-0.025	-0.099	22.893	0.029
13	-0.093	-0.033	23.597	0.035
14	-0.021	0.096	23.634	0.051
15	-0.053	-0.111	23.871	0.067
16	0.061	-0.068	24.195	0.085
17	0.126	0.109	25.588	0.082
18	-0.026	0.083	25.651	0.108
19	-0.074	-0.131	26.155	0.126
20	-0.008	0.021	26.162	0.161
21	0.026	0.141	26.227	0.198
22	0.054	0.028	26.513	0.230
23	0.031	-0.087	26.612	0.273
24	-0.120	-0.112	28.104	0.256
25	-0.262	-0.244	35.454	0.080
26	-0.003	-0.012	35.455	0.102
27	0.155	0.049	38.189	0.075
28	0.128	-0.059	40.089	0.065

Figure 7.1: Breusch-Godfrey statistic (left side) Ljung-Box Q-statistics (right side)
Serial autocorrelation of the residuals at lag 4 and lag 5.

[293]Residuals are precisely the estimates of the errors terms.
[294]For instance the ACF value for AR(1) process, k lags apart: $\gamma_k = \rho_1^k$ (decreases usually geometrically); ACF value for MA(1) at lag $k = 1$: $\theta_1/(1+\theta_1^2)$, $\mathrm{k} > 1 = 0$ (cuts off usually). However, higher ordered and combined serial correlation may produce more complex patterns in the correlogram.

correlation with $t = 0$ equals zero (null: no serial autocorrelation in residuals). Figure 7.1 shows examples of how to detect serial correlation with the two latter tests. The correlogram displays spikes at lags 4 and 5 with significant *Q-statistic*s. This indicates serial correlation in the residuals. If there is no serial correlation in the residuals, all lags are close to zero (no spikes) - then also called white noise[295] - and Q-statistics are insignificant with large p-values accordingly.

AC REMEDIES FOR AC: A few traditional measures are available to correct for first-order autoregressive correlations of error terms (AR1), such as the 'Method of Generalised Differencing' in joint combination with the 'Hildreth-Liu' and the 'Cochrane-Orcutt' method. These approaches do not required the time-series data to be changed, are linear in nature, and rely on the (a) incorporation of equation (8) and (9) in the regular time-series model as well as (b) the iterative estimation of the unknown ρ. Correcting for a an MA(1), however, is more straightforward since one could simply use the *one-period lagged values of the error* to improve the *current* error. As both approaches yield several drawbacks with regard to higher-ordered serial correlation, modern econometric software have built-in features based on nonlinear regression techniques to correct for any type of correlation and order.[296] By simply adding one or more additional variables[297] to regression equation (1) residuals "are made" uncorrelated. Consequently, the estimated coefficients, coefficient standard errors, and t-statistics can be interpreted in the usual manner of OLS, unbiased and reliable.[298] Other remedies for serial correlation may simply be by-products of a direct adjustment of the time-series data, for instance when *de-trending* or *differencing* is applied to make explanatory variables stationary. However, once error autocorrelation remains in the data, spikes in a correlogram often provide important information in the search for an appropriate estimation model, as demonstrated below in the Box-Jenkins approach and the modelling example.

Issue 2: Non-Stationarity

NATURE OF STATIONARITY: In a time-series regression model as equation (1), all time-series X^n and Y^n would have to be stationary to obtain meaningful parameter estimations[299] via OLS and to understand about how changes in X^n affects Y^n. The β values should always be valid across time and *not* a function of time (therefore they do not carry subscript for time). Since regression

[295]'White noise' originates from physics, from white light, a combination of lights of different wavelengths in the electromagnetic spectrum. In acoustics, simultaneous occurrence of frequencies with identical power produce noise.
[296]See IHSEviews (2014b) p. 92.
[297]So-called AR-terms or MA-terms, corresponding to the identified type and order of serial correlation (AR(p), MA(q).
[298]For example, to correct for a first-order serial correlation the term AR(1) has to be included in the regression. The associated coefficient to term AR(1) then is the estimated serial correlation coefficient $\hat{\rho}$ which lies between -1 and 1 and should not be at the edge of the range. If one intends to correct of higher ordered correlation, e.g. on the fourth lag, the terms A(1), A(2), A(3), A(4) might have to be included, or simply AR(4) to adjust for seasonality or shocks.
[299]Besides the practical justification, theoretical ones relate to the *law of large numbers* and the *central limit theorem*.

analysis in liaison with time-series is often used to predict or forecast Y^n, stationarity ensures the consistency of statistical properties of time-series for 'past' and for 'future' values. Then sample statistics would remain meaningful across time and comparable across the time-series. For this reason, stationarity demands *constant means* and *variances over time* of each series in the set as suggested in assumption (A7).[300] In other words, some sort of 'data stability' is required for a proper regression. What (A7) actually implies is that that each value X_t in a time-series, comes from *one* specific underlying data generation process (DGP) for all time periods, rather than from *multiple* DGP processes in multiple periods. In so far, trends in general pose a problem for time-series regression.[301] A consistently upwards trending time-series is per definition said to be *non-stationary.* Means and variances grow over time. If untreated, this may create the phenomena of *spurious regression*, that is, when two trending time-series appear to be correlated only because they are trending. Obviously this may lead to misguiding but sometimes funny conclusions as demonstrated brilliantly by Vigen (2015). With arbitrarily changing or time-dependent statistical properties induced by trends or other irregularities such as level shifts/break-points, any attempt to establish a reasonable correlation among the series would fail or produce skewed results. In particular, predictions or extrapolations of regression models fitted to non-stationary series should be avoided. Therefore, stationarity has to be introduced to all time-series variables before modelling.[302] However, this implies that one first needs to identify which of the series are already stationary and which are not.

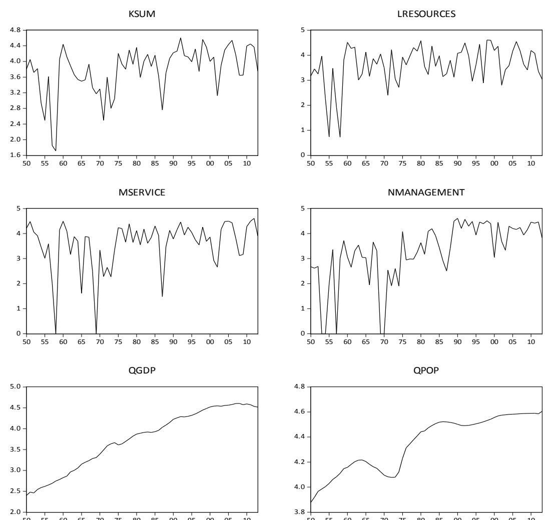


Figure 7.2: Before stationarizing (non-stationary).

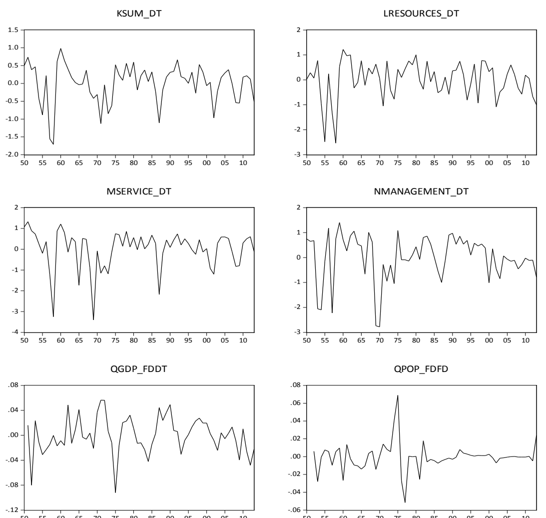


Figure 7.3: After stationarizing (stationary).

[300]A more precise formulation would refer to a stochastic process, where *"a stationary time series process is one whose probability distributions are stable over time"* in the sense *"that the joint probability distribution must remain unchanged"* when one takes *"any collection of random variables in the sequence and then shift that sequence some time periods ahead."* This part refers to *covariance stationarity, strict stationarity* also requires the pattern of correlation between subsequent terms in a series to be consistent over time (Wooldridge (2009) p. 378).

[301]Economic time series and particularly performance scores have a tendency to grow over time, very few in practice are stationary. Costa and Markellos (1997) claim that the issue has *"received limited attention"* in relevant studies.

[302]Interestingly, assumptions A4 and A5 already assume some form of stationarity, albeit only for the error terms.

DETECTION OF NON-STATIONARITY: Similar to autocorrelation, there are two ways to assess whether a time-series is *stationary* or *not stationary*: *visual observation* or *statistical testing*. Visually assessed, a stationary time-series shows no observable trend patterns over time and relatively stable horizontal alignment (=roughly constant variance). For instance, the six plots of Figure 7.2 suggest that all series appear to be *non-stationary*. They display some form of trend, most obviously the series for GDP and population. A visual assessment might be swift, cheap and often even correct, but is still rather vague and informal. Therefore, any visual indications should be statistically tested for each time-series with the so-called Augmented-Dickey-Fuller (ADF) test. The test bases on the following logic: Once a time-series is stationary, it would tend to fall back to some deterministic mean, i.e. patterns of smaller values to be followed by larger ones and vice versa (on average). ADF then assumes a time-series X_t to follow an AR(1) process in the regression form $X_t = \rho X_{t-1} + \varepsilon_t$ and tests whether the AC coefficient $|\rho| \geq 1$[303]. At $|\rho| = 1$ a so-called *unit root* is present which makes the test also termed Unit-Root-Test.[304] Once this property is true, the series X_t is rendered *not stationary* with increasing variance over time and approaching infinity. If the property is not true, X_t is termed *trend-stationary* (or straightly *stationary* in the case of $|\rho| = 0$). Trend-stationarity - which is stationarity around some trend-line as imaginable in Figure 3 - indicate that it may be suitable to apply trend correction

Null Hypothesis: QGDP has a unit root
Exogenous: Constant
Lag Length: 1 (Automatic - based on SIC, maxlag=10)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.442584	0.1346
Test critical values:	1% level	-3.540198	
	5% level	-2.909206	
	10% level	-2.592215	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(QGDP)
Method: Least Squares
Date: 06/15/16 Time: 17:08
Sample (adjusted): 1952 2013
Included observations: 62 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
QGDP(-1)	-0.014010	0.005736	-2.442584	0.0176
D(QGDP(-1))	0.342070	0.120742	2.833064	0.0063
C	0.073783	0.023796	3.100576	0.0030

R-squared	0.281631	Mean dependent var	0.032880
Adjusted R-squared	0.257280	S.D. dependent var	0.033016
S.E. of regression	0.028453	Akaike info criterion	-4.233937
Sum squared resid	0.047765	Schwarz criterion	-4.131012
Log likelihood	134.2521	Hannan-Quinn criter.	-4.193526
F-statistic	11.56526	Durbin-Watson stat	1.813175
Prob(F-statistic)	0.000058		

Figure 7.4: ADF shows the GDP is non-stationarity.

Null Hypothesis: QGDP_FD has a unit root
Exogenous: Constant
Lag Length: 0 (Automatic - based on SIC, maxlag=10)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-4.690213	0.0003
Test critical values:	1% level	-3.540198	
	5% level	-2.909206	
	10% level	-2.592215	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(QGDP_FD)
Method: Least Squares
Date: 06/15/16 Time: 17:09
Sample (adjusted): 1952 2013
Included observations: 62 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
QGDP_FD(-1)	-0.540865	0.115318	-4.690213	0.0000
C	0.017091	0.005465	3.127490	0.0027

R-squared	0.268276	Mean dependent var	-0.001508
Adjusted R-squared	0.256080	S.D. dependent var	0.034327
S.E. of regression	0.029607	Akaike info criterion	-4.169866
Sum squared resid	0.052596	Schwarz criterion	-4.101248
Log likelihood	131.2658	Hannan-Quinn criter.	-4.142925
F-statistic	21.99810	Durbin-Watson stat	1.905875
Prob(F-statistic)	0.000016		

Figure 7.5: ADF shows that the first-difference of GDP is stationary.

[303]The reasoning of this test is slightly different from that of testing ρ for auto-correlation in error terms as described in the previous section. There the series of error terms is supposed to be stationary (null: $\rho = 0$). The OLS-based test works properly under the null. However, testing for unit roots means testing for non-stationarity (null: $\rho = 1$), which makes the AFD test automatically take the differences of a series to be on the OLS framework. That is the reason for the commonly cited notion that a series, which is only stationary in its first-differences is said to have a unit root.

[304]The following quote is surely an oversimplification of some fairly complex mathematical issues regarding the unit root, but in its essence it is a nice and intuitive interpretation of the role of a unit-root in an AR process/flow: *"The nature of an AR flow is determined by a few special, "characteristic" directions [..]. Associated with each characteristic direction is a number, its "root" or "eigenvalue." When the size of the number is less than unity, the flow in that characteristic direction is towards a central location. When the size of the root is greater than unity, the flow accelerates away from a central location."* Taken from Huber (2012).

measures, such as de-trending or differencing. Figure 7.4 depicts a typical output of a unit-root test, with the null being one of non-stationarity: *"series has a unit root"*. Despite the theoretical complexity, the application of the ADF test in modelling is rather straightforward. The test essentially delivers a negative score, the ADF t-statistic, its p-value and various corresponding critical values/thresholds[305] for different significance levels. The higher the score, the stronger the acceptation of the null and *vice versa*. To fully reject the null and to declare X_t stationary, the t-statistic would have to be at least lower than the highest threshold value, as clearly exhibited in Figure 7.5 (t-statistic -4.69 < -3.54)[306].

REMEDIES FOR NON-STATIONARITY: Figures 7.2 to 7.4 and the remarks above indicate that stationarity can be achieved by *de-trending* or *differencing* the series X^n and Y^n. *De-trending* is suitable when the trend appears to be deterministic and its structure is known (e.g. linear or quadratic by observation). Then the time-series X^n is simply regressed on *time.*[307] If model and time component are significant the residual series of this linear regression can be used as a de-trended representative for the original series (marked as "_DT" in the headers of Figure 7.3). For a *trend-stationary* series, the t-statistic of the ADF test would drop below the test thresholds from above, immediately after the application of de-trending. A series with a $|\rho|$ consistently larger than one, however, requires one or more iterations of *differencing* to achieve stationarity, since mean, variance, and autocorrelation are still not constant over time, even after de-trending. A standard approach to this problem is to build a model using the so-called first-difference of the variables instead of their level. The first-difference of a time series equates to the absolute changes from one time period[308] to the next (marked as "_FD" in the headers of Figure 7.3): from each value X_t^n in a series X^n its previous value X_{t-1}^n is subtracted which forms a new, stationary series $X^{n*} = X_t^n - X_{t-1}^n, \forall t$. A stationary time-series X^{n*} obtained by differencing is called difference-stationary. Occasionally, data does not become stationary after first-differencing and a second iteration is required, which gives a series of the *change of a change* rate (marked as "_FDFD" in the headers of Figure 7.3). In practice, differencing almost never goes beyond second-order differences. The number of differencing iterations for a time-series to become stationary is termed 'order of integration' expressed as I(d) with ($d = 0,1,2$ ...). Hence, a straightly stationary time series is I(0), a first-differenced one is I(1), and so forth.

Overall, *differencing* is a more severe measure than *de-trending*. It should be applied if stationarity cannot be achieved by de-trending, as it also removes information from the data.

[305]Based in the so-called Dickey-Fuller distribution which are reference values, depending on the sample size.
[306]See IHSEviews (2014b) p. 471, *Unit Root Testing* for a discussion of stationary and non-stationary time series.
[307]In statistical packages this can be done by adding a trend-term to a regression of the form $X^n = c + "trend"$.
[308]Note that differencing changes the interpretation of the variable from "levels" to "change of levels."

Models subsequently get a much lower R^2. On the positive side, with differencing, results might be less likely to be spurious in nature as statistical properties of individual time series over time are stabilized by smoothing level changes as well as by trend and seasonality elimination.[309]

Box-Jenkins Model Building

Non-stationarity of time-series and *autocorrelation of the error terms* are the two main obstacles for time-series regression and need to be resolved when one intends to rely on OLS and its inferences. While tackling non-stationarity appears a pivotal preparatory issue before modelling, the removal of autocorrelation might be done "on the run" during the regression analysis. To handle both issues in consecutive manner makes even more sense when one considers the good chance that in stationarized time-series most of the error autocorrelation might have already been removed. This would simplify the remaining modelling process significantly. Therefore, modelling should *first* assess stationarity, and *second* correct for remaining autocorrelation.

This can be done systematically with the so-called Box-Jenkins (B-J) procedure, also called *ARIMA modelling* (Box et al., 2008). The notion ARIMA (p, d, q) is a composition of the concepts AR(p), I(d) and MA(q) as introduced above: I(d) stands for the order of integration, that is the level of differencing required to stationarize a time-series, AR(p) and MA(q) then stand for the *autoregressive* and *moving-average* terms (and their order) to handle (residual) autocorrelation. Conventional ARIMA modelling is in fact a statistically sophisticated and powerful approach to extrapolate/forecast individual time-series and therefore used in the sense of *prediction*[310]. However, the focus of this research is to assess the relation *between* multiple time-series via regression without forecasting, rather in a sense of *estimation* (cause-and-effect approach). Therefore, relevant key features of ARIMA modelling are adapted herein accordingly to fulfil assumptions (A3) to (A7) and to obtain meaningful OSL results. The method is rather hard to explain to untrained users, but the overall intention is to build a model with *small residuals* that exhibit *no patterns of residual autocorrelation*.

Figure 7.6 below exhibits the model building procedure derived from Box et al. (2008). Interestingly, the lead author is also the creator of the well-known aphorism *"All models are wrong, some are useful"* (Box, 1976). The procedure essentially involves four main stages: *(1) visualization*, *(2) stationarization*, *(3) model selection*, and *(4) evaluation*. The first two steps are

[309]Costa and Markellos (1997): In the context of performance measurement, stationarization *"is a serious drawback for econometric techniques, since their apparent stochastic nature contradicts their assumptions regarding the existence of deterministic trends* [of performance measurements over time]".

[310]Using AR terms to forecast the deterministic parts of the series and MA term to model the disturbance components.

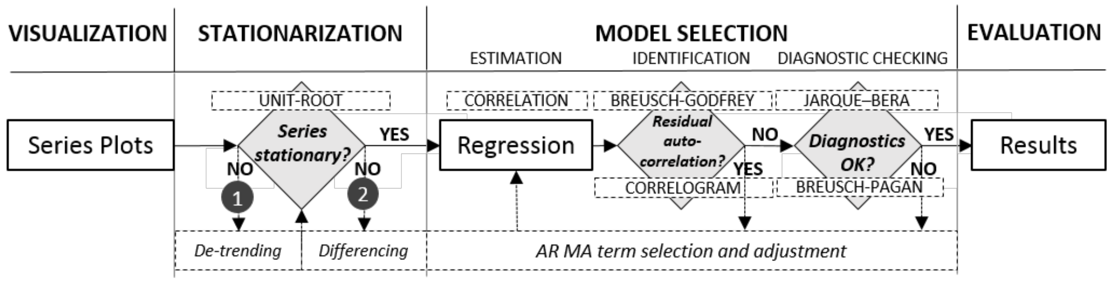


Figure 7.6: Box-Jenkins based model building procedure and related tests (framed by dashed lines).

of preparatory nature and individually applied to all time-series relevant for the model. The two latter steps are concerned with modelling, i.e. individual regression analysis. The stages are briefly explained in the following.

(1) *Visualization* means to plot each series individually and to look for particularities, such as possible trends, seasonality, outliers, and the nature of variance. This might indicate the need for further actions, specifically in terms of stationarity. For instance if one spots an obvious linear trend in the plot the series is not stationary.

(2) *Stationarization*-stage aims at *de-trending* or *differencing* the data if required and thus to ensure to ensure that the series are sufficiently stationary. As an initial measure, the intuition about the state of stationarity gained from visual inspection should be confirmed or disconfirmed by *unit-root testing.* When tested as non-stationary, one could first try to *de-trend* the series, test for unit-roots again and once needed, to *difference* the series d times until it gets stationary. A series would then be termed 'I(d)' or '*integrated at order* d'. With each series stationary, the model selection part can be initiated after ruling out correlation among the series by checking the correlation matrix.

(3) *Model selection* is an iterative approach with the goal to obtain a proper model free from residual autocorrelation of error terms. The centrepiece of the Box-Jenkins methodology is based on three stages: (a) e*stimation*, (b) *identification*, and (c) *diagnostic checking*[311]. (a) *Estimation* is the starting point and refers to performing an initial standard regression to make preliminary inferences about the parameters (coefficients) and related statistics. *Identification* (b), or specification is concerned with residual auto-correlation in the regression model and its description as an auto-regressive, moving-average or mixed process as introduced above. This step specifies the number of correction terms for auto-correlation to enter the regression by trial and error as follows: One has to test first via *Breusch-Godfrey* whether residuals are auto-correlated at all. Then *correlogram* plots for the residual autocorrelation and the embedded *Q-statistic* visually indicate the underlying process or relevant individual auto-correlative lags[312] (see Figure 7.1). This information is then used to build a new tentative model which includes the correction terms AR(p) or MA(q) or both accordingly. The number and order of these terms is determined by shape of the autocorrelation (ACF)[313] and partial-autocorrelation function (PACF)[314] in the residual correlogram. More precisely, (combinations of) certain rules[315] are applied according to

[311]It should be noted that the original order identification, estimation, diagnostic checking prosed by BJ was slightly altered since once has to first run a regression to achieve the criteria required for the identification stage.

[312]Process correction vs. individual lag correction: entering MA(1) and MA(2) is understood as a process with correlated residuals on both the first and second lag. In contrast, adding only MA(12) and would mean autocorrelation occurs only at the twelfth lag in a seasonal manner.

[313]*ACF*: correlations between e_t and e_{t-1} for all lags. *PACF*: coefficients of regression e_t on e_{t-k} for all lags.

[314]The ACF serves for identifying the number of MA terms. The PACF serves or identifying the number of AR terms.

[315]There are only a few fail save-rules for ARIMA identification, see here Table 7.15 .

the spikes observed at different lags. The tentative model is then subjected to the *estimation* step again in order to re-estimate the relevant parameters plus those of the correction terms. The procedure is iterative. Steps (a) and (b) should be repeated until auto-correlation is removed. A model is valid when the residuals are "white noise," i.e. uncorrelated/absent of serial correlation[316]. Box et al. (2008) stress that valid models should be reasonably parsimonious with respect to the coefficients, with only a few correction terms in order to prevent overfitting[317]. Finally, (c) *diagnostic checking* might indicate overall model (in)adequacy. Diagnostics should be at least in a line with the requirements of error homoscedasticity and normality, which can be assessed via Breusch-Pagan-Godfrey[318] test and Jarque-Bera test, respectively. One might repeat the previous steps in order to find the "best" model with the most favourable AR or MA or ARMA setting. The modified model is then fitted again and subjected to (2) and (3) until the "best" model is obtained. Model improvements would be indicated in the diagnostics by the changes of R^2 (higher is better) or SBC[319] (lower is better).

(4) *Evaluation* refers to the comparisons of different regression models and their validity as well as the visualization of results.

Further Time-Series Regression Models

Equation (13) describes a so-called *finite distributed lag model (FDL)*[320]. This is in fact the additive mixture of the previous two models of equations (1) and (2), assuming that impacts from all independent variables last over a finite number of periods and all lags jointly affect the dependent variable (see also Fearnley and Bekken (2005), pp. 3ff.).

Table 7.4: Finite lagged time-series regression models.

finite lagged (dynamic)	$Y_t = \beta_0 + \sum_{j=1}^{n} \sum_{i=1}^{k} \beta_{nk} X_{t-k}^{n} + \varepsilon_t$	(41)

7.4 Practice: Decision-Performance Modelling

While the previous section gave a general overview on the *theoretical* foundations of time-series regression, this section is concerned with the *practical modelling* of the temporal relation between managerial decisions and performance through regression. *First*, the key objectives of the modelling process, corresponding outputs and their underlying logic are defined in brevity. *Second,* in order to achieve these objectives, preparatory data enhancements and transformation measures are explained. *Third*, the complexity of modelling is illustrated by enlisting all models and modelling branches accordingly.

[316] Wooldridge (2009) names the final model '*dynamically complete*'.
[317] Overfitting: inclusion of correction terms for marginally significant intermediate lags.
[318] Hereinafter referred to simply as Breusch-Pagan, as opposed to the Breusch-Godfrey test for serial correlation.
[319] Schwarz-Bayesian-Information Criteria.
[320] $t = \{0,1,2 \ldots t\}$, $k = \{0,1,2 \ldots k\}$, $n = \{1,2, \ldots, n\}$; t…year assessed; $t-k$…lag (past year that affects t); n…indicator for independent variable ; Y_t…dependent variable; X_t^n…independent variable; β_n…coefficient (elasticity); β_0…intercept; ε_t…sequence of errors or disturbances.

Modelling Point of Departure [*Where to start?*]

An inventory should initially summarize what has been achieved and concluded so far in the previous chapters and sections with regard to the forthcoming regression analysis:

(1) The decision-performance link should be modelled individually for each operator. ***(Chapter 4)***

(2) The regressions should rely on four data pillars available for a time-span of up to 64 years: performance-, decision-, contextual-, and social-economic data. The dependent variable (DV) is *performance data*. The main independent variables (IV) is the *decision data.* The secondary independent variables (SIV) are *contextual data* and *socio-economic data.*

Time-series for three *performance types* were calculated through DEA (effectiveness, efficiency, mixed performance). ***(Chapter 6)***

Time-series for four *decision super-categories* were derived from CA and operationalized by merging thematically similar decision main-categories: SUM or RESOURCES, SERVICE, and MANAGEMENT. **(*Chapter 5)***

(3) Methodologically it is suggested to use *static* and *lagged* time-series regression models to separately assess impacts of variables from current and past periods, the latter of which are termed time lags. The modelling purpose is *estimatio*n, not forecasting.

It is further recommended to align/support the regression with the Box-Jenkins model building procedure. ***(Chapter 7.3)***

Bearing this in mind, the subsequent modelling process envisages two main objectives, namely *model straightforwardness* and *model diversity*.

Modelling Philosophy [*Which objectives to aim at?*]

O1 - MODEL STRAIGHTFORWARDNESS: The objective of straightforwardness sub-sums the efforts to provide meaningful, comprehensible and intuitive *results* through modelling, but also in in terms of *presentation* of modelling results, in a language and format understandable also to a non-academic and non-technical audience. The objective is achieved by (S1) applying appropriate data transformations, (S2) avoiding "overloaded" models in terms variables and, (S3) using charts to visualize numerical results to facilitate interpretations and evaluations.

O2 - MODEL DIVERSITY: The unique time-series database should be utilized multi-dimensionally. Thus, for each operator a variety of different regression models should be estimated and compared. A larger number of models particularly addressing different perspectives of the research issue would contribute to a better understanding of the relation between managerial decisions and operator performance in general. Model diversity can be achieved by the examples given in Table 7.5. All measures except of (D3) are somehow predefined technical variations of the modelling technique (*"playing around with the tool"*), reflected in the section *Modelling Framework.* In contrast, (D3) is a pivotal feature to reduce the degree of uncertainty within the holistic approach in general (*"playing around with the data"*). Up to now, uncertainty arises mainly from inappropriate - because unknown - weighting of decision categories as described in Table 5.12. Hence, the introduction of additional weighting scenarios as part of preparatory data works is dealt with separately in the section *Modelling Preparation.*

Table 7.5 outlines both modelling objectives and gives examples in brevity. *In general, this research favors regression models that explain the observed data in the simplest way. The overall objective is to produce multiple but simple models.*

Table 7.5: Modelling objectives, examples and references.

	O1 - Model Straightforwardness		**O2 - Model Diversity**
S1	intuitive units/values/metrics	D1	static and dynamic model
S2	simplicity and parsimony of models	D2	variation of the time-span for of time-series
S3	appropriate visual presentations	D3	*variation of the decision data*
		D4	variation of the independent variables
		D5	variation of dependent variable
		D6	reasonable large number of lags
S1	Section *Modelling Preparation/Data Transformation*	D3	Section *Modelling Preparation/Data Enhancement*
S2	Section *Modelling Framework/Model Estimation*	∀≠D3	Section *Modelling Framework/Model Configuration*
S3	Section *Modelling Framework/Model Presentation*		

Modelling Preparations [*What Kinds of Data and Which Form?*]

Data preparation refers the context-driven, non-automated manipulation of input data to make it suitable for further analysis. "*Better data means better models*" (Linoff and Berry, 2011). This commonly includes fixing problems with the raw data, such as missing values, outliers, and standardization. Since such measures were directly applied in the corresponding sections data preparation in this research refers to two additional tasks: (1) Enhancement of information from the data by introduction of weight scenarios for decision and contextual categories, and (2) transformation of variables to reasonable economic metrics to produce sound findings.

DATA ENHANCEMENT - WEIGHT INTRODUCTION: *Data enhancement* refers only to the managerial decision data processed in Chapter 5. Up to this point, decision categories were treated *unweighted*, that is, without any prior assumptions about differences in their relative importance. Technically speaking, all categories were assumed equal in importance.[321] The underlying motivation was to simply let the data "speak" and to obtain initial results that rely on rather "pure" data without manipulations from the modeller. However, in the regression analysis this preliminary approach needs to be corrected towards a more realistic representation of managerial decision-making over time for the following reasons.

- Differences in category importance modify the structure of decision time-series and thus allows to test various regression scenarios.

[321]Equality in category importance is a result of standardizing each series to its maximum as described in Chapter 5.

- In reality, the operator management seems likely to face differences in the relative importance[322] of decision categories. The differences might be related to the very nature of the categories as described in Tables 5.3.[323]

Differences in category importance can be modelled through the introduction of pre-defined category weights as shown in Tables 7.6 and 7.7 below. The weights are assigned first to decision sub-categories and secondly to decision main-categories. The former corrects for differences in the importance of sub-categories per main-category, the latter for differences in the importance of main-categories in super-categories. Methodologically this approach is similar to that of a *composite index* building (Kaydos, 1999).[324] Weights per main- or super-category sum up to unity and can be interpreted as percentages. However, the "real" weights of the underlying problem remain unknown. Due to the lack of literature in the field and the lack of time to conduct a full-scale survey such as *Delphi*, the knowledge gap is bridged by hypothesizing three weight scenarios 'w0', 'w1', 'w2'. Doing so at least enables some form of sensitivity analysis (Kavran et al., 2007; Liu et al., 2013b). Scenario 'w0' is the unweighted initial scenario with equal weights; scenarios 'w1' and 'w2' then test different weight configurations displayed in the tables below.

(1) Table 7.6 concerns *building the decision main-categories*. For example, the sub-category *customer* has the highest weight (0.5) in the main-category *service*. This means that 50% of a final *service* decision score is attributed to customer-related decisions. Note that sub-category weights do not change from scenario'w1' to 'w2', except for management.

(2) The upper part of Table 7.7 concerns *building the super-categories* based on different main-category contributions to test for different operator policies or orientations. As to highest aggregate SUM for instance, scenario 'w1' would clearly be a *service-oriented scenario (30%)*, in contrast to the rather network-oriented but more balanced scenario 'w2' (network 25% but management *and* service 20%). The less aggregated super-categories RESOURCES, SERVICE and MANAGEMENT essentially rely on the same main-category weights as SUM but outline differences within the super-category more precisely. For instance the super-category RESOURCES, *personnel decision* are relatively more important than *network decisions* in 'w1' and *vice versa* in 'w2'. It should be noted that the configuration of MANAGEMENT directly relies on variations at sub-category level, by stressing either *optimization* in 'w1' (60%) or *development* in 'w2' (50%).

[322]Note that the *relative importance* of decision categories displayed in the charts of Chapter 5 only occurs due to the comparisons of standardized decision activity levels of different decision categories at the same time. The resulting relative differences simply comes from the data itself, rather than from prior assumption/impositions.

[323]For instance, as for the two sub-categories of *network decisions*, it is appropriate that frequently occurring *line management* measures might be less important than rarely occurring *network (re)organisation measures*. As such, the latter should play a larger role when building the final time-series of *network decisions* by summing up all sub-categories. Alternatively, when building the super-categories such as SUM, the final *network decisions* time-series might not be as important as *service decisions* (e.g. for a service-oriented operator) but more important than the *fleet decisions* categories. Further, the relative importance of *management decisions* might always be higher than that of network decisions, due to its complexity and multiple objectives. This "ranking" then has to be reflected in SUM.

[324]The procedure: (1) weights w_n of Table 7.6 are used to correct the AL_{mn} scores per sub-category by multiplication. (2) Then the new main-category score AL_{mN}^{w} is calculated $AL_{mN}^{w} = \sum_{n=1}^{q} w_n \, AL_{mn}$ with $\sum w_n = 1$. (3) The procure is repeated for each main-category per super-category using the weights of Table 7.7. See Kaydos (1999) p.109.

Table 7.6: Weight scenarios for decision sub-categories to build corresponding main-category.

MAIN-CATEGORY	sub-category	weight scenario w0	w1	w2
network	line management	0.25	0.20	0.20
	accessibility	0.25	**0.40**	0.40
	(re)organization	0.25	0.30	0.30
	other innovation	0.25	0.10	0.10
fleet	fleet upgrade	0.50	**0.80**	0.80
	technology upgrade	0.50	0.20	0.20
personnel	incentives	0.33	0.30	0.30
	training	0.33	**0.50**	0.50
	other	0.33	0.20	0.20
schedule	frequency changes	0.50	0.20	0.20
	other	0.50	**0.80**	0.80
fares	fare change	0.50	**0.60**	0.60
	other	0.50	0.40	0.40
service	operations	0.33	0.30	0.30
	customer	0.33	**0.50**	0.50
	IT	0.33	0.20	0.20
management	optimization	0.33	**0.60**	0.30
	development	0.33	0.30	**0.50**
	research	0.33	0.10	0.20

Most important sub-categories are marked **bold**. Redundancies grey.

Table 7.7: Weight scenarios for decision main-categories to build corresponding super-category.

SUPER-CATEGORY	main-category	weight scenario w0	w1	w2
SUM	network	0.14	0.10	**0.25**
	fleet	0.14	0.05	0.10
	personnel	0.14	0.15	0.15
	schedule	0.14	0.05	0.05
	fares	0.14	0.15	0.05
	service	0.14	**0.30**	0.20
	management	0.14	0.20	0.20
RESOURCES	network	0.33	0.33	**0.50**
	fleet	0.33	0.17	0.20
	personnel	0.33	**0.50**	0.30
SERVICE	schedule	0.33	0.10	0.17
	fares	0.33	0.30	0.17
	service	0.33	**0.60**	**0.67**
MANAGEMENT	management	1.00	1.00	1.00

Most important main-categories are **bold**. Consistencies grey.

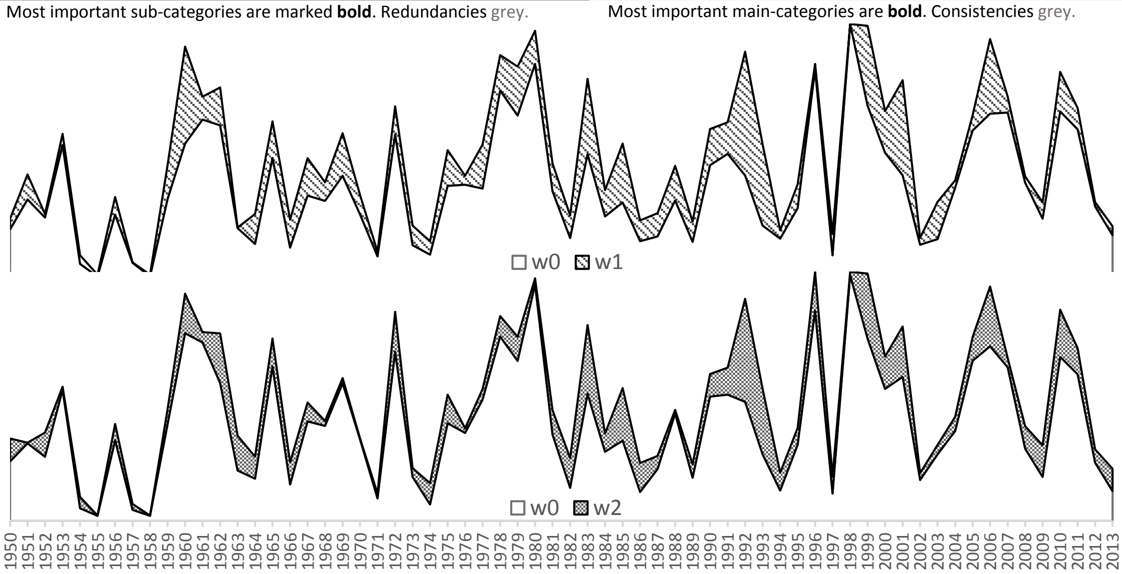


Figure 7.7: Enhanced data example. Effect of weight introduction on super-category RESOURCES. Porto.

Figures 7.7 exhibits the effects of weight introduction on the RESOURCES variable by pair-wise comparison of 'w1' and 'w2' to the unweighted scenario 'w0'. Obviously, time-series are altered through weight introduction. The dark areas then correspond to the induced information.[325]

DATA TRANSFORMATIONS: With the previous step finalized, the data set is complete but still in its original[326] (however, standardized and weight adjusted) format and thus suitable for a transformation to reasonable economic metrics. Often regressions with in economics rely on the transformation of both the dependent and independent variables to their natural logarithms

[325]Weights for the contextual data: legal (0.3), energy (0.4), demand (0.1), other (0.2), fixed for w1 and w2.
[326]See an example of count data in regression with Gillen and Lall (1997): number of airline hubs, runways, gates.

(so called '*log-transformation*'). By taking advantage from some of the magical properties of logarithms, log-transformation is applied mainly for the three reasons:

(1) *Straightforwardness:* In so-called *log-log* regression model, the beta-coefficients associated with the independent variables can be interpreted as elasticities. Elasticities relate to effects from marginal changes in the explanatory on the explained variable, expressed in percentages[327]. Thus, a *beta-coefficient* simply measures the percentage change of the dependent variable caused by a 1% change of the independent variable, keeping all other variable constant (*ceteris paribus*). In economics, units are not always well defined or consistent. Thus, it is recommended to refer to percentage changes from reference values. Percentage effects are obviously easier to compare than unit effects. Further, a beautiful property of logarithm relates to the application of differencing, which might be required for stationarization: the first-difference of a logged variable is approximately equal to its percentage change for small changes.[328] Thus, first-differences of logged variables can be interpreted as growth rates[329] (Banerjee et al., 2015; Gillen and Lall, 1997; Holvad, 2010; Oum and Yu, 1994; Wooldridge, 2009).

(2) *Statistical facilitation:* Time-series with signs of upwards trend, increasing volatility and variance get more stable and less skewed by altering the scale. Outliers might look less "outlying". Also, the need for further data interferences like de-trending, differencing and ARMA terms might be reduced thus simplify the whole modelling process.

(3) *Linearization:* Non-linear multiplicative models would become linear through log-transformation and thus suitable for linear regression.

Table 7.8 summarizes all required data transformations for all variables eventually leading the log-transformation.[330] First, values of zero in the decision and contextual data pose a problem, as the log of zero is not defined. The data is thus scaled to percentage levels, and zeros and values lower than one are replaced by values of one to apply log-transformation to non-negative

Table 7.8: Data transformations of variables and interpretation in regression analysis.

	Transformation	**Dependent V**	**Independent V**						
#	(effect on data range)	Performance Data **X10** ¦ **Y14** ¦ **Z10**	Decision Data **KSUM**	**LRES**	**MSER**	**NMAN**	Contextual Data **QCON**	External Data **QGDP**	**QPOP**
0	original standardized	$0 < Y_t < 1$	$0 \leq X_t \leq 1$				$0 \leq X_t \leq 1$	$0 < X_t < 1$	
1	multiply by 100	$0 < Y_t < 100$	$0 \leq X_t \leq 100$				$0 \leq X_t \leq 100$	$0 < X_t < 100$	
2	replace zeros by 1	$0 < Y_t < 100$	$1 \leq X_t \leq 100$				$1 \leq X_t \leq 100$	$0 < X_t < 100$	
3	replace <1 by 1	$1 \leq Y_t \leq 100$	$1 \leq X_t \leq 100$				$1 \leq X_t \leq 100$	$1 \leq X_t \leq 100$	
4	**log-transform all N**	$\mathbf{0 < 4.61}$	$\mathbf{0 < X_t < 4.61}$				$\mathbf{0 < X_t < 4.61}$	$\mathbf{0 < X_t < 4.61}$	
Interpretation of Variables - Levels and Growth Rates									
4	log (N) = level	performance level	decision activity level				contextual level	GDP level	POP level
5	First-differenced log(N) = growth rate	performance growth rate	decision activity level growth				contextual level growth	economic growth rate	population growth rate
6	Second-differenced log(N) = Δgrowth rate	Δ performance growth rate	Δ decision activity level growth				Δ contextual level growth	Δ economic growth rate	Δ population growth rate
Interpretation of Beta - Elasticities			β_1	β_1	β_2	β_3	β_4	β_5	β_6
5	% change of Dependent Variable **caused by** 1% change of Independent Variable		β_n = *% change of performance growth rate* **caused by** *1% change of decision activity level*				*1% change of contextual level*	*1% change of economic growth rate*	*1%change of Δ population growth rate*

X10, Y14, Z10, KSUM, LRES, MSER, NMAN, QCON, QGDP, QPOP = variables; Grey: theoretical, cases not applied

[327]Kockelman et al. (2013): Elasticities evaluate the *"practical significance"* of variables as to their impact on the explained variable, while *"statistical significance"* describes if parameters are statistically different from zero.

[328]Example: percentage change of N from 95 to 96 is 1.041% ≈ first-difference of log(N) = (ln(96)-ln(95))*100=1.047%.

[329]Banerjee et al. (2015), proof on page 19: The first difference of GDP is the economic growth rate. Then the second difference of GDP is the growth of the economic growth rate. When the second difference is a positive constant, and the first difference is positive, the rate of growth is growing and the time-series grows ever faster.

[330]The original values were standardized to unity.

values. Most importantly, the table further shows, how to interpret the variables *after transformation and regression* with reference to their estimated beta-coefficients.[331]

Modelling Framework [*Which Models to Run and How to Present?*]

In order to achieve the objective of *model diversity* as stated in Table 7., *multiple* regression models with different configurations are estimated using the Box-Jenkins method. The creation of the variety of models needs to be performed systematically. This is done by the *modelling framework* proposed in Figure 7.8 serving various purposes. The modelling framework

- is an auxiliary structure to organize the modelling workload,
- quantifies the scope (and limitations) of this research in terms of model and variable variations as well as number of time lags modelled,
- breaks the bigger-picture down to the formulation of individual models,
- illustrates the modelling principle herein and builds a bridge to results presentation and inferences.

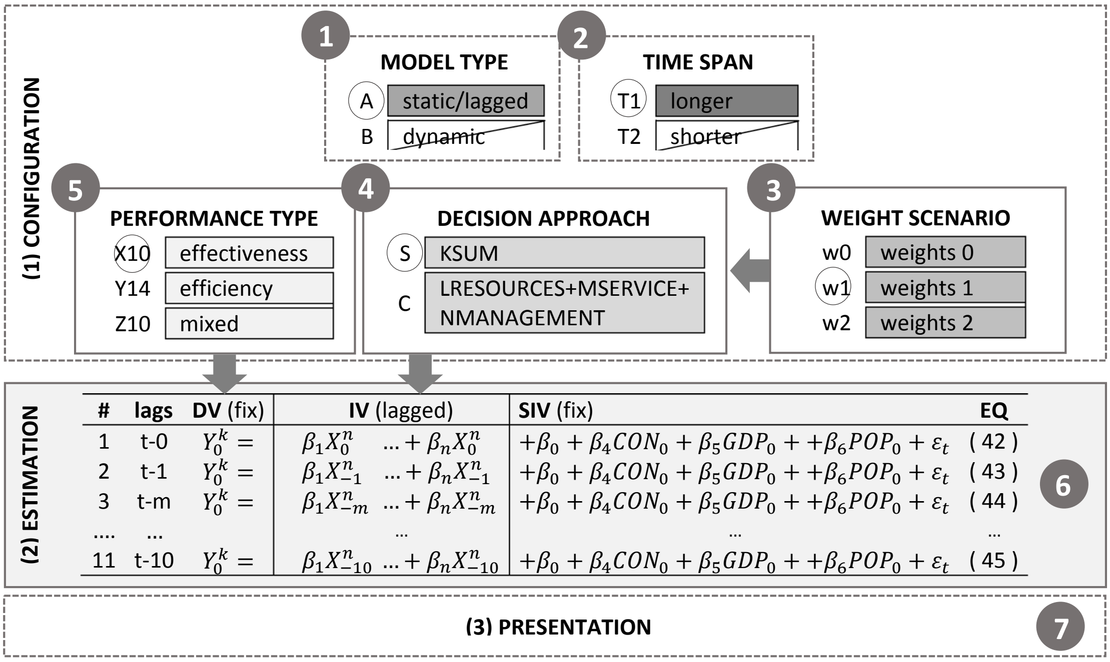


Figure 7.8: Modelling Framework Top-Down.

The framework relies on three stages: model configuration, estimation, and presentation:

MODEL CONFIGURATION: In five consecutive steps, this stage concerns the *model type* and the determination of the *variables* that enter the regression analysis. *Step 1* refers to the choice between the basic *static/lagged* regression model and the dynamic finite-distributed-lag model as introduced above ('A' or 'B'). *Step 2* considers the option to use time-series over their total

[331]For instance, an estimated $\beta_1 = 0.03$ for KSUM in $t = 1$ would suggest, that a 10% increase of the operators overall decision activity level contributes to the average performance growth rate by 0.3%, holding other factors constant. An assumed annual growth rate of 2% would then increase to 2.06% by the enforced decision activity.

time-span or cut them, e.g. to the last 30 years ('T1' or 'T2')[332]. *Step 3* refers to the different weight scenarios applied to the decision categories. Accordingly, each weight scenario 'w0', 'w1', 'w2' corresponds to changes of the independent decision variable(s). The independent variables are selected in *Step 4*, offering two basic decision approaches: Approach 'S' uses KSUM as single variable - that is the totalized activity level over all decision categories - in order assess the effects of aggregated managerial action on performance. Approach 'C' considers all super-categories LRESOURCES, MSERVICE and NMANAGEMENT simultaneously as variables in the regression model.[333] Since, each decision super-category is assumed to target different aspects of the operator's production process (e.g. resources→inputs, service→outputs, management→both) the segmentation might yield different effects on different performance types. *Steps 5* finally refers to the selection of the dependent variable with the performance type's effectiveness ('X10'), efficiency ('Y14') and mixed performance ('Z10') as options.

MODEL ESTIMATION: A specific model configuration then goes through the process of multiple regression models in *Step 6*, which are the centrepiece of the analysis. The model formulation displayed in Figure 7.8 is based on the following assumptions for any given configuration:

(1) The dependent variable (DV) Y_t^k is *performance*. The main independent variables (IV) are *decisions* X_t^n. The secondary independent variables (SIV) are *externals* CON_t, GDP_t, POP_t to capture non-controllable effects[334] on operator performance.

(2) Lags up to 10 years are modelled with lagged decisions. Externals are assumed to affect performance instantly. Thus, they are not lagged.

(3) First, effects from *current* decisions on performance are modelled through a static regression model. In the 1st model, performance Y_0^k at time $t = 0$ is regressed on decisions X_0^n at time $t = 0$ and externals at time $t = 0$ (Equation 1 or 14).[335]

(4) Then effects from lagged decisions on performance are modelled individually through lagged regressions. In the 2nd model, performance at time $t = 0$ is regressed on decisions X_{-1}^n at time $t - 1$ and externals at time $t = 0$ (Equation 15)). In the ith model, performance at time $t = 0$ is regressed on decisions X_{-m}^n at time $t - m$ and externals at time $t = 0$ (Equation 16). In the 11th model, performance at time $t = 0$ is regressed on decisions X_{-10}^n at time $t - 10$ and externals at time $t = 0$ (Equation 17).

Overall, 11 separate regressions (lag models) are performed and parameters estimated accordingly (e.g. β_1 for lag 0, β_1 for lag -1, ...) with the Box-Jenkins procedure (see Figure 7.6[336]), which form a "block" of information. This is applied for all configurations over all operators. Table 7.9 summarizes the scope of this research. The minimum count of models is 594, that is, 54 configurations *times* 11 regressions, or 54 blocks. Future research might extent this count.

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[332]See Cooper et al. (1995) or Jarboui et al. (2012). Note that *Steps 1* and *2* are rather theoretical options for future research and ignored herein. The focus of this work is the basic *static/lagged* regression model for *longer* time-series.
[333]Hereinafter decision approach S is termed 'SUM-approach' and scenario C is termed 'CLUSTER-approach'. Also, note that 'performance variables/data' are termed 'performance', 'decision variables/data' are termed 'decisions', 'external variables/data' are termed 'externals'. A model for a lag is termed 'lag model'.
[334]Same variables as in Pina and Torres (2001), Graham (2008); Hilmola (2011), Santos et al. (2014).
[335]See a similarl model set-up applied in Dang-Thanh (2012) but with Tobit regression.
[336]Stationarization might be performed beforehand for all variable, thus B-J starts with (3) Model selection.

Table 7.9: Scope of research = number of models (theoretical options in framework).

Steps	0 operator	1 model type	2 time span	3 weights	4 decision approach	5 performance	6 years (lags+1)	Scope
modelling options	Hamburg Porto Dresden	static (dynamic)	long (short)	w0 w1 w2	SUM CLUSTER	effectiveness efficiency mixed	11	
# of options	3	1 (+1)	1(+1)	3	2	3	11	**594**(x4)

MODEL PRESENTATION: In *estimation* - other than in *forecasting* - interpreting coefficients is pivotal (Holvad, 2010). The amount of models, however, contributes to the objective of *model diversity* while at the same time making it substantially difficult or impossible to present results of single, model-based cases. Thus, results have to be presented in a more aggregated manner. This is achieved by two means: *results consolidation* and *results visualisation*.

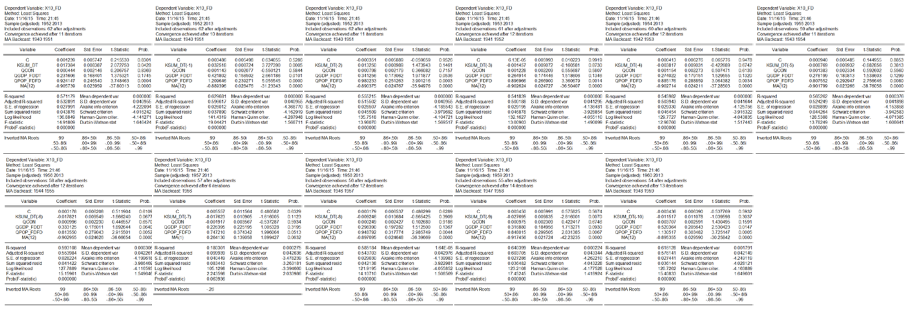


Figure 7.9: Theoretical, unfiltered regression output of 11 regressions. Porto. KSUM.

STEP 1 - RESULTS CONSOLIDATION: Consider the encircled configuration 'T1-A-w1-S-X10' from above is modelled for Porto and presented in Figure 7.11. The 11 regressions - one tableau for each lag (t) to $(t-10)$ - would display 11 coefficients and 11 summary statistics such as R^2, *Prob.*, *AIC* and so forth. The obtained information is too complex to apprehend. It needs to be filtered[337], analysed[338] and consolidated automatically for further comparison and conclusions.

Table 7.10: Consolidated regression output for eleven regressions.

#	+lag/ year	KSUM β_1	QCON β_4	QGDP β_5	QPOP β_6	MA(12)	R-squared	Adjusted R-squared	Log likelihood	Prob (F-statistic)	Akaike info criterion	Schwarz criterion	Durbin-Watson
1	0	0.017	n.s.	n.s.	0.924	-0.906	0.57	0.53	136.88	0.00	-4.22	-4.02	1.65
2	+1	0.033	n.s.	0.422	1.210	-0.889	0.63	0.60	141.43	0.00	-4.37	-4.16	1.57
3	+2	n.s.	n.s.	0.341	0.980	-0.890	0.56	0.52	135.75	0.00	-4.19	-3.98	1.57
4	+3	n.s.	n.s.	n.s.	0.897	-0.903	0.54	0.50	132.16	0.00	-4.14	-3.93	1.49
5	+4	n.s.	n.s.	n.s.	0.885	-0.903	0.55	0.50	129.77	0.00	-4.13	-3.92	1.52
6	+5	n.s.	n.s.	n.s.	0.808	-0.902	0.57	0.52	128.54	0.00	-4.15	-3.94	1.61
7	+6	-0.018	n.s.	0.333	0.814	-0.903	0.59	0.55	127.79	0.00	-4.20	-3.99	1.55
8	+7	n.s.	n.s.	n.s.	0.747	0.264	0.18	0.10	105.13	0.06	-3.48	-3.26	2.03
9	+8	n.s.	n.s.	n.s.	0.949	-0.897	0.59	0.54	121.92	0.00	-4.14	-3.92	1.51
10	+9	-0.028	n.s.	0.317	0.848	-0.917	0.64	0.60	123.21	0.00	-4.26	-4.04	1.42
11	+10	n.s.	n.s.	0.520	1.131	-0.895	0.62	0.58	120.73	0.00	-4.25	-4.03	1.65
	mean	0.001	-	0.387	0.927	-0.795	0.55	0.50	127.57	0.01	-4.14	-3.93	1.60
	min	-0.028	-	0.317	0.747	-0.917	0.18	0.10	105.13	0.00	-4.37	-4.16	1.42
	max	0.033	-	0.520	1.210	0.264	0.64	0.60	141.43	0.06	-3.48	-3.26	2.03

n.s.: not significant: p-value $> \alpha = 0.1$

[337]*Filtering*: only coefficients with a pre-defined p-values enter the table, such as p≤ 0.1 [See similar levels applied in Wei et al. (2013), Odeck and Bråthen (2007); Wang (2011), Ceder (2007), Kerstens (1996), Jarboui et al. (2012).]

[338]*Analysis*: avg/min/max explanatory power, avg/min/max effect size, best model, counting of time-lags, spikes, etc.

Consolidated results are expressed in tables such as Table 7.10 above, which provide compact information for each lag model and descriptive information for each block. Concerning the interpretation of each lag model the key interest is to make inferences from the estimated beta-coefficients[339] of the decision variables (e.g. the 11 β_1 for *KSUM* in the given example).

However, *first* note that the lag models of Table 9 are captioned '+lag', which could also understood simply as "year". This is because for presentation purposes it appears more intuitive to alter the interpretation of lags from *retrospective* to *prospective:* In modelling, the interpretation of coefficients is how the *explained* variable is affected by *current* or *past explanatory* variable (retro).[340] In presentation, however, the interpretation is how *current explanatory variables* affect *current* or *future explained* variables (pro).[341,342] In other words, all changes in the explained variable at different points of time come from one standardized base-line of decisions taken at $t = 0$. Applying the prospective logic on lag +6/year 6 of Table 7.10, suggests that the effect from current decisions on performance growth in six years turns out to be negative by -0.018%. As to other information in Table 7.10 - without going too much in detail - one could immediately see that QCON[343] is consistently not significant, or that all models are significant, and that their explanatory power ranges from 18% to 64%. One might also observe that model number 2 is the "best" model, as it displays the highest R², LL, and lowest AIC a SBCs.

STEP 2 - RESULT VISUALIZATION: As shown in Table 7.10, not all lag models of KSUM result in significant coefficients, which makes them interpretable as being zeros. Further, the results indicate the presence of *tendencies* or *patterns*, i.e. *betas* going from positive to negative over time. Thus, it makes sense to *visualize* the decision coefficients/elasticities for all lag models as in Figure 7.10[344]. In combination with the prospective view, suchlike bar charts give visual and

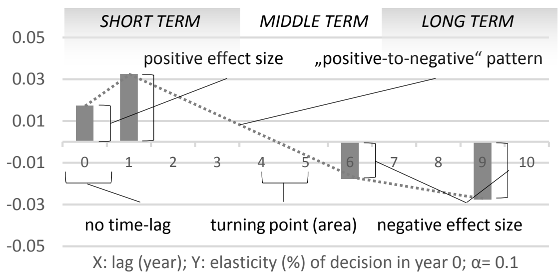


Figure 7.10: Pattern of effects over time.

Findings	Definition
effect patterns or trends	Regular, meaningful, observable form of increasing, decreasing, alternating elasticities over time.
time-lags	Existence of years with $\beta = 0$ before initial year with $\beta > 0$.
effect direction	Positive, negative or zero effect.
[earliest turning point]	*[Years with transition from positive to zero or negative effect and vice versa or trend reversal.]*

Table 7.11: Key findings from effect visualization.

[339]Again, beta coefficient = *elasticity* = the *effect* from marginal changes of decisions on performance in percentages. These terms are used here interchangeably.
[340]E.g. β_1 for lag -6, describes the effect from decisions six *past* lags apart on *current* performance.
[341]E.g. β_1 for lag +6, describes the effect from *current decisions* on performance five *future* periods apart.
[342]*Modelling*: viewed from the explained variable. *Presentation*: viewed from the explanatory variables. Appendix 18 shows that, technically, there is no difference between these perspectives as to relevance of the beta-coefficient.
[343]Externals are not lagged. The coefficients $\beta_4, \beta_5,\ \beta_6$ correspond to the same year as the explained variable.
[344]The segmentation *short, middle, long term* refers to intervals from 0-3, 4-6, 7-10 years.

intuitive information how recent decisions affect future performance growth over the *short*, *middle* or *long term*. Following the definitions of Table 7.11, the charts specifically help to assess phenomena such as *effect patterns*, *time-lags* and *effect directions* through observation. Here is an example of how to use the chart: "*With regard to effect patterns over time, Figure 7.11 enables to observe that decisions at* $t = 0$ *yield a positive effect on performance growth in the first years, as opposed to the latter years, which exhibit a negative effect. Turning points are around years 4 and 5. No time-lags are observable. One can conclude that after some time, decisions might no longer contribute to performance growth but rather slowing it down. This would imply that the management should revise its actions latest around the turning points.*"

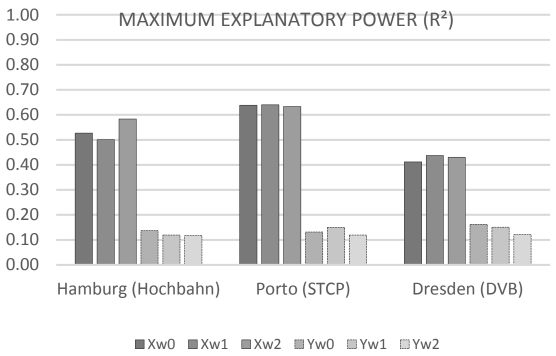


Figure 7.11: Example - explanatory power of model per weight scenario, performance type, operator.

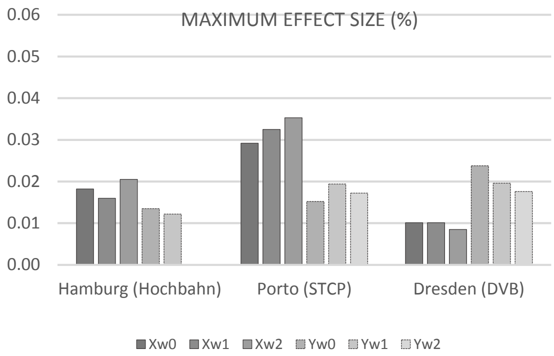


Figure 7.12: Example - max effect sizes of SUM per weight scenario, performance type, operator.

Another type of visualization is presented in Figures 7.11 to 7.12, which provide further condensed information for each regression block using the following metrics: (a) *number of significant betas, effect size range,* and number of *time-lags* per model block; (b) average *effect size* from external variables (c) *average explanatory power* and *best model* as model evaluation criteria. With the charts, one might detect changes/anomalies for each model configuration. The metrics allow to derive *average effect sizes per variable* and *time-lag intervals* per variable.

For any scientific research, an essential challenge is it to design the communication of knowledge and results in the most effective way. Too complex information might impede the reader to think about the key issues addressed. The innovative visualizations thus facilitate to draw *conclusions* with regard to the research questions.

The next section demonstrates how the EViews 8.0 is used for modelling. One might directly jump to section 7.5 for findings and in-depth interpretations of results.

EXCURSUS: Modelling Example with EViews

The example primarily intends (a) to illustrate the reasoning of result generation, (b) to clarify about the standards applied in the modelling process (in particular with reference to the Box-Jenkins methodology), and (c) to give an impression about how the modelling is practically performed with EViews 8.[345,346] However, the following example - chosen randomly among the set of models suggested in the previous section - represents just one iteration of a procedure exercised multiple times with all models. The initial model, modelling steps, corresponding tests, plots and outcomes are briefly illustrated and discussed, complementing the *theoretical* information on autocorrelation and stationarity from above with *hands-on* modelling. Table 7.12 summarizes the key steps required to ensure the OLS framework, ordered by their position in the modelling process.

Table 7.12: Pivotal Steps, Objectives and Checks in Modelling.

Steps	Objective		Checks/Tests
0	*Model Formulation*		
1	Stationarity	(A7)	*plots, unit-root test*
2	No multi-collinearity	(A2)	*correlation matrix*
3	No autocorrelation	(A5)	*Breusch-Godfrey, Correlogram, equation diagnostics*
4	Zero mean Normality	(A3) (A6)	*Jarque-Bera*
5	Homoscedasticity	(A4)	*Breusch-Pagan test*
6	*Model Evaluation*		*β coefficiencts, p-values, summary statistics*

0 MODEL FORMULATION: The example aims at modelling the effects from activities in *three decision categories*, one *context* and two *external* variables (explanatory variables/regressors) on *effectiveness* in Porto at time t (explained variable/regressand) during 1950-2013. Thus, the multi-variate regression model is composed of six explanatory time-series. The complete model is given by Equation (18). It should be stressed that the decision variables are those of a weight scenario without weights ('w0') and lagged by five time periods ($t-5$) to assess effects from past decision activities on recent performance. The remaining variables are generally not lagged, since their impact is assumed to unfold directly in the assessment period t.

$$X10_t = \beta_0 + \beta_1 LRESOURCES_{t-5} + \beta_2 MSERVICE_{t-5} + \beta_3 NMANAGEMENT_{t-5} + \beta_4 CON_t + \beta_5 GDP_t + \beta_6 POP_t + \varepsilon_t \qquad (46)$$

1 CHECKING FOR STATIONARITY: In order to ensure assumption (A2) it is first recommended to plot all series and assess them visually for trends and other particularities that might indicate non-stationarity or cause modelling problems. Figure 7.13 below exhibits differently shaped trends for every variable, except of the contextual variable CON. For instance, the variables *resources* and *service* show slight linear trends in contrast to the variables *management*, *GDP*

[345]Commercial statistical package for time-series oriented econometric analysis (estimation + forecasting) and other statistical and econometric analyses, such as cross-section, panel data analysis and more: http://www.eviews.com/.
[346]For an introductory read in EViews see also Agung (2009), Vogelvang (2005) and Startz (2013).

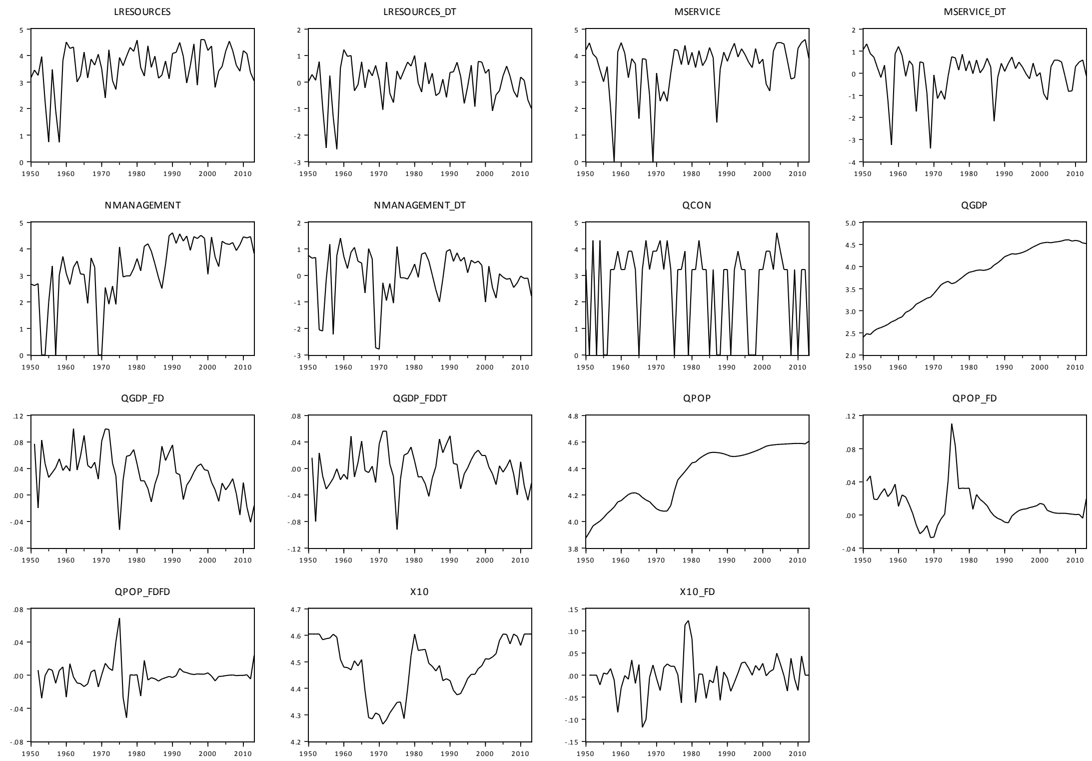


Figure 7.13: Time-series before and after stationarization.

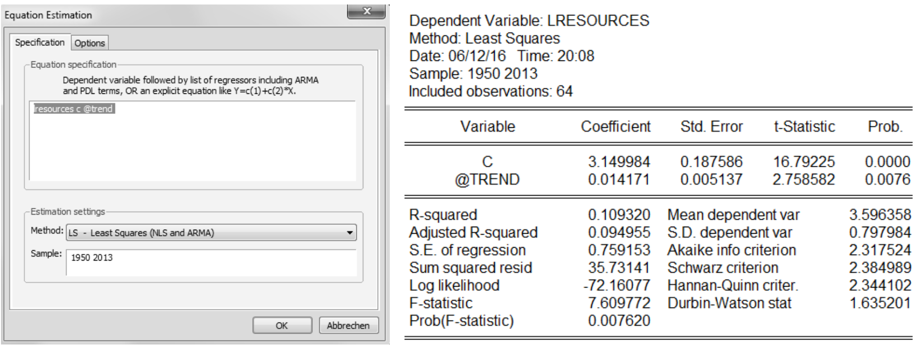
and *POP* (population) that are strongly trending upwards. The patterns preliminarily suggest the issue of non-stationarity and the application of correction measures such as *de-trending* or *differencing*. The nature of stationarity should be confirmed through the unit-root test. Table 7.13 summarizes ADF statistics and its threshold as explained, for all levels of intervention. As a thumb rule one could say that the smaller the t-statistics, the less trending a time-series is.

Table 7.13: Results unit-root/ADF test for all variables.

Variable	**Intervention**						**Final marking**
	NO (original)		DE-TRENDING		DIFFERENCING		
	t-Statistic	Prob.*	t-Statistic	Prob.*	t-Statistic	Prob.*	
LRESOURCES	-5.92404	0.0000	-6.45914	0.0000	-	-	*LRESOURCES_DT*
MSERVICE	-5.66705	0.0000	-6.10535	0.0000	-	-	*MSERVICE_DT*
NMANAGEMENT	-3.95276	0.0030	-5.8377	0.0000	-	-	*NMANAGEMENT_DT*
QCON	-7.4128	0	-	-	-	-	*QCON*
QGDP	*-2.44258*	0.1346	-	-	-5.64819	0.0000	*QGDP_FDDT*
QPOP	*-1.14292*	0.6933	-	-	-6.94521	0.0000	*QPOP_FDFD*
X10	*-2.01399*	0.2803	-	-	-6.08205	0.0000	*X10_FDFD*

*MacKinnon (1996) one-sided p-values.
For stationarity, t-statistic has to be smaller than critical values: (1% level=-3.54), (5% level=-2.91), (10% level=-2.59). If larger, marked *italic.*

The unit root test for the *original* data implies that the decision variables are stationary, despite their trend, as for instance the lowest t-statistics of -3.95276 from management is smaller than the largest threshold -2.591799. *GDP*, *POP* and the explained variable *X10* (effectiveness), however, are clearly not stationary. Even when rendered stationary, trends should be removed from the data. From the visual inspection it can be concluded that it is recommended to *de-trend* the variables *resources, service* and management and to at least *first-difference GPD, POP* and *X10. De-trending* is achieved by regressing a series against time and then using the residuals



Dependent Variable: LRESOURCES
Method: Least Squares
Date: 06/12/16 Time: 20:08
Sample: 1950 2013
Included observations: 64

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.149984	0.187586	16.79225	0.0000
@TREND	0.014171	0.005137	2.758582	0.0076

R-squared	0.109320	Mean dependent var	3.596358
Adjusted R-squared	0.094955	S.D. dependent var	0.797984
S.E. of regression	0.759153	Akaike info criterion	2.317524
Sum squared resid	35.73141	Schwarz criterion	2.384989
Log likelihood	-72.16077	Hannan-Quinn criter.	2.344102
F-statistic	7.609772	Durbin-Watson stat	1.635201
Prob(F-statistic)	0.007620		

Figure 7.14: De-trending the variable resources.

for further analysis. In EViews this is done be adding the term '@trend' to a regression model with a constant as shown in Figure 7.14[347]. The right hand-side of the chart confirms the slight positive trend in the time-series *resources*. Consequently, the residual series of this trend regression replaces the original series for *resources*. The de-trending process is similarly applied to *service* and *management* leading to the decreased t-statics as shown in Table 7.13 in the column 'de-trending'. The series stabilization may also be observed in Figure 7.13. Considering the high t-statistics of *GDP, POP* and *X10 de-trending* is obviously not sufficient to introduce stationarity to this variables. Therefore, *GDP* and *X10* become only stationary after first-differencing, POP after second-differencing. This is outlined ADF t-statistics that is clearly below the threshold shown in column the 'differencing' of Table 7.13.[348]

Table 7.14 shows the descriptive statistics of all stationarized time-series comprehensively.

Table 7.14: Descriptive statistics of stationarized time-series.

	LRESOURCES_DT	MSERVICE_DT	NMANAGEMENT_DT	QCON	QGDP_FDDT	QPOP_FDFD	X10_FD
Mean	-6.21E-16	-6.67E-16	2.64E-16	2.596822	9.31E-18	-0.000343	0
Median	0.148159	0.26901	0.080665	3.218876	0.001001	-0.000344	0
Maximum	1.221475	1.324468	1.406758	4.60517	0.056402	0.068905	0.123623
Minimum	-2.535512	-3.403671	-2.777562	0	-0.092137	-0.05165	-0.118051
Std. Dev.	0.753104	0.925731	0.917774	1.620028	0.02894	0.015548	0.040624
Skewness	-1.171348	-1.755153	-1.2593	-0.861908	-0.483386	0.924552	0.015856
Kurtosis	4.898037	6.569557	4.495015	2.051554	4.063141	10.07913	5.214985
Jarque-Bera	24.24204	66.83729	22.87578	10.32291	5.42041	138.2944	12.8813
Probability	0.000005	0	0.000011	0.005733	0.066523	0	0.001595
Sum	-3.89E-14	-4.02E-14	2.13E-14	166.1966	6.73E-16	-0.021288	0
Sum Sq. D.	35.73141	53.98965	53.06545	165.3429	0.051928	0.014746	0.102318
Obs.	64	64	64	64	63	62	63

2 CHECKING FOR MULTICOLINARITY: Explanatory variables must not be mutually correlated. The construction of a Pearson-based correlation matrix for the explanatory variables will indicate whether any given pair of right-hand side variables might cause problems with collinearity, that is when one or more variables are approximate linear combination of the others. Despite being straightforward and easy to understand, correlation scores are not really considered the best indicators for multicollinearity (because of being restricted to bi-variate assessment). At least

[347]Or '@trend^2' in case of a quadratic trend.
[348]The entire the stationarization-process is reflected in right hand-side column of Figure 7.13 where the suffix "_dt" stands for de-trending and the "_fd" for differencing, respectively.

Covariance Analysis: Ordinary
Date: 06/13/16 Time: 09:16
Sample (adjusted): 1952 2013
Included observations: 62 after adjustments
Balanced sample (listwise missing value deletion)

Correlation Probability	LRESOURC...	NMANAGE...	MSERVICE...	QCON	QGDP_FDDT	QPOP_FDFD
LRESOURCES_DT	1.000000 -----					
NMANAGEMENT_...	0.199887 0.1193	1.000000 -----				
MSERVICE_DT	0.358407 0.0042	0.349349 0.0054	1.000000 -----			
QCON	-0.021324 0.8693	-0.038086 0.7688	0.031474 0.8081	1.000000 -----		
QGDP_FDDT	0.194304 0.1302	-0.121046 0.3487	-0.226474 0.0767	-0.077538 0.5492	1.000000 -----	
QPOP_FDFD	-0.159353 0.2160	0.179648 0.1624	0.044117 0.7335	-0.096448 0.4558	-0.296593 0.0192	1.000000 -----

Figure 7.15: Correlation matrix for explanatory variables.

their magnitude can indicate the likeliness of a multicollinearity problem. Some researcher argue that r exceeding 0.4 might point at such issue. Consequently, the correlation matrix of Figure 7.15 clearly rules out correlation between the explanatory variables in the example. In so far the data is ready to enter regression analysis.

3 CHECKING FOR AUTOCORRELATION: Based on Equation 16 a tentative regression is exercised, yielding the results of Figure 7.16. The p-values imply that only *POP* is significant at 10%, the model itself is not significant. The low Durban-Watson statistics (1.38) suggest the presence of at least some first-order autocorrelation, as the lower bound threshold of 1.404 for 6 repressors and 65 observations is slightly missed (UniBo, 2016). The DW score should be around the value of 2 in the case of no residual autocorrelation. This step - as per BJ also ‘identification’ - is the trickiest and most time-consuming one in the modelling process as it aims at “finding” the best composition of AR and/or MA terms to enter the regression to correct for residual correlation. However, much of fitting an ARMA model is guesswork and trial-and-error using the information given in the correlogram, specifically from the ACF and PACF. As the inclusion of these terms is not based upon theoretical considerations it might however be supported by some sort of heuristic or checklist as compiled below. To assess the state of residual correlation first a correlogram is plotted and visually checked for recognizable patterns, which should be given primary attention. The derived suggestions are then verified via Breusch-Godfrey test for serial correlation. Both tests are displayed in Figure 7.17: for the case presented, the correlogram on the left-hand side obviously demonstrates that de-trending and differencing removed all ideal-typical autocorrelation patterns in the ACF and PACF. These would have been more helpful to indicate which terms ought to enter the regression. However, the correlogram shows isolated serial correlation on the first and twelfth lag with spikes exceeding the dashed line, which are confidence limits. This means that the current error terms is affected by the errors of 1 and 12 periods back in time. This can be confirmed by the corresponding significant test statistics on

Dependent Variable: X10_FD
Method: Least Squares
Date: 06/13/16 Time: 15:40
Sample (adjusted): 1955 2013
Included observations: 59 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.007080	0.011077	0.639188	0.5255
LRESOURCES_DT(-5)	-0.009521	0.007829	-1.216177	0.2294
MSERVICE_DT(-5)	-0.004600	0.006926	-0.664065	0.5096
NMANAGEMENT_DT(-5)	0.009094	0.006658	1.365832	0.1779
QCON	-0.002603	0.003703	-0.702980	0.4852
QGDP_FDDT	0.193641	0.207697	0.932321	0.3555
QPOP_FDFD	0.776016	0.402105	1.929885	0.0591

R-squared	0.121135	Mean dependent var	0.000376
Adjusted R-squared	0.019728	S.D. dependent var	0.041898
S.E. of regression	0.041483	Akaike info criterion	-3.416072
Sum squared resid	0.089484	Schwarz criterion	-3.169585
Log likelihood	107.7741	Hannan-Quinn criter.	-3.319853
F-statistic	1.194537	Durbin-Watson stat	1.380199
Prob(F-statistic)	0.323935		

Figure 7.16: Tentative regression output.

Date: 06/12/16 Time: 22:30
Sample: 1950 2013
Included observations: 59

Lag	AC	PAC	Q-Stat	Prob
1	0.307	0.307	5.8330	0.016
2	-0.063	-0.173	6.0817	0.048
3	0.058	0.152	6.3007	0.098
4	0.159	0.087	7.9449	0.094
5	0.031	-0.042	8.0070	0.156
6	-0.023	0.013	8.0426	0.235
7	0.097	0.096	8.6889	0.276
8	-0.080	-0.199	9.1392	0.331
9	-0.154	-0.034	10.852	0.286
10	-0.088	-0.064	11.424	0.325
11	-0.073	-0.085	11.820	0.377
12	-0.391	-0.387	23.516	0.024
13	-0.286	-0.005	29.899	0.005
14	-0.097	-0.149	30.655	0.006
15	0.058	0.200	30.931	0.009
16	-0.029	-0.041	31.002	0.013
17	-0.002	0.174	31.002	0.020
18	0.020	-0.096	31.036	0.029
19	-0.151	-0.071	33.081	0.024
20	-0.098	-0.170	33.974	0.026
21	0.105	0.123	35.016	0.028
22	0.208	-0.039	39.216	0.013
23	-0.041	-0.068	39.382	0.018
24	0.073	0.016	39.924	0.022

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	2.143507	Prob. F(12,40)	0.0356
Obs*R-squared	23.09122	Prob. Chi-Square(12)	0.0270

Test Equation:
Dependent Variable: RESID
Method: Least Squares
Date: 06/12/16 Time: 23:00
Sample: 1955 2013
Included observations: 59
Presample missing value lagged residuals set to zero.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.005068	0.010552	0.480309	0.6336
LRESOURCES_DT(-5)	0.001074	0.007400	0.145156	0.8853
MSERVICE_DT(-5)	-0.007479	0.007299	-1.024592	0.3117
NMANAGEMENT_DT(-5)	0.002276	0.006243	0.364492	0.7174
QCON	-0.002445	0.003601	-0.678928	0.5011
QGDP_FDDT	0.036126	0.221607	0.163019	0.8713
QPOP_FDFD	-0.037258	0.453048	-0.082238	0.9349
RESID(-1)	0.356680	0.147302	2.421421	0.0201
RESID(-2)	-0.207519	0.157087	-1.321042	0.1940
RESID(-3)	0.018858	0.169714	0.111118	0.9121
RESID(-4)	0.164259	0.178434	0.920557	0.3628
RESID(-5)	0.007216	0.174697	0.041305	0.9673
RESID(-6)	-0.111020	0.179438	-0.618710	0.5396
RESID(-7)	0.276772	0.177349	1.560606	0.1265
RESID(-8)	-0.139243	0.190603	-0.730536	0.4693
RESID(-9)	-0.107093	0.181872	-0.588836	0.5593
RESID(-10)	-0.021922	0.197308	-0.111105	0.9121
RESID(-11)	0.064706	0.181865	0.355790	0.7239
RESID(-12)	-0.479697	0.169499	-2.830086	0.0072

R-squared	0.391377	Mean dependent var	-1.41E-18
Adjusted R-squared	0.117496	S.D. dependent var	0.039279
S.E. of regression	0.036899	Akaike info criterion	-3.505848
Sum squared resid	0.054462	Schwarz criterion	-2.836811
Log likelihood	122.4225	Hannan-Quinn criter.	-3.244683
F-statistic	1.429005	Durbin-Watson stat	1.992669
Prob(F-statistic)	0.170975		

Figure 7.17: Testing for serial autocorrelation of residuals.

the right-hand side. However, absent of strong ACF or PACF patterns and with both function equally spiky at the same lags one is free to try several combination of AR(q) and MA(p) terms according to S7, S8, S9, S10 and S12 in the ARMA modelling checklist proposed in Table 7.15.

The overarching principle of model identification is *parsimony*[349], which favours low order models with only a few AR or MA terms. In EViews, AR and MA parts of the model are generally specified using e.g. the keywords AR(1), AR(2) or MA(1to2) in the regression equation. As modelling principle P4 suggests, in the example one may start with a lower AR model and check whether residual correlation from the 12th lag disappears. When proven persistent, one might

[349]Coelli (2005): Parsimony is *"choosing the simplest functional form that gets the job done adequately."*

Table 7.15: Checklist for model identification in ARMA modelling. Adapted from Levenbach (2015).

SHAPE OF ACF and/or PACF		**POTENTIAL MODEL**
S1	No decay to zero	Series is not stationary
S2	All zero or close to zero	Errors are essentially random or white noise. Done.
S3	ACF cuts off at some point q	MA (q) model
S4	PACF cuts off at point p	AR(p) model
S5	ACF alternating positive/ negative, decaying to zero	AR model. PACF identifies order.
S6	ACF decay, starting after a few lags	ARMA model
S7	ACF one or more spikes, rest are essentially zero	MA model, order around where AFC becomes zero
S8	ACF with non-zero spikes at the MA terms	MA model
S9	ACF spike at fixed intervals	AR model, seasonal
S10	ACF and PACF cuts off at same point q	ARMA (q, q)
S11	ACF and PACF cuts off at different point	AR or MA model rather than an ARMA model
S12	ACF and PACF show same spikes, else zero	AR or MA model, seasonal
S13	ACF and PACF decay gradually to zero	ARMA(p,q)
MODELLING PRINCIPLES		
P1	Principle of parsimony as to the number of AR and MA terms. Thumb rule: up to 3 terms in total.	
P2	Analyzing the simplest case first.	
P3	Prefer pure AR or MA model over ARMA models.	
P4	When ACF and PACF contain both AR and MA parts, fit first an AR or MA model of low order and reassess correlogram if more AR or MA terms should be added.	
P5	Guessing MA or AR terms is always and options. Box-Jenkins is trial and error.	
P6	A single significant spike just outside the confidence limits, not in the first few lags might be ignorable.	
P7	Higher ordered, unrestricted MA processes should be avoided. Exception single MA terms at higher lags.	
P8	Models with the lower order of differencing are generally preferred.	
RESULT INTERPRETATION		
R1	Parameter estimates should not be larger than 0.9. If unity the model might be over-differenced.	
R2	Sum of AR parameters should not be close to 1.	
R3	Inverted have to be roots inside the circle (modulus <1)	
R4	Inverted roots have moduli very close to one, which is typical for many macro time series models.	
R5	R^2 is much smaller for differenced models.	
EVIEWS SPECIFICS		
E1	Process Term vs. Single Lag Term: AR(1to3) is an unrestricted 'process term'. But, simply typing AR(3) is a 'lag term', which forces the estimate of AR(1) and AR(2) to zero. You may want this on rare occasions, for example, when dealing with seasonal components. This also applies to MA terms.	
E2	Add any MA, AR, SAR, SMA terms that you like. EViews will only use the ones that are listed explicitly.	

Compiled from: Levenbach (2015), IHSEviews (2014b), Cross Validated (2014), Schwert (2014), NIST (2012), Janko et al. (2012), Brooks (2008). List does not claim completeness and exclusiveness.

then enter another AR or MA term.[350] After several trials, adjustments and reiterations with different terms, an adequate representation for serial autocorrelation is found (Figure 7.18). The model includes two additional terms AR(1) and MA(12), both of them significant. Given the DW statistic, the rather flat ACF/PACF shape and the outcomes of all the remaining parameters, the model can be considered as the "best possible".[351] As such, the main goal of removing serial correlation is achieved and residuals are essentially 'white noise' or random.[352]

[350]While choosing this AR MA specification, one might also refer to the "memory-logic" explained above as per which an AR process takes hold "forever", whereas an MA process only for a few lag. As to modelling, the effects on performance changes, the former notion would implicate that this year's change might somehow linked to last year's change and so on via the error terms. Thus, when indicated, allowing "some" memory might be a reasonable option in this research context. In contrast, occurrences of the latter type as the spike at lag 12 might be considered one-time shocks without memory, as the correlation would only last one time period.
[351]In reality, one may not get *the* perfect model but it can be approximated as best as possible, e.g. by varying the ARMA(p,q) configuration while assessing the corresponding effects on statistics such as R^2 (higher values are desirable), AIC or SBC (lower values are desirable). For each iteration, changes in these statistics are tracked. When their values appear exhausted/optimal and other diagnostic seem "ok", the "best" or "final" model is reached.
[352]The remaining spike at the second lag can be ignored since it lies *inside* the confidence band.

Dependent Variable: X10_FD
Method: Least Squares
Date: 06/12/16 Time: 22:34
Sample (adjusted): 1956 2013
Included observations: 58 after adjustments
Convergence achieved after 16 iterations
MA Backcast: 1944 1955

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.000217	0.007467	-0.029068	0.9769
LRESOURCES_DT(-5)	-0.014029	0.007690	-1.824210	0.0742
MSERVICE_DT(-5)	0.004591	0.005337	0.860077	0.3939
NMANAGEMENT_DT(-5)	0.006648	0.005765	1.153198	0.2544
QCON	0.002186	0.002469	0.885233	0.3804
QGDP_FDDT	0.311522	0.200756	1.551742	0.1272
QPOP_FDFD	1.165552	0.267972	4.349522	0.0001
AR(1)	0.353524	0.144172	2.452104	0.0178
MA(12)	-0.893315	0.027649	-32.30967	0.0000

R-squared	0.640426	Mean dependent var	0.000306
Adjusted R-squared	0.581720	S.D. dependent var	0.042261
S.E. of regression	0.027332	Akaike info criterion	-4.219798
Sum squared resid	0.036605	Schwarz criterion	-3.900074
Log likelihood	131.3741	Hannan-Quinn criter.	-4.095259
F-statistic	10.90904	Durbin-Watson stat	1.816792
Prob(F-statistic)	0.000000		

Inverted AR Roots	.35			
Inverted MA Roots	.99	.86+.50i	.86-.50i	.50+.86i
	.50-.86i	-.00-.99i	-.00+.99i	-.50-.86i
	-.50+.86i	-.86+.50i	-.86-.50i	-.99

Date: 06/12/16 Time: 22:35
Sample: 1950 2013
Included observations: 58
Q-statistic probabilities adjusted for 2 ARMA terms

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.058	0.058	0.2035	
		2	-0.240	-0.244	3.7724	
		3	-0.037	-0.006	3.8586	0.049
		4	0.090	0.037	4.3778	0.112
		5	-0.037	-0.060	4.4691	0.215
		6	-0.091	-0.059	5.0294	0.284
		7	-0.017	-0.028	5.0489	0.410
		8	-0.154	-0.206	6.6953	0.350
		9	-0.156	-0.160	8.4276	0.296
		10	-0.035	-0.116	8.5188	0.384
		11	0.054	-0.049	8.7322	0.462
		12	-0.121	-0.195	9.8470	0.454
		13	-0.022	-0.045	9.8852	0.541
		14	-0.009	-0.168	9.8911	0.626
		15	0.098	0.001	10.674	0.638
		16	0.111	0.002	11.691	0.631
		17	0.030	-0.049	11.765	0.697
		18	-0.002	-0.065	11.766	0.760
		19	-0.000	-0.062	11.766	0.814
		20	0.001	-0.121	11.766	0.859
		21	0.038	-0.034	11.902	0.890
		22	-0.091	-0.213	12.706	0.890
		23	-0.095	-0.155	13.608	0.886
		24	-0.006	-0.152	13.612	0.915

Figure 7.18: Summary final model (left) and correlogram with white noise/uncorrelated errors (right).

Inverse Roots of AR/MA Polynomial(s)
Specification: X10_FD C LRESOURCES_DT(-5) MSERVICE_DT(-5) NMANAGEMENT_DT(-5) QCON QGDP_FDDT QPOP_FDFD AR(1) MA(12)
Date: 06/14/16 Time: 13:49
Sample: 1950 2013
Included observations: 58

AR Root(s)	Modulus	Cycle
0.353524	0.353524	

No root lies outside the unit circle.
ARMA model is stationary.

MA Root(s)	Modulus	Cycle
-0.857922 ± 0.495321i	0.990643	2.400000
-0.495321 ± 0.857922i	0.990643	3.000000
0.857922 ± 0.495321i	0.990643	12.00000
-0.990643	0.990643	
0.990643	0.990643	
1.67e-16 ± 0.990643i	0.990643	4.000000
0.495321 ± 0.857922i	0.990643	6.000000

No root lies outside the unit circle.
ARMA model is invertible.

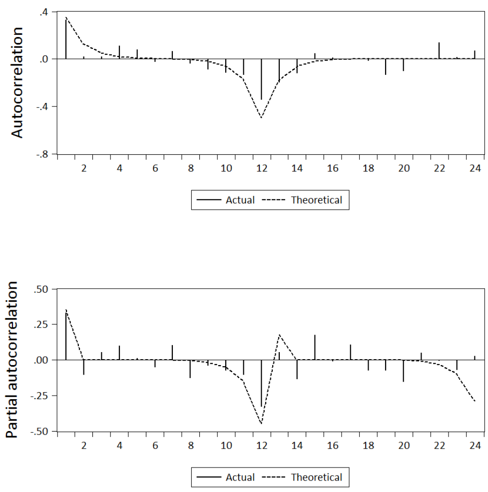
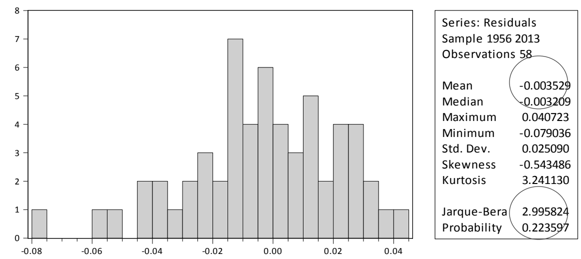


Figure 7.19: ARMA equation diagnostics (left) and vertical correlogram (right).

Figure 7.19 further confirms the model´s validity through further diagnostics: (a) All roots lie *inside* the unit circle as their *modulus* is smaller than unity; (b) the model is properly specified as the residual (actual) and estimated (theoretical) ACF and PACF are close.

4 CHECKING FOR NORMALITY: To make inferences about whether the error terms are normally distributed, the Jarque-Bera (JB) test statistic is applied. JB essentially tests whether the skewness and kurtosis of a series are different from those of a normal distribution. The null hypothesis of the JB test is ‘skewness kurtosis are that of a normal distribution’. For the example assessed, the left-hand side chart of Figure 7.20 reports a large probability[353] of 0.22 and a kurtosis around the value of three. This implies that the null hypothesis cannot be rejected and that the data is consistent with a normal distribution around the mean.

[353]The probability that a Jarque-Bera statistic exceeds the observed value under the null. A small probability value leads to the rejection of the null hypothesis of a normal distribution. See IHSEviews (2014b).



Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	0.449918	Prob. F(6,51)	0.8417
Obs*R-squared	2.915698	Prob. Chi-Square(6)	0.8194
Scaled explained SS	2.629738	Prob. Chi-Square(6)	0.8537

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 06/12/16 Time: 23:04
Sample: 1956 2013
Included observations: 58

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000457	0.000286	1.596197	0.1166
LRESOURCES_DT(-5)	0.000177	0.000197	0.898518	0.3731
MSERVICE_DT(-5)	0.000138	0.000174	0.793605	0.4311
NMANAGEMENT_DT(-5)	-8.84E-05	0.000169	-0.524481	0.6022
QCON	6.58E-05	9.47E-05	0.694854	0.4903
QGDP_FDDT	-0.001874	0.005289	-0.354376	0.7245
QPOP_FDFD	-0.005348	0.010118	-0.528574	0.5994

R-squared	0.050271	Mean dependent var	0.000631
Adjusted R-squared	-0.061462	S.D. dependent var	0.001012
S.E. of regression	0.001043	Akaike info criterion	-10.78119
Sum squared resid	5.55E-05	Schwarz criterion	-10.53252
Log likelihood	319.6546	Hannan-Quinn criter.	-10.68433
F-statistic	0.449918	Durbin-Watson stat	1.548606
Prob(F-statistic)	0.841664		

Figure 7.20: Normality test and Heteroscedasticity test.

5 CHECKING FOR HOMOSCEDASTICITY: Testing for homoscedasticity can be done with the Breusch-Pagan-Godfrey (BPG) test. BPG essentially regresses the squared residual on the original regressors to tests whether error variance is equal over time or whether error variances are a multiplicative function of one or more variables. The null hypothesis for the test is 'errors are homoscedastic.' Considering the p-value for the F-statistic on the right-hand side of Figure 7.20 the null cannot be rejected. The data is consistent with constant error variance.

Table 7.16: Final model equation. Significant variables marked bold.

$$X10\_FD = -0.0002 - \mathbf{0.0140} * \boldsymbol{LRESOURCES\_DT(-5)} + 0.0046 * MSERVICE\_DT(-5) + 0.0066 * NMANAGEMENT\_DT(-5) + 0.0022 * QCON + 0.3115 * QGDP\_FDDT + \mathbf{1.1656} * \boldsymbol{QPOP\_FDFD} + [\boldsymbol{AR}(\mathbf{1}) = \mathbf{0.3535}, \boldsymbol{MA}(\mathbf{12}) = \mathbf{-0.8933}] \quad (47)$$

6 MODEL EVALUATION AND RESULTS: The final model representation with coefficients substituted by its numerical estimates is given in Equation 19. The logic of ARMA modelling becomes obvious: For forecasting purposes, the value of ARMA coefficients would simply be added to determine the estimated score of explained variable X10_FD. In terms of explanatory power, Figure 7.18 displays a R^2 of 0.64. In other words, about 64% of the variance of the dependent variable can be explained with the independent variables. Considering that some of the data is differenced this appears a fairly good score. The estimated parameters β with p-values ≤ 0.1 reveal the following about the relation between decisions and effectiveness during 1950-2013 in Porto: A 1% change in the activity levels of *resources decisions* at $t = 0$ affects the *performance* growth rate at $t = 5$ negatively by -0.014%, *ceteris paribus*. The effect has a lag of 5 years. In contrast, a 1% change of annual change of the *population growth rate* at $t = 5$ affects *performance growth* positively by 1.17%, *ceteris paribus.* The effect has no lag. With relaxed significance levels, one might read that a 1% change in *economic growth (GDP)* could affect *performance growth* positively by 0.31%. Other variables are not found to be significant.

7.5 Results: The Decision-Performance Link

Eventually, the link between managerial decisions and operator performance can be established and compared. The underlying regression model is the *static* one of equation X; the time-span is 1950-2013. Relying on visualizations of coefficients/elasticities/effects, sub-section R1 *first* concerns the identification and description of *effect patterns* derived from three weight scenarios for two performance types[354] and three operators. Sub-section R2 to R4 aim at presenting the outputs in aggregated *numbers*, such as the *effect size magnitude* and *time-lags* per *decision variable* or *effect sizes* of *external variables* and general *model evaluation criteria*.[355] The last part of this chapter then *summarizes* all results accordingly and gives *interpretations*.

R1: Effects Patterns of Managerial Decisions

R1.1 to R1.4 presents the elasticities for models with SUM as single explanatory decision variable and models with RESOURCES, SERVICE, and MANAGEMENT as multiple explanatory decision variables. R1.5 introduces a result-based measure of pattern *reliability*.[356,357]

R1.1 - SUM(ED) DECISIONS AND PERFORMANCE GROWTH: Figure 7.21 below shows elasticities for SUM as single explanatory decision variable. Table 7.17 summarizes the observations.

Table 7.17: Summary - effects from SUM(ed) decisions.

SUM	pattern	time-lag	effect direction		
			short term	middle term	long term
Hamburg	A/A	yes/yes	+/+	+/+	+/0
Porto	B/B	no/no	+/+	-/-	-/0
Dresden	C/B	no/no	+/+	-/-	0/0

effectiveness/efficiency

As to *effect patterns* of SUM as an explanatory variable, Figure 7.21 suggests the following findings: **[1]** Initially, three distinct effect patterns are observable across the three operators. *First,* in Hamburg, effects show cyclical but largely positive structures peaking in the short, and middle term. Long-term effects appear to be zero. *This effect pattern is labelled 'A'. Second*, in contrast, Porto´s effects drop after a 2 years. Only short-term effects are positive. Middle- and long- term effects are negative or zero. *This effect pattern is labelled 'B'. Third*, in Dresden effects on effectiveness drop even faster than in Porto. Already after the first year, negative effects (or zero) are observable. *This effect pattern is labelled 'C'.* **[2]** Except for Dresden, the patterns occur independently from the performance type. No major differences are observable in the way

354 Mixed performance models are left out, since the results correspond either to those of effectiveness or efficiency.
355 A synopsis of R1 to R3 can be found in section 7.6.
356 In the following *figures*, all weight scenarios w0, w1, w2 and their averages are plotted simultaneously per year.
357 The embedded *tables* summarize the information given in the figures and contribute to Table 7.26 (Synopsis).

effectiveness or efficiency growth are affected over time. **[3]** Hamburg's decision effects are lagged by one year. Porto and Dresden's decisions take effect on performance growth instantly. **[4]** For both performance types and all operators, short-term effects are positive, reaching the maximum effect latest after 2 years.

EFFECTS on EFFECTIVENESS GROWTH	EFFECTS on EFFICIENCY GROWTH

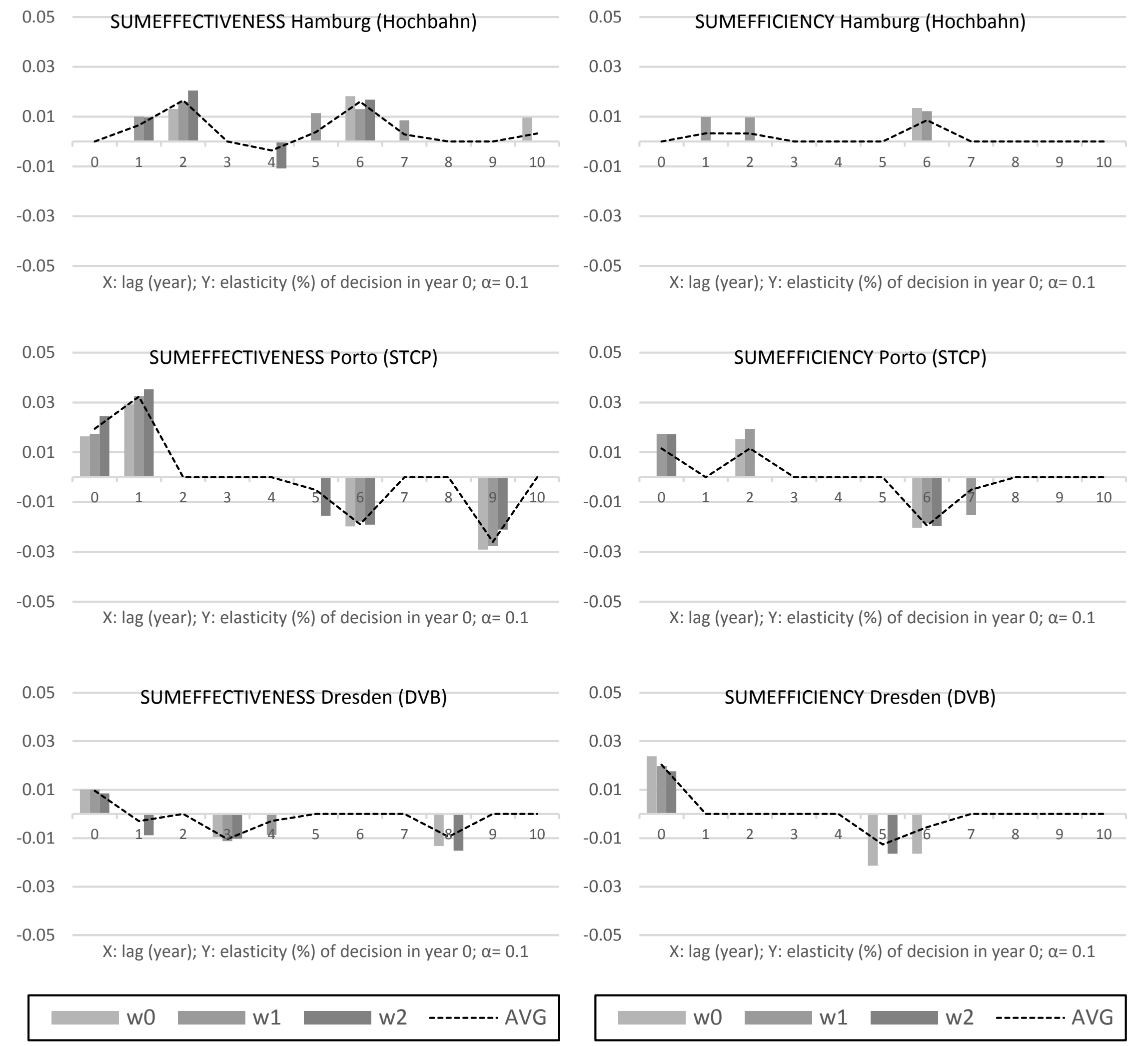


Figure 7.21: Effect from SUM managerial activity on performance in 10 years. Hamburg, Porto, Dresden. '50-2013.

R1.2 - RESOURCES DECISIONS AND PERFORMANCE: Figure 7.22 displays the elasticities for RESSOURCES as one of three explanatory decision variables. Table 7.18 summarizes the observations. As a first observation **[5]**, one could directly see that all blocks are less spiky and with lower effect sizes than the cumulative approach. As to *effect patterns,* **[6]** Hamburg continues to show pattern 'A' for effectiveness growth, however significantly downwards shifted and with negative values as low points. The effect appears to build up until year 6. Efficiency growth shows no effect pattern at all, just one positive spike at year nine. Porto keeps effect pattern 'B' for both performance types with comparatively strong positive effects in the short

Table 7.18: Summary - effects from RESOURCES decisions.

SUM	pattern	time-lag	effect direction		
			short term	middle term	long term
Hamburg	A/	no/yes	+/0	+/0	-/+
Porto	B/B	no/no	+/+	-/0	-/0
Dresden	/	yes/yes	+/-	0/0	-/0

effectiveness/efficiency

term but early occurring negative effects on effectiveness growth. There are no suggestions for negative effects on efficiency growth in the mid- or long-term. Dresden shows no effect patterns but indications for a small positive (negative) effect on effectiveness growth in the short term (long term) and a negative one on efficiency growth in the short-term. **[7]** One might confirm the presence of time-lags except for Porto. **[8]** Short-term effects on effectiveness are positive for all operators but decline rapidly in Porto and Dresden. Short-term effects on efficiency are only positive for Porto.

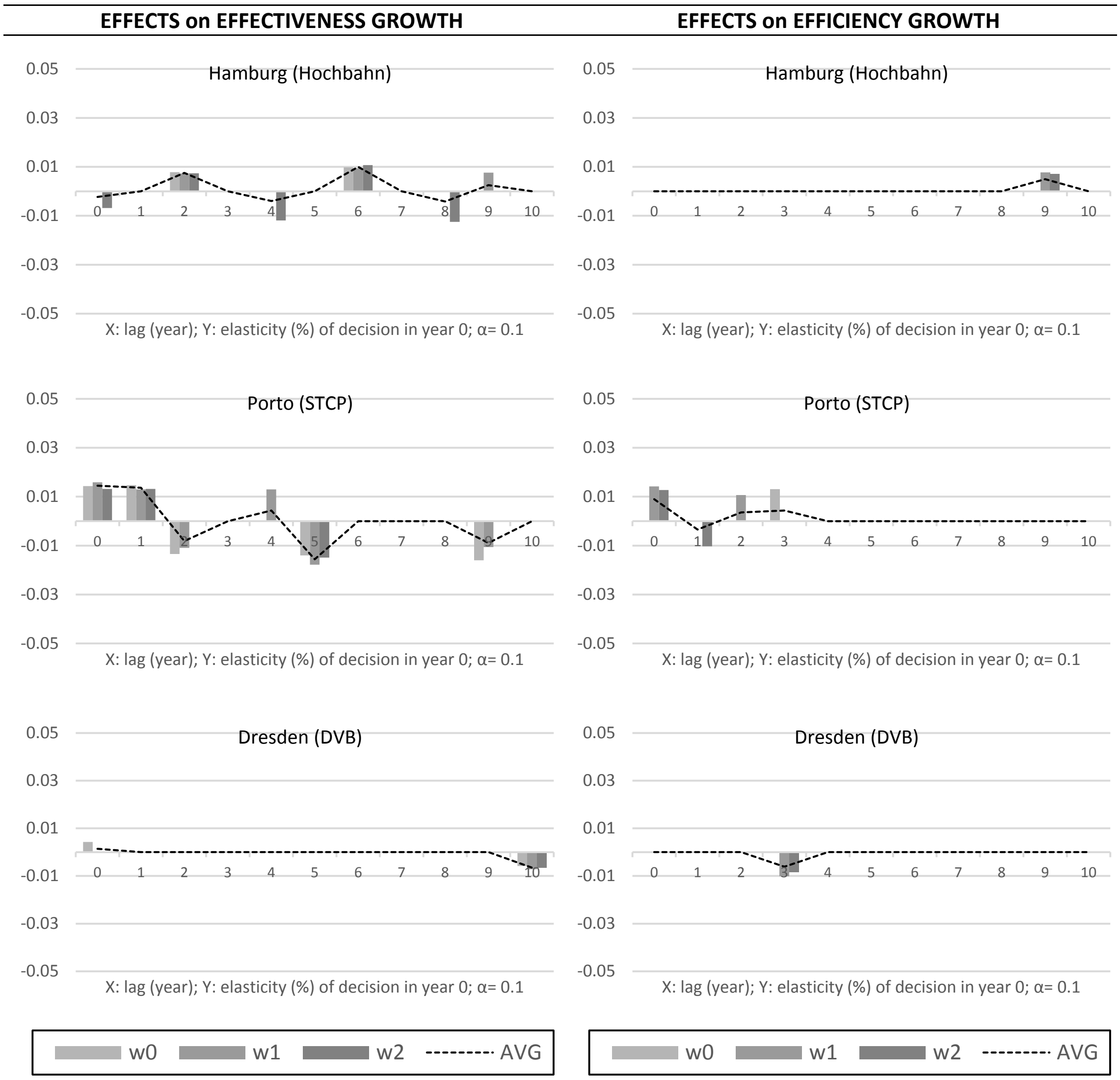


Figure 7.22: Effect from RESSOURCES decisions on performance in 10 years. Hamburg, Porto, Dresden. 1950-2013

R1.3 - SERVICE DECISIONS AND PERFORMANCE: Figure 7.23 presents the elasticities for SERVICE as one of three explanatory decision variables. Table 7.19 summarizes the observations.

Table 7.19: Summary - effects from SERVICE decisions.

SUM	pattern	time-lag	effect direction		
			short term	middle term	long term
Hamburg	A/A	yes/yes	+/+	0/0	+/+
Porto	B/B	yes/no	+/+	0/0	-/-
Dresden	C/C	no/no	+/+	0/0	+/0

effectiveness/efficiency

Again, observation [5] applies: The assessment of disaggregated super-categories results in less significant/spikey charts. **[9]** The *effect patterns* are still similar to the previous findings. Hamburg shows pattern 'A' but now without significant negative effects in the short and middle term and peaking around year 7/8. Porto shows a mitigated version of pattern 'B' with negative effects only occurring in the long term. Dresden exhibits a reduced version of pattern 'C' with-

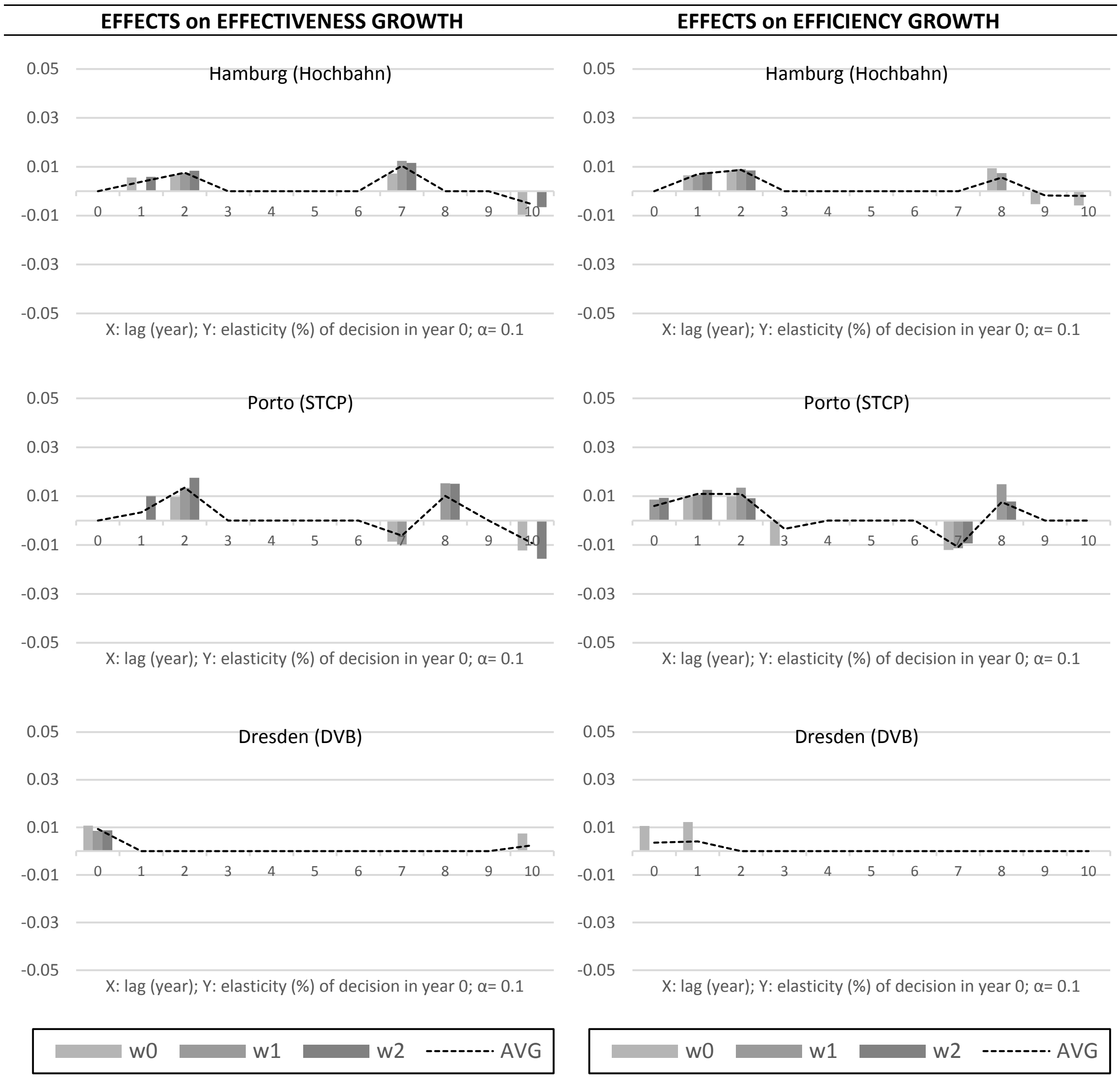


Figure 7.23: Effect from SERVICE decisions on performance in 10 years. Hamburg, Porto, Dresden. 1950-2013

out negative effects and indications of recovery in the long term. **[10]** The effect patterns for each operator apply for both performance types. **[11]** *Time-lags* are observable for both performance types in Hamburg but only Porto´s effects on effectiveness. **[12]** For all operators, short-term effects on both performance types are positive and build up in the first 2 years.

R1.4 - MANAGEMENT DECISIONS AND PERFORMANCE: Figure 7.24 presents the elasticities for MANAGEMENT as one of three explanatory decision variables. Table 7.20 below summarizes the observations. *First*, observation [5] is re-confirmed. **[13]** One could also immediately see that the effects from the super-category MANAGEMENT on performance growth tend to be minimalistic in Hamburg. **[14]** However, despite small effects, Hamburg continues to show a trimmed pattern 'A' peaking at year 5 for effectiveness and 8 for efficiency. Similar to SERVICE, Porto´s effect pattern 'B' is somewhat stretched. Negative effects appear only over the long term, for both performance type. As to effectiveness growth, Dresden shows a flipped version

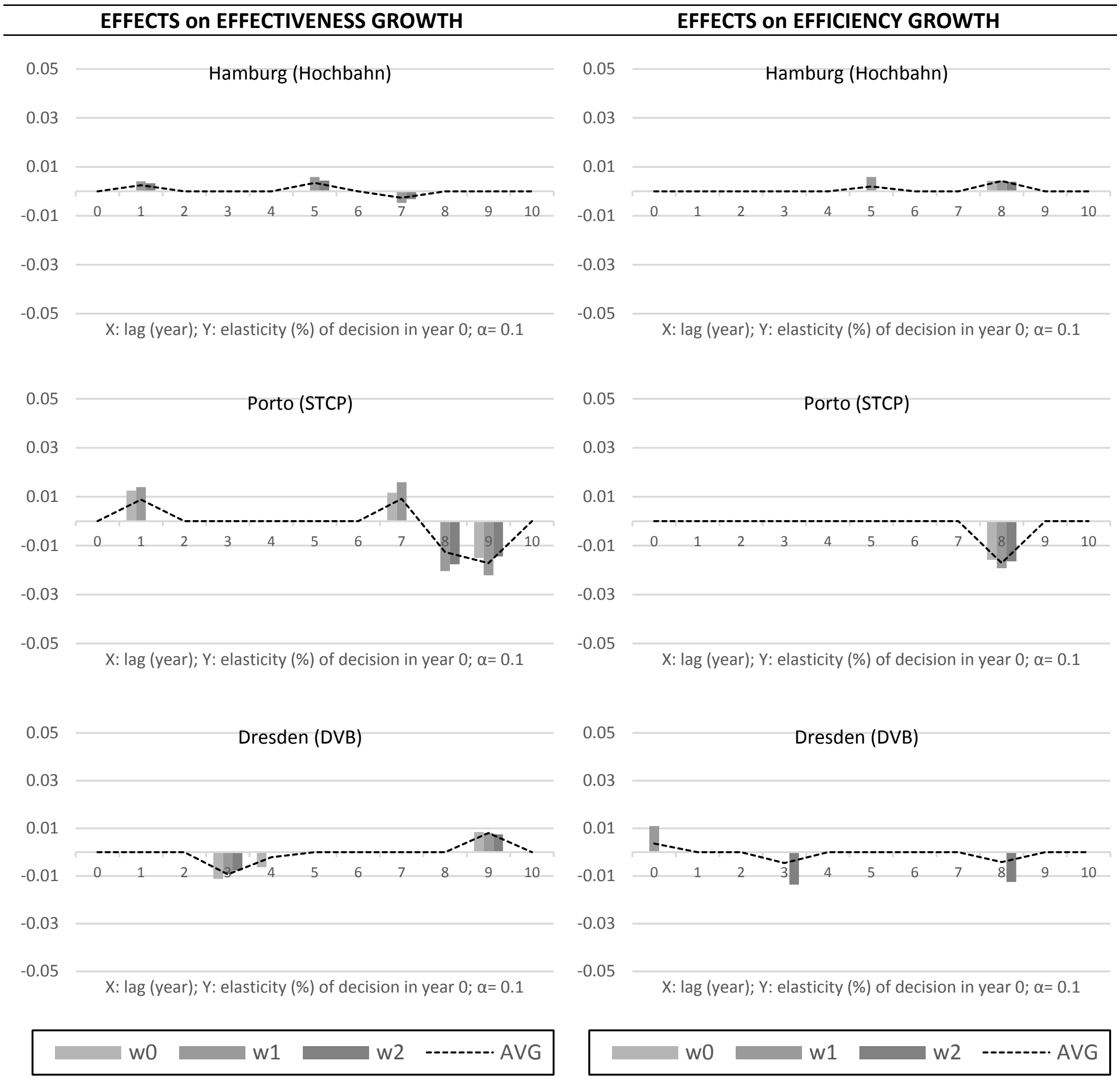


Figure 7.24: Effect from MANAGEMENT decisions on performance over 10 years Hamburg, Porto, Dresden. '50-2013

of effect pattern ‘B’ (i.e. ‘B*’) with initially negative but over the long-term recovering positive effects. In contrast, effect pattern ‘C’ seems to be fully applicable to model effects on to Dresden´s efficiency growth. **[15]** As to time-lags, except for Dresden´s effects efficiency growth, all other effects from MANAGEMENT are lagged.

Table 7.20: Summary - effects from MANAGEMENT decisions.

SUM	pattern	time-lag	effect direction		
			short term	middle term	long term
Hamburg	A/	yes/yes	+/0	+/+	0/+
Porto	B/	yes/yes	+/0	0/0	-/-
Dresden	B*/C	yes/no	-/+	-/-	+/-

effectiveness/efficiency

R1.5 - NUMBER OF SIGNIFICANT BETAS: From the observations above it becomes clear that with a higher number of significant coefficients or “spikes” per figure, suggestions about the persistence of a pattern can be accomplished more easily. More “spikes” lead to a higher reliability of conclusions about effect patterns. In other words, model blocks with a large number of significant coefficients appear to be more useful. Thus, the idea is to use the metric “*number of significant betas per block”* as an auxiliary measure to assess how different model configurations relate to pattern reliability[358]. According to the plots in the first row of Figure 7.25 below, five remarkable observations should be stressed: **[16]** The underlying *decision approaches* produce different quantities of significant coefficients. The SUM-approach yields a higher number than the CLUSTER-approach[359]. Further, in the SUM approach differences between operators seem to be less strong. **[17]** Within the CLUSTER approach, a reliability ranking would be as follows: SERVICE > RESOURCES > MANAGEMENT. In other words, though patterns from MANAGEMENT decisions might be consistent across operators they occur rather weakly and conclusion about them might thus be drawn with caution. **[18]** Modelling the effects on *effectiveness growth* produces generally more significant coefficients than modelling *efficiency growth*, except for the SERVICE variable. **[19]** At operator level, the “reliability ranking” is Porto > Hamburg > Dresden. This suggest that Porto’s models produce comparatively more significant coefficients than Dresden and Hamburg. Therefore, resulting patterns are supposed to be more reliable. **[20]** The introduction of weight scenarios as a data enhancement measure appears beneficial for the modelling process: The number of significant coefficients increases with the weight scenarios, thus creating a broader and more reliable information base for pattern identification.

[358]Note that here “pattern reliability” is not to be interpreted as a statistical reliability.

[359]Compared on variable level: SUM (53) > RESOURCES (37), SUM > SERVICE (50), SUM > MANAGEMENT (32).

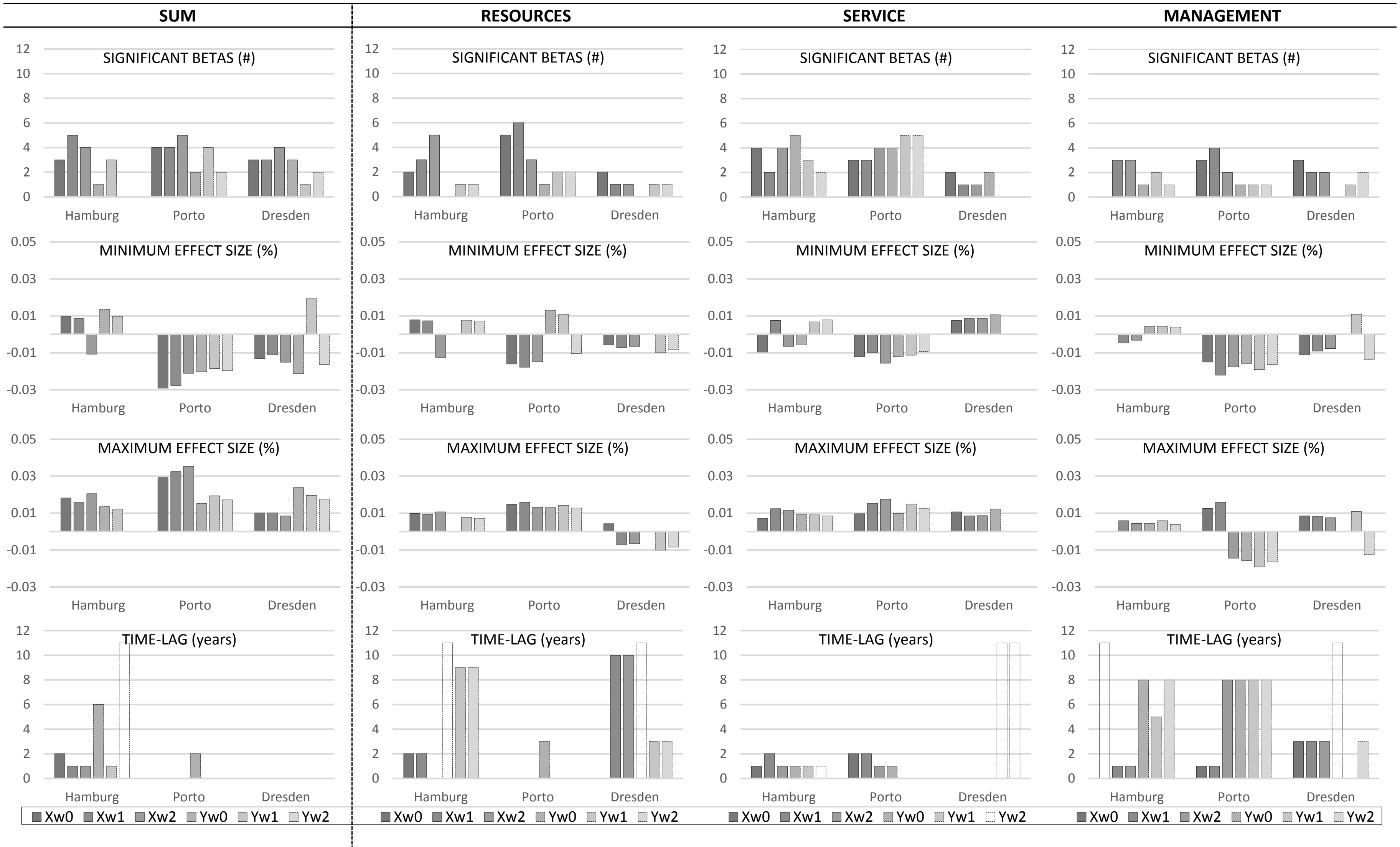


Figure 7.25: Significant betas, effect size range, and time-lags per regression block. Notation in Legend: X=Effectiveness; Y=Efficiency. w0,w1,w2=weight scenarios.

R2: Effect Sizes and Time-Lags of Managerial Decisions

The previous section was concerned with the detection of *patterns* to describe the relation between managerial decision-making and performance over time visually. Though one might find sufficient information about effect sizes and time-lags in each single figure of R1.1 to R1.4, results need to be further streamlined to produce substantial outcomes in numerical form. This is achieved by calculating and visualizing the metrics of Table 7.21 for each model block. In a *first step,* the plotted metrics then help to assess and describe how results between the different model configurations vary overall (Figure 7.25). Leading to one of the key outputs of this research, in a *second step* the metrics are used to quantify the *effect size magnitude* and *time-lag intervals* for each decision variable, performance type and operator (Tables 7.22, 7.23).

Table 7.21: Further streamlining results per block through proxies.

Metric	Definition	Dimension	**Metric Aggregate**
effect size range *per weight scenario*	minimum to maximum effect size per block	*"the higher/lower the better"*	magnitude of effect size *per variable*
time lags *per weight scenario*	year in which $\beta > 0$ for the first time per block	*"the lower the better"*	time-lag interval *per variable*

R2.1 - EFFECT SIZES: The *effect size range* refers to the minimum and maximum values of coefficients per block as displayed in R1 to R4, and in condensed form in the second/third row of Figure 7.25. One might expect that maxima are positive and minima are - depending on the underlying pattern - positive *or* negative in sign. Especially large effects in either direction seem to be meaningful results. Once trios of neighbouring bars in Figure 7.25[360] show at least similar signs, the results appear to be consistent across the weight scenarios per performance type, i.e. the lows and highs of different weight scenarios would be roughly similar. **[21]** From the first impression, the effect sizes seem to be consistent, without major outliers. **[22]** The magnitude of effects per block is significantly higher and more consistent across weight scenarios in the SUM approach than in the CLUSTER approach. It can be said that the latter seems to be more likely to create differing results at weight scenario level. Its most consistent variable appears to be SERVICE. **[23]** Despite causing minor inconsistencies, weight scenarios seem to contribute to effect size changes, which again justifies their application. **[24]** The effect size range appears to be wider for effectiveness than efficiency and different for each operator. **[25]** A resemblance of ranges between the SUM- and CLUSTER-approach in terms of the sign of maxima and minima seems to be roughly given (i.e. negatives lows in one correspond to negatives lows in the other). By averaging the metrics across weight scenarios, Table 7.22 displays the '*effect size magnitudes*

[360]Figure 7.25 displays the metrics for each operator and two performance types per decision approach as follows: Three consecutive bars on the x-axis correspond to three weight scenarios tested first for effectiveness, followed by three bar with weight scenarios for efficiency. This logic applies for all decision approaches, operators, and variables.

Table 7.22: Effect size magnitude of decision variables.

Variable	Operator	Effect on **Effectiveness Growth (Es)** *magnitude max (min) (%)*	Effect on **Efficiency Growth (Ey)** *magnitude max (min) (%)*	Es>Ey max	Es<Ey min
SUM *(aggregated managerial activity)*	Hamburg	0.019 (0.003)	0.013 (0.012)	yes	yes
	Porto	**0.033 (-0.026)**	0.018 **(-0.020)**	yes	yes
	Dresden	0.010 (-0.014)	**0.021** (-0.007)	no	yes
RESOURCES *decisions*	Hamburg	0.010 (0.001)	0.008 (0.008)	yes	yes
	Porto	**0.015 (-0.017)**	**0.014** (0.005)	yes	yes
	Dresden	-0.004 (-0.007)	-0.010 **(-0.010)**	yes	no
SERVICE *decisions*	Hamburg	0.011 (-0.003)	0.009 (0.003)	yes	yes
	Porto	**0.015 (-0.013)**	**0.013 (-0.011)**	yes	yes
	Dresden	0.010 (0.009)	**0.013** (0.011)	no	no
MANAGEMENT *decisions*	Hamburg	0.006 (-0.004)	**0.005** (0.005)	yes	yes
	Porto	0.005 (**-0.019**)	-0.018 **(-0.018)**	yes	yes
	Dresden	**0.009** (-0.010)	-0.001 (-0.002)	yes	yes
The highest (lowest) value per variable and performance type is marked **bold**. X>Y: effect on effectiveness > effect on efficiency				10:2	10:2

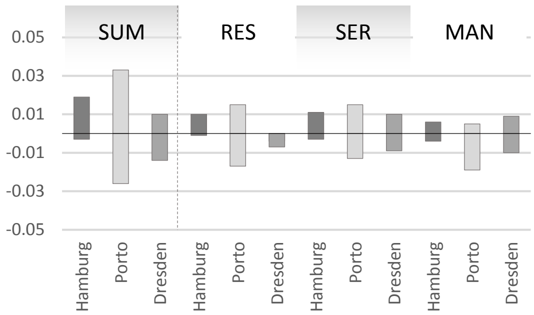


Figure 7.26: Effect size on effectiveness growth (max-min).

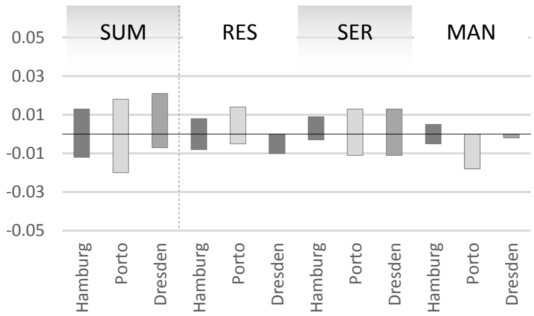


Figure 7.27: Effect size on efficiency growth (max-min).

of variables'.[361] Depending on the underlying pattern, positive values might correspond to *short-term effects*; negative ones may correspond to *medium* or *long-term effects*. In Figure 7.26/27, maxima and minima of Table 7.22 are plotted. As to the bar charts, three cases are observable:

- When both bars are *balanced,* positive and negative effects on performance growth might cancel each other out over time.
- When the absolute of the maxima is smaller than the absolute of the minima, a variable tends to affect performance growth rather negatively (*negative balance*).
- When the absolute of the minima is smaller than the absolute of the maxima, a variable tends to affect performance growth rather positively (*positive balance*).

The following findings can be made with regard to effect sizes compared across **A**[362] decision approaches, **B** decision variables, **C** performances types, and **D** operators:

A The SUM approach leads to effects twice as high as effects from individual variables (up to 0.033% or -0.026%), which is plausible since effects add up. **[26]**

B Effects on effectiveness growth are consistently higher than effect on efficiency growth in either direction (see 10:2 in Table 7.22). The difference of effects on either performance indicator can account for up to 25%. **[27]**

[361]Similar to the dashed lines in R1.1 to R1.4, the values Table 7.22 are based on arithmetical averages of effect size ranges per block w0, w1, w2 as displayed in Figure 7.25. However, results are presented in a *range* since further averaging e.g. across significant coefficients over time would lead to effects close to zero, which is not meaningful.
[362][A] is of methodological nature to assess whether decision *aggregation* yields different results than *disaggregation*.

C Regardless of the performance type and operator, the global *positive* effect size ranking of decision variables is SERVICE (up to 0.015%) > RESOURCES (up to 0.015%) > MANAGEMENT (up to 0.009%). The maximum *negative* effects are as follows: SERVICE (up to -0.013%) > RESOURCES (up to -0.017%) > MANAGEMENT (up to -0.019%). This balance/imbalance suggests that overall effects from SERVICE decisions are likely to be positive, rather negative from RESSOURCES decisions and most likely negative from MANAGEMENT decisions, which exhibits the strongest global negative effect in the CLUSTER approach.[363] **[28]**

D In the SUM-approach, *Porto* shows the highest effect size on effectiveness growth (up to 0.033%) and *Dresden* the highest one on efficiency growth (up to 0.021%). In the CLUSTER-approach the global effect size ranking is *Porto > Hamburg > Dresden* for effects on effectiveness growth and *Hamburg > Porto > Dresden*[364] for effects on efficiency growth. Speaking in absolute terms it can be said that overall, Porto appears to exhibit the largest effect sizes regardless of the variable, decision approach, or directions **[29]**. In *Hamburg*, highest positive effects come from SERVICE decisions (up to 0.011%), highest negative effects from RESOURCES (up to -0.008%). In *Porto*, highest positive effects come from SERVICE and RESOURCES decisions (both up to 0.015%), highest negative effects from MANAGEMENT decisions (up to -0.019%). Finally, in *Dresden* highest positive effects come from SERVICE decisions (up to 0.013%), highest negative effects from RESOURCES decisions (up to -0.01%) **[30]**. Interestingly, none of *Hamburg's* maxima is negative. In contrast, in particular MANAGEMENT decisions affect efficiency growth negatively in *Porto* and *Dresden*, which is indicated by maxima below zero. This also applies for RESOURCES decisions in *Dresden*, for both performance types. *Hamburg's* decision effects on performance tend to be much more promoting than *Porto´s* and *Dresden´s.* The former exhibits a continuously positive balance between maximal and minima effects (8/8 cases) as opposed to *Porto* (5/8 cases) and Dresden (*3/8 cases*) **[31].**

R2.2 - TIME-LAGS: A time-lag is simply the count of years before a variable displays an initial positive coefficient. For instance, if the first positive spike is at $t = 3$ the time-lag is 3 years (i.e. periods from 0-1, 1-2 and 2-3). As previously, explained the detection of time-lags gives valuable information about how long the management might have to "wait and see" until decisions take effect. The following observation are made from Figure 7.25, last row:[365] **[32]** Time-lags are significantly different in the SUM-approach and the CLUSTER-approach, which appears to be correct. Aggregated decisions activity is more likely to be unlagged. In contrast, individual decision categories might be lagged or not, by nature. Since the latter variables build the former, already one unlagged variable would render the SUM-approach unlagged. Thus, fewer lags can be observed in the SUM-approach. **[33]** In the CLUSTER-approach time-lags are consistent for weight scenarios but vary per variable, performance type (but not too much per operator). Table 7.23 summarizes the *average time-lag* intervals of variables.

[363]One might also simply count the case in which abs(max)-abs(min)>=0. Over both performance types, this yields the same ranking: SERVICE decisions 6/6 cases, RESOURCES 4/6 cases, MANAGEMENT 3/6 cases.
[364]The ranking is caused only through the negative maxima of Porto and Dresden in MANAGEMENT and RESOURCE.
[365]Note that in Figure 7.25 the case of time-lag = 0 corresponds to an empty spot and time-lag =11 to a blank bar.

Table 7.23: Time-lags of decision variables.

Variable	Operator	Effect on **Effectiveness Growth** *time-lag interval (years) and type*		Effect on **Efficiency Growth** *time-lag interval (years) and type*	
SUM *(aggregated managerial activity)*	Hamburg	1-2	short	1-11	*undefined*
	Porto	0	no	0-2	short
	Dresden	0	no	0	no
RESOURCES *decisions*	Hamburg	0-2	short	9-11	long
	Porto	0	no	0-3	short
	Dresden	0-10	*undefined*	3-11	medium
SERVICE *decisions*	Hamburg	1-2	short	1	short
	Porto	1-2	short	0-1	short
	Dresden	0	no	0-11	*undefined*
MANAGEMENT *decisions*	Hamburg	1-11	*undefined*	5-8	medium to long
	Porto	1-8	*undefined*	8	long
	Dresden	3	short	0-11	*undefined*

The highest (lowest) values per variable and performance type is marked **bold**.

Four lag types are found: *'no'* (effect works instantly), '*short'* (effect works within the first three years), *'medium'* (effect works within 4 to 6 years) and *'long'* lag (effect works only after 7 years). Note that the label '*undefined'* is used when the range is too large. Results might be ignored accordingly. The following findings can be drawn from a comparison of time-lag intervals across **A** decision approaches, **B** performances types, **C** decision variables, and **D** operators:

A The time-lags in the SUM-approach largely correspond to the shortest of the CLUSTER-approach, with a maximum of 2 years **[34]**.

B Effectiveness growth is most likely affected instantly or in the short term, latest within three years after a decision was taken **[35]**. Lags of effects on efficiency growth cannot be clearly defined. They show a tendency of being short-termed either. However, they might also be lagged several years **[36]**.

C Effects from RESSOURCES-decision appear lagged up to three years but might also need longer to take effect. Effects from SERVICE-decisions are consistently unlagged or only lagged for up to two periods. MANAGEMENT decisions cannot be standardized as their ranges heavily spread. However, there are indications that they might take effect rather in medium or long term **[37]**.

D There are no major differences in time-lags between the operators**.** For instance, for effects on effectiveness growth from SUM, SERVICES or RESOURCE decisions the maximum difference is *unlagged* or *lagged by two years*. **[38]** Few differences can be found in the CLUSTER-approach with MANAGEMENT decisions (on effectiveness) and RESOURCES decisions (on efficiency). In the former cases, a lag of three years is suggested for Dresden, whereas Porto and Hamburg cannot be defined. In the latter case, Hamburg exhibits no lags, contrary to Porto and Dresden, which shows a medium to long-term lag **[39].**

R3: The Role of External Variables

In the regression, performance growth was assumed to be affected by managerial decision-making *and* external factors. The latter ones are captured by a contextual variable (CON), gross-domestic product growth (GDP) and the change of population growth rate (POP).[366]

[366]CON=log; GDP: first-differenced log; POP: Second-differenced log (see section 7.4 for interpretation)

Table 7.24: Effect sizes external variables.

Approach	Operator	Effect on Effectiveness Growth *(%)*			Effect on Efficiency Growth *(%)*			multiples of max decision effect size			multiples of max decisions effect size		
		CON	GDP	POP	CON	GDP	POP	CON	GDP	POP	CON	GDP	POP
SUM	Hamburg	**-0.003**	**0.15**		**-0.003**		**-0.26**	0.16	8	0	0.23	0	20
	Porto		0.37	0.94				0.00	11	28	0.00	0	0
	Dresden	-0.003	0.36	**-0.33**				0.30	36	33	0.00	0	0
CLUSTER	Hamburg	-0.003	0.18		-0.003	**-0.12**	-0.20	0.27	17	0	0.33	14	23
	Porto	*0.006*	**0.43**	**1.06**	**-0.004**		**0.47**	0.40	29	70	0.29	0	34
	Dresden	**-0.004**	0.35	-0.35		**0.31**		0.40	35	35	0.00	24	0

The highest (lowest) values per variable and performance type is marked **bold**.

Table 7.24 displays the average effect sizes of external variables per model. This leads to the following findings from their comparison across/with **A** decision approaches, **B** performances types, **C** external variables, **D** operators and, **E** effect sizes from decision variables:

A Effect sizes appear largely similar between the two approaches, i.e. the results are not working in opposite direction. However, the efficiency model seems to indicate no effect from GDP for all operators in the SUM approach, which might be a modelling issue or in accordance with results from Brons et al. (2005) **[40]**.

B Except for contextual variables, effects from externals variable on effectiveness and efficiency growth *differ* in magnitude (and partially in direction), regardless of approach and operator **[41]**.

C An effect size ranking for externals might be as follows (in absolute figures): *POP>GDP>>CON*. Effects from CON are almost consistently negative. This makes sense, since CON captures exclusively negative events stated in the annual reports. Thus, it can be assumed that an increase of these events has a negative effect on operator performance, however, a comparatively low one (lower than 0.01%). Effects from GDP on effectiveness growth appear to be consistently positive (up to 0.43%) but might be positive, zero or negative with regard to efficiency. One could therefore only conclude that GDP might have a positive effect on effectiveness. Effects from POP vary strongly between operators and can be positive (up to 1.05%) or negative (up to -0.35%). Growing population rate might enhance *or* reduce performance growth, depending on the operator **[42]**.

D External effects vary between operators, particularly GDP and POP. In absolute terms, Porto again accounts for the highest effect sizes. *Hamburg's* positive effects on effectiveness come from GDP (up to 0.18%). POP has no effect. Efficiency growth is negatively affected by GDP (up to -0.12%) and POP (-0.26%). *Porto´s* effectiveness growth is positively affected from GDP (up to 0.43%) and significantly strong from POP (up to 1.05%), the latter of which affects efficiency growth positively (up to 0.47%). In *Dresden*, GDP and POP seem to be antagonists with regard to their effects on effectiveness (35% and -0.35%). Efficiency growth, however, is only affected by GDP (up to 31%). Performance in Porto and Dresden seems affected stronger by GDP than in Hamburg. For all operators, CON is small and negative (except for Porto´s effectiveness)**[43]**.[367]

[367] *Why CON might be exceptionally positive for Porto*? A repeatedly stated problem in STCP reports is the increasing inner-city traffic jam (which is absent in such severity in Hamburg/Dresden). The congestion may, however, have two outcomes: reduced (operational) speed for the operator/people *and* a change of behaviour: People start switching to public transport, as the overall costs of individual car use rises comparatively stronger than that of public transport use. With fixed fares, waiting time in a bus is less "expensive" than in a car with a running engine and probably rising energy costs. Consequently, a negative external effect - as cited in the report - might still increase operator ridership.

E Obviously, the effect sizes of external and decision variables differ significantly in magnitude (in the order of $\% * 10^{-2}$ vs $\% * 10^{-3}$). To quantify the differences, the right-hand side of Table 7.24 displays the '*multiples of the maximal decision effect size'*. The metrics essentially tell by which factor the external variables contribute more to operator performance growth than managerial decisions. For instance, CON effects have approximately 1/3 of the strength of managerial decisions. Depending on the operator, however, effects from GDP and POP can be up to 70 times stronger than managerial decisions. Once the direction of effects is positive, external effects might massively boost operator performance. However, when negative, external effects bear the risk to outweigh any effects from management decision, once these are not adjusted accordingly[368] or external effects are not cancelled out otherwise **[44]**.[369]

The previous findings are summarized to key conclusion in section 7.6.

R4: Model Evaluation

The missing piece in modelling process is to measure how "good" the models are when one compares them across **A** decision approaches, **B** performances types, and **C** operators. This is done the average explanatory power (R^2) over all regressions, blocks and all weight scenario models displayed in Table 7.25. R^2 is commonly understood as the explained percentage of the variance of the dependent variable, which is performance growth. Note that each R^2 per model, also corresponds to the lowest AIC or SBC, and thus to the supposedly "best" model feasible.

Table 7.25: Average explanatory power over all models.

Approach	**Operator**	Modelling **Effectiveness Growth** R^2 *(%)*	Modelling **Efficiency Growth** R^2 *(%)*
SUM	Hamburg	0.38	0.09
	Porto	0.56	0.05
	Dresden	0.39	0.08
CLUSTER	Hamburg	0.40	0.18
	Porto	0.64	0.11
	Dresden	0.40	0.11

One should recall that first-differenced data is regressed on partially second-differenced data. This procedure comes with a loss of information from the data. Subsequently, explanatory power drops but might still be acceptable at lower levels[370] considering the modelling and data transformation background (see Table 7.15). Table 7.25 gives the following suggestion:

A CLUSTER approaches leads to slightly better models than the SUM approach, regardless of the performance type or operator **[45]**.

B Modelling effectiveness growth yields significantly better models than modelling efficiency growth, regardless of the approach **[46]**.

[368]*Hamburg*: negative GDP *and* POP for efficiency. This might be a reason why the operator is effectiveness-oriented.
[369]*Dresden*: compensation of negative POP effects through positive effects from GDP.
[370]In a line with García Sánchez (2009), in this research also *weak* signals are of interest. The author claims that even an R^2 of 10% contains information value in the presence of a lot of noise. For Coelli (2005) noise is a derivative of *"the risky environment in which production takes place"*, a feature which surely applies to *public transport management*.

C Effectiveness growth models for *Porto* show the highest explanatory power (up to 64%), followed by *Dresden* and *Hamburg* (up to 40%). The order changes for efficiency growth models: *Hamburg* (up to 18%), *Dresden* and *Porto* (up to 11%). Figure 7.28 below further demonstrates, that the best models are "located" at different years/lags: Hamburg (2,6), Porto (1,9), Dresden (0,3,8) for effectiveness; Hamburg (0,1,6,8), Porto (0,2,6,8), Dresden (0,3) which yield interesting findings when jointed with the pattern of R1.1 to R4.1 **[47]**.

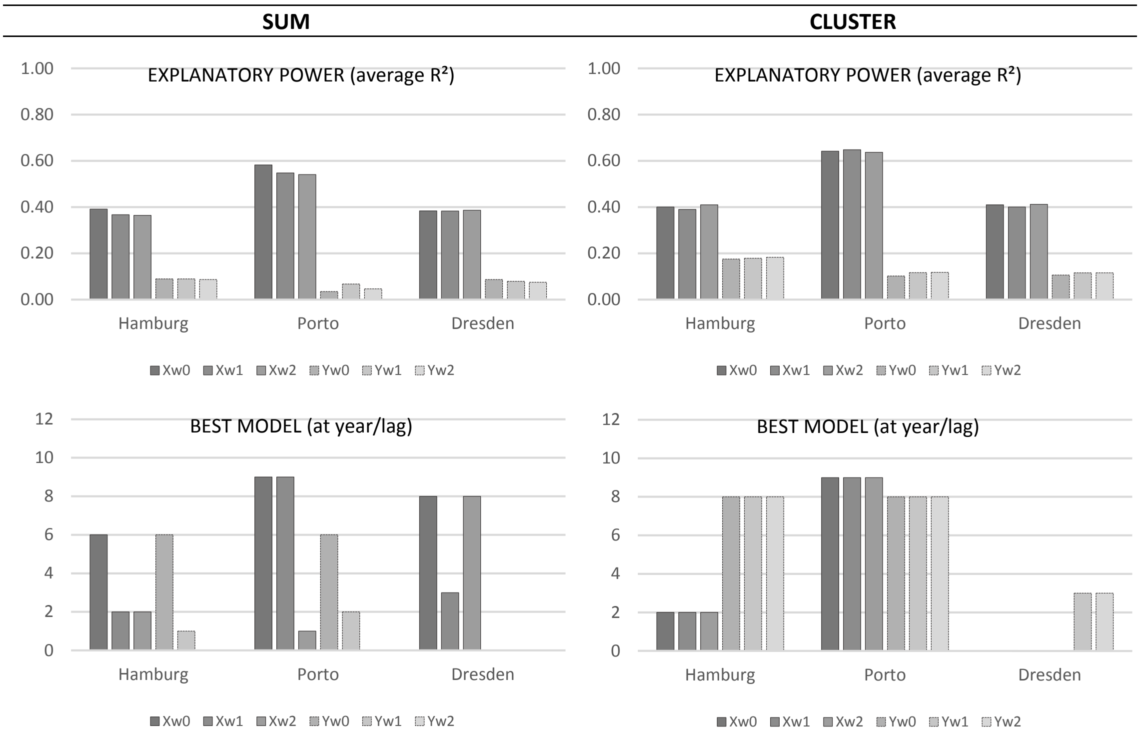


Figure 7.28: Summary statistics - explanatory power and best model.

7.6 Summary of Results and Interpretation

Overall, *qualitative managerial decisions* as defined in the context of this research appear to affect the *performance growth* of an operator, at least marginally. However, the nexus is rather multi-facetted. Results depend much on the performance perspective, the methodological approach taken or the operator assessed. In order to streamline the results of the previous sections in the best possible way, Table 7.26 below intends to combine all information for all variables simultaneously. Reduced to the most essential outcomes of this work - *effect patterns*, *effect-sizes*, *time-lags*, and *explanatory power* - the synopsis tableau facilitates a direct comparison between *decision approaches*, *performance types* and *operators* in a straightforward, and most importantly non-numerical manner. Note that in addition, *overall effects* per variable are considered, which is the overall balance of *positive* and *negative* effects over the 10 years assessed. In the greater picture, Table 7.26 can be considered *the key output* of this research to which all previous research questions, chapters and sections point.

Table 7.26: Synopsis - the decision-performance link at a glance.

ES	Approach/ Variable	Operator	Effects on **Effectiveness Growth** L	*short-term*	*middle-term*	*long-term*	*over-all*	Effects on **Efficiency Growth** L	*short-term*	*middle-term*	*long-term*	*over-all*
VERY LOW $\%(*10^{-2})$	SUM *(aggregated managerial activity)*	Hamburg	1	++	++	+	+++		+	+		++
		Porto	0	+++	-	--	+	1	++	-		-
		Dresden	0	+	-	-	--	0	++	--		+
	RESOURCES *decisions*	Hamburg	1	+	+	-	++	9			+	+
		Porto	0	++	--	-	-	1	++			++
		Dresden		+		-	-	3	-			-
	SERVICE *decisions*	Hamburg	1	+		+	++	1	++		+	++
		Porto	1	++		-	++	0	+++		-	++
		Dresden	0	+		+	++		+			+
	MANAGEMENT *decisions*	Hamburg		+	+		+	5		+	+	+
		Porto		+		--	--	8			-	--
		Dresden	3	-	-	+	-		+	-	-	-
	CONTEXTUAL *events*	Hamburg	-					-				
		Porto	+					-				
		Dresden	-									
VERY HIGH $\%(*10^{-1})$	GDP *growth*	Hamburg	++					--				
		Porto	++									
		Dresden	++					++				
	Δ POPULATION *growth*	Hamburg						--				
		Porto	+++					++				
		Dresden	--									

positive effect (+++strong ++moderate +weak); *negative effect* (---strong --moderate -weak); ES=effect size; L=Lag, years; grey=high R²; empty=n/a

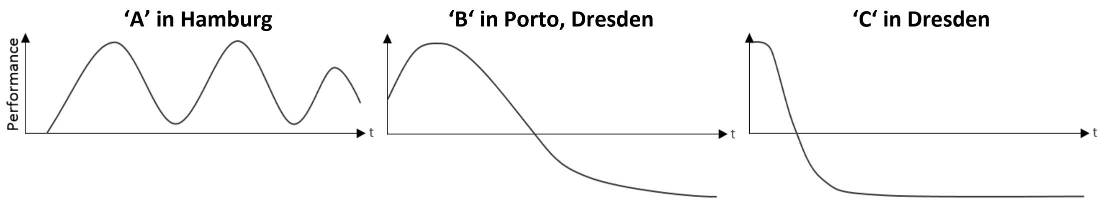


Figure 7.29: Schematized effect patterns 'A', 'B', 'C' of managerial decisions attributed to operators.

The previous accomplishments lead to the following *key conclusions* for this chapter.[371]

(1) *Temporal differences*: Effects from decisions change over time, but differently for each operator (Figure 7.29). Three relative stable *effect patterns* are identified. In pattern 'A' effects appear to be positive over time. In pattern 'B' (later) and 'C' (sooner) at some point, effects tend to become zero or reduce performance growth.

This suggests that in the latter cases managerial decisions could not be properly trimmed to be consistently beneficial for the production process over time. Reasons for that phenomenon might be found in the lower degree of managerial autonomy to take the best economic decisions (rather than political ones) or to adjust decisions more frequently to reality.

(2) *Strong early effects:* Strong positive effects from decisions on performance growth can be achieved in particular over short term (until up to three years after a decision is taken). Effects might built up or decline within that interval. Over the long term, effects are likely to taper off or become negative and might thus cancel out early positive effects. Short and long-term effects are differently balanced over time.

[371] Note that each indent can be traced back for further clarification to the references indicated: **(1)** 1,2,6,9,10,14 **(2)** 4,8,12,31,33,38 **(3)** 3,7,11,15,32,33 **(4)** 21,28,29,30,47 **(5)** 13,17,28,30,37 **(6)** 42,43,44 **(7)** 6,9,18,27,35, 36, 42,43 **(8)** 6,9,14,19,29,43,46 **(9)** 18,23,33 **(10)** 2,5,16,19,22,25,26,28,34,39,45,47.

This result appeals to intuition and confirms a basic assumption of this work: qualitative managerial decision are performance-oriented, -enhancing, -enabling and take effect rather swiftly. However, it appears also legit that under certain circumstances managerial decisions might not be sustainable regarding their positive effect on performance overtime and might have to be revised/adjusted/improved.

(3) *Short time-lags:* Effects might be lagged up to 2 years. Time-lags vary per decision variable and performance type, but appear *similar* between operators.

This indicates that in public transport management similar decisions roughly need the same time to take effect. Operators (as well as users) seem to share similarities in their adaptability to system changes. Appraisal studies and cause-effect evaluations should thus incorporate time-lags to produce meaningful results.

(4) *Small effect sizes:* Coefficients are consistently small $(\% * 10^{-2})$ but vary in magnitude between decision variables and operators.[372] Porto accounts for the largest and Dresden for the smallest effect on performance growth.

The indications are three-fold. (a) Only a significant, large adjustment of decision activities would instantly affect performance at reasonable levels. (b) Small effects are not necessarily a problem, as they might add up over time, so that the overall effect of a decision is much higher. This appears intuitive as it was demonstrated that performance changes occur by the piece. (c) Probably any non-negative short-term effect is a sufficiently valid result for managers. It would set a lower bound for the assumptions about the nature of managerial decisions in a sense that they should at the minimum not worsen performance thus being at least 'performance preserving'.

(5) *Service first:* For all operators and performance types, SERVICE decisions yield the highest and fastest working effects on performance growth (temporarily and overall). Effects from RESOURCES decisions are weaker, and possibly lagged and overall negative. Effect from MANAGEMENT are strongly lagged, weak and overall negative.

The results suggest that demand-orientation is pivotal for the business and that operative and tactical decision may have a higher impact on performance than strategic decisions.[373]

(6) *Dominant external effects:* Effects from GDP and population are much higher than effects from decision variables, and vary significantly between operators[374]. Effects from the contextual variable CON are lower than effects from decision variables. The effect size ranking of absolute scores is POP>GDP>>CON[375]. Population growth might reduce or enhance performance.[376] GDP might affect effectiveness positively.[377] GDP effects on efficiency, however, might be positive, zero or negative.[378]

This indicates that in public transport management the main source of (in)efficiency may be (non-discretionary) external factors. In contrast, managerial practices

[372]Small effect sizes are not rare, as demonstrated by Kerstens (1996), Holvad (2010), Wei et al. (2013), Link (2016).

[373]In accordance with findings from Peltokorpi (2011).

[374]In line with Margari et al. (2007).

[375]The Porto effectiveness case with POP>GDP effect implies that increasing economic prosperity only partially increases demand for public transport. Larger shares appear to go to demand from individual transport.

[376]*Negative effects* from population (a) on *effectiveness*: resources required to accommodate more passengers grow over-proportionally to the realized passenger surplus. A likely scenario for operators at full capacity; (b) on *efficiency*: problems with congestion as in García Sánchez (2009). Vice versa for positive effects as in Santos et al. (2014).

[377]See Santos et al. (2014) and Graham (2008): *"Economic vibrancy provides incentives or opportunities for increased productivity."* This suggest that over the long run negative demand effects form car ownership are overcompensated.

[378]Results are in line with Brons et al. (2005), Kerstens (1996), Pina and Torres (2001) Walter (2010). They show that the nexus 'GDP/car-ownership/population/operational-speed' not necessarily affects operator *efficiency*. However, this might indicate that development of these parameters is already taken into consideration by the management.

(discretionary internal decisions) seem to play a far smaller role comparatively. Further, the results suggest that managerial decisions may control for contextual effects but not for major external trends. However, magnitude and direction of effects from external factors on operator performance seem to depend *inter alia* on the transport systems general state (quality of service, ridership, accessibility, fares, etc.), the levels of congestion, the operator's capacity constraints, managerial responsiveness *and* political commitment.

(7) *Effectiveness outreaches Efficiency:* The link between managerial decisions and effectiveness appears more established than that towards efficiency: (a) Effects on effectiveness growth are significantly higher. (b) Effectiveness growth is most likely affected instantly or in the short term, but latest within three years after a decision was taken. (c) Explanatory power and other criteria are remarkably better for effectiveness models. (d) Both performance types are differently affected by external factors.

The result appeals to intuition when one considers the comparatively strong effects from SERVICE decisions as concluded above. SERVICE decisions are majorly demand-oriented and thus have a direct effect on the operator's success in moving more people. In contrast, managerial measures appear limited with regard to efficiency growth and could at best considered 'efficiency preserving'.[379] On could conclude that most efficiency gains might simply come from quantitative adjustments of production inputs and thus rather from *hardware* than *software* decisions. However, majorly due to the partial inflexibility towards ad hoc output/supply adjustments as well as the relatively fixed relation among inputs (vehicle:drivers:network), operator management might preferably focus on customer acquisition and retention measures rather than "squeezing" the last digit of efficiency from their operations. Therefore, focusing too much or exclusively on the rather narrow concept of efficiency seems no longer suitable for advanced performance research in public transport.[380]

Three conclusion can be drawn with regard to *model quality* and *methodological approach*:

(8) *Validity:* Models for Porto show outstanding quality for both decision approaches, and account for the highest explanatory power (Hamburg for the lowest). From modelling perspective, results for Porto might be closer to the real world than results for Hamburg. Alternatively, since Hamburg is less volatile, it could simply be more difficult to model.

(9) *Decision weighting matters:* The introduction of weight categories appears very beneficial particularly with regard to model diversity and the potential to assess results through averages. Most importantly, the introduction of weights improved effects sizes and explanatory power of the models, despite being rather arbitrarily chosen.

(10) *Decision (dis)aggregation "pays off":* In terms of model quality, the SUM- and CLUSTER-approach are consistent. They do not produce opposing results. For instances, the magnitude of effect sizes for the SUM-approach is always higher than that for individual variables, as effects directly add up. With the highly aggregated SUM-approach, effect patterns stay relatively stable, are more "spiky" and consistently applicable for both performance types. In contrast, the CLUSTER-approach accounts for higher individual effect sizes and explanatory powers and gives meaningful information about individual decision variables. However, due to some tolerable loss of information, the decision patterns are rather fragmented in this approach.

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[379]This might be linked to a less flexible relation among resources and but also between resources and supply.

[380]This result is in the lines with Diana and Daraio (2014):*"An effectiveness analysis should consider indicators that do not necessarily coincide with those used to monitor the efficiency of the firm"*. For the authors effectiveness is a 'wider concept' than efficiency as it may translate/connect to benefits that go from emission reduction to social equality.

8 Conclusions and Future Research

The present PhD thesis proposes an innovative and holistic framework to assess the effects of managerial decisions and other factors on non-parametrically measured economic performance of three public transport operators from Portugal and Germany, namely Hamburg Hochbahn (Hamburg), STCP (Porto) and DVB (Dresden) over the course of 64 years (1950-2013). The core approach of this work took advantage of a two-staged Data Envelopment Analysis (DEA). In contrast to previous research in that field, the DEA logic herein was shifted from a *cross-sectional* to a *time-series* one, which allowed for individual assessment of operator performance against its past values (termed as s*elf-benchmarking*). In other words, a conventional DEA with three inputs and two outputs was applied *over time* and their standard effectiveness and efficiency scores were regressed on managerial decision data in a time-series regression framework. Individual findings were then compared across the three operators in order to identify similarities and differences. The production and decision data was collected from annual reports of the operators, available in digital and analogue form. However, since being of qualitative origin (text-based), the latter of which had first to be categorized and operationalized by means of manual Content Analysis (CA) a text-analysis tool from policy analysis and social science.

Table 8.1 below summarized the main outputs of this research grouped in the following types: *Concepts and Methods*, *Numbers and Interpretations*, *Support and Databases*.

(1) *Concepts and Methods* are pivotal methodological and technical innovations, developments and means to approach the research questions from scratch. As this work is largely on the edge of public transport performance research, obviously some outputs could not be linked to renowned references. They remain partly introductory or conceptual and involved making assumption about the "real world", many of them justified by observation e.g. to introduce managerial decisions to a public transport production model, to categorize and weight managerial decisions or to measure management focus and characteristics over time. Other techniques presented herein, however, advance state-of-the-art techniques proposed in literature, e.g. by exploiting the potential of *time-series DEA* or *time-series regression* in order to make meaningful

inference upon all varieties of performance over time and associated effects from managerial decisions, respectively.

(2) *Numbers and Interpretations* are the centrepiece of this work. They refer to any quantitative (and to minor degrees qualitative) results achieved from (1). This includes innovative ways to present these results and to draw conclusions for the research field for instance from visualizations and charts. The purpose here is to assure the validity and comparability of the chosen approaches with similar research and to give empirical orientation with regard to the some of the research questions raised and beyond.

(3) *Support and Databases* are meaningful by-products of this work as they might be immediate inputs for future research ambitions. *The former one* relates to rather supportive outputs, such as the extensive comparison of measurement methods in performance analysis, the identification of key problems of this research field as well as software- and modelling related achievements. These might essentially help future researchers to decide which method to choose in which case, what problems to tackle (next) or how to model certain issues with EViews. In addition, *the latter output,* databases, opens the field for further (performance) analysis and facilitates to explore various topics, such as differences of performance measurement methods and other issues in a more consistent manner (e.g. by applying multiple methods to the same dataset). The three databases are unique. Until now no long-term decision, production and performance data for public transport operators has ever been published before.

Table 8.1: Output of this thesis, type and chapter.

Ch		Thesis Outputs	Output Type A Concepts and Methods	 B Numbers and Interpretations	 C Support and *Databases*
3	**LR**	**extended public transport production model**	X		
3		extensive comparison of measurement methods			X
4		identification of research issues in performance analysis			X
5	**Managerial Decision = X**	**categorization scheme for managerial decisions**	X		X
5		introduction of learning curves and standardisation of data	X		
5		**managerial decision and context time-series**		X	*X*
5		similarity of managerial decisions across operators	X	X	
5		assessment of management focus (static and dynamic)	X	X	
5		assessment of management characteristics	X	X	
5		clustering and aggregation of managerial decisions	X	X	
7		weighting of managerial decision categories	X	X	
6	**Performance = Y**	**production data time-series**		X	*X*
6		**performance data time-series**		X	*X*
6		performance evolution (performance over time)		X	
6		performance orientation (efficiency vs. effectiveness)	X	X	
6		performance initiators and targets (resources)	X	X	
6		best performing years of operators	X	X	
6		resource dissipation and managerial response	X	X	
6		assessment of operator scale over time	X	X	
7	**Y=f(X)**	**effects patterns of managerial decisions on performance**	X	X	
7		**effect sizes of managerial decisions on performance**	X	X	
7		**effect lags of managerial decisions on performance**	X	X	
7		**effects from external variables on performance**	X	X	
7		Box-Jenkins based modelling manual for EViews			X

Ch=Chapter; LR=Literature Review; **key outputs**

When implementing the proposed approach it was kept in mind that decision-making and thus performance in public transport is in fact of multidimensional nature, interlinked with many factors. Those may be the operator's perspective on performance and its objectives, personal managerial preferences, the interaction/control with/from stakeholders, pressure groups, other actors of the system, the interaction with transport market as a whole, the pace of technological change in the industry and many more. It appeared quite difficult to account for all these criteria at once. The models chosen therefore reflect just a simplified framework for a rather complex reality. By no way, this work postulates that the proposed methods and concepts are the best ones. Overall, they should be understood as a starting point offering substantial room for improvements in future research.

8.1 Findings and Implications

This chapter elaborates on output (B) by outlining briefly upon the most important conclusions from the modelling Chapters 5, 6, 7. For additional information, more details or further interpretation one might be referred to the summary section of these chapters.

Managerial Decisions in Public Transport: X

In terms of preliminary data generation, Chapter 5 was concerned with modelling *managerial decisions* that target inputs and outputs of the public transport production process in a qualitative manner to increase productivity. As a starting point for a six-staged Content Analysis, seven decision main-categories of operational, tactical and strategic nature were developed (*network, fleet, personnel, schedule, fares, service, and management decisions*) and refined to nineteen decision sub-categories. Decision (sub)categories were defined extensively and illustrated with examples. Accordingly, for each operator relevant text-based data from the annual reports was coded and assigned to a structured decision matrix and operationalised to count data per category. In further steps methodology related data problems were solved to obtain a numerically valid database suitable for static and dynamic interpretation trough charts and as input for regression (where decision time-series in different categories would be used as independent variables). The charts were then analysed in a descriptive manner with a focus on the similarity or differences between operators in decision-making over time.

In summary, various *similarities* across the three operators could be observed. Despite being weak, they might point at the existence of some common principles in operator management. It further indicates that relevant decision-makers may share a somewhat similar mind-set about how to design and manage their business. Similarities in decision making appear to be particularly stronger when (A) operators work under the same regulatory framework (e.g. Hamburg and Dresden after 1990) or (B) they have the same size (high similarity between Porto and Dresden). The analysis shows that significant operator heterogeneity cannot be confirmed.

A cross-sectional DEA approach might therefore be valid, specifically when (A) and/or (B) apply. Methodologically, these similarities also demonstrate that the arbitrary decision classification might have been appropriate to describe public transport decision-making. A few findings on the [C1] similarities and [C2] differences between operators are presented in the following:

[C1] Overall managerial activity (in terms of decisions taken) appears to increases over time, indicating a busier and more intervening management in recent times. The dominant decision categories are *service > management > personnel > network*. Some of these decision categories might be mutual substitutes over time. *Network*-associated measures appear to be of higher importance in past than in recent years. In contrast, decisions related to *service*, *management* and *personnel* could be partially identified as corresponding mirror images with increasing importance in recent years. Since most network decisions relate to regular line management measures as defined, from managerial perspective these seem to be carried out in the first place to reach the customer and to generate demand (*1. Where should service be delivered?*). Other decisions would then be conditional or complementary to these actions (*2. How and when should service be delivered?*). This leads to the conclusion that without a properly managed network, no service delivery would be possible. Thus, despite network decision being still important in everyday operator business, managerial focus seems to have gradually shift from *network*- to *service*- or *resource-related* decisions over time, suggesting that the network becomes somewhat stable. In particular, the dynamic decision analysis indicates that service- and customer-orientation became increasingly popular for managers only from the late 80s/early 90s on (paradigm shift). In addition, the proper management of staff as a productive resource appears to be a more recent trend.

This implies the proposal of three evolutionary decision-making stages in public transport shaped by a coherent development from solid decisions to first create the product itself towards service creation and organization 1. *network development,* 2. *service and customer focus,* 3. *resources and management optimization*. The latter two stages might particularly be a result of regulatory reformation of public transport in Europe. Contrary to previous studies, the results clearly indicate that the network is an elementary part of operator decision-making. Network should thus be considered a key input in performance analysis, suggesting that the commonly applied two-inputs-one-put DEAs may not be accurate enough to represent a production model in public transport.

Schedule, fare and *fleet* decisions do not seem to have the same continuous importance over time for the management as other decision categories. They occur rather ad-hoc. For the former two this might be explained by their impact on customers: Fare increases appear to be a delicate matter once applied multiple time in a row. Schedules in turn might be perceived as a cities' rhythm which users are generally well accustomed to. Therefore, multiple consecutive changes of these parameters could have a strong impact on ridership. However, the decision-making patterns exhibit that the managements rather seemed trying to concentrate relevant actions, supposedly to give the customers sufficient time to adapt. As to the latter, also fleet-related decisions appear to be partially bundled indicating are more re-active/flexible than a pro-active/planned management, supposedly affected by external, fleet financing related factors.

[C2] Changes in operational environment and beyond seem to affect managerial decision making differently per operator (display by the level-shifts in the decision time-series). Hamburg did not experience major external changes. Thus, its decision curves appear to move comparably smoother over time. This suggests higher levels of intended, planned and controlled management. In contrast the comparably stronger volatility and jumpiness of the curves from Dresden (reunification 1990, crisis 2008) and in particular in Porto (revolution 1974, competition 2001, crisis 2008) suggests that significant external events of political, economic or competitive nature appear to cause/facilitate/trigger/impose subsequent managerial actions. For instance, the construction of Metro do Porto led to significant activity changes in Porto (STCP) with regard to *network* (restructuring measures), *service* (improvements due to competition), *management* (reorganisation and cost-cutting measures), *personnel* (reallocation of staff), *schedule* (intermodality) and *fares* (fare-integration). In addition, the financial crisis of 2008 and affected decision-making remarkably for this operators expressed by increased managerial activity in almost all decision categories (indicating hasty managerial adjustments). Overall, these peculiarities suggest that operator size might play a role. Hamburg seems much more resilient (less vulnerable) against external effects, in that it does not have to completely adjust/change its decisions-making ad hoc.

With regard to an overall assessment of decision-making, Hamburg seems concerned with the *"provision of transport services"* whereas Porto and Dresden rather seem concerned with the *"administration of transport services"*. The role of the individual car use might give an ample explanation for these phenomena: Public transport in Hamburg was continuously challenged by car-ownership, which forced the operator to be rather service-orientated. This powerful market force was obviously weaker in Porto and especially in Dresden for a large stretch of time, as due to the political and economic framework car ownership has lagged behind.

Performance in Public Transport: Y

Chapter 6 gave a temporal perspective on operator performance, in particular on the concepts of *effectiveness* and *efficiency*. Initially a database of long-term production data (i.e. inputs and outputs of the service production process) was developed and plots analysed descriptively. Then, by means of time-series DEA with a standard three-input-one-output configuration with VRS performance time-series for three operators were modelled. This is considered the *first stage* of the *two*-stage DEA (the series would later serve as dependent variables in the regression model, the second stage). Finally, these were assessed through innovative approaches to the DEA outputs, namely *thetas, weights, lambdas, and slacks (over time)*. The research questions predominantly aimed at making inferences from [C3] the raw *production data*, [C4] *performance evolution*, [C5] the *relation between effectiveness and efficiency* as well as [C6] alternative measures and, generally, the degree of similarities between operators.

[C3] Gradual, smooth quantitative changes of the *production data curves* over time suggest that the operator management either acts in a planned manner *or* likely is constrained in flexibility supposedly due to contractual commitments (staff, public). Concerning the *key inputs* for service provision in public transport, the following trends could be identified for all operators: *Networks* tend to increase up to a saturation stage. *Fleet* size decreases, but individual vehicle size might increase simultaneously. *Personnel* is significantly reduced over time. Concerning the *key outputs,* it appears that smaller operators are less resilient against demand shocks: Hamburg reversed the negative effects from private motorization over time, whereas Porto and Dresden are still seriously affected. From *operational perspective* the data suggests that over time *journeys* get shorter, s*ystem speeds* increase but appear capped recently (probably due to technical regulations (rail) or congestion), and that o*ccupancy rates* decline to a steady baseline of about 17% regardless of the mode-mix, city size or city structure.

[C4] The overall average operator *performance* is around 90%. In line with previous studies, performance curves over time were found to be *u-shaped* for all performance types and operators, displaying a substantial downturn phase roughly from the late 60s to the mid-90s. However, performance appears to recover in the long run (or inefficiencies in public transport decrease). Interpretation of the performance increase might be found in the gradual regulatory and organizational changes the public transit operator were subjected to. In particular in the last decade, operators show almost identical results for all performance models. The results point at the existence of a common pattern of performance evolution for public transport operators (tentatively termed as *"performance lifecycle"*) as well as consistent managerial ambitions to essentially improve performance. In addition, the same regulatory environment seems to produce similar performance curves (Hamburg/Dresden one regulatory system since 1990). There seem to be differences in performance volatility between Hamburg (lower) and Porto/Dresden (higher). Sudden political and regulatory changes seem to take effect on performance through demand-shocks in the short- and middle term. Especially Porto and Dresden show, how sensitive effectiveness curves are to externally induced changes of the demand structure (both positively and negatively). However, over the long-term performance appears to be affected rather by megatrends in the transport market *and* the managerial responsiveness and flexibility to deal with them (both positively and negatively). For instance, the long-lasting performance downturn experienced by all operators suggests that managerial adjustments were systemically lagged and/or could not keep pace with declining demand caused by individual car use.

[C5] A closer look at the dynamics of the performance types *effectiveness* (demand-side) and *efficiency* (supply-side) reveals that in contrast to propositions from previous studies both indicators cannot be regarded as opposing managerial objectives. Their scores largely move in the same direction. However, there might exist some form of effectiveness- or efficiency-orientation of operators (Hamburg subject to the former, Porto and Dresden the latter), which is supported by results of decision modelling. In the long-term both dimension seems to develop to balanced objectives, implying that recently effective operators also tend to be efficient.

[C6] Several alternative measures that are usually not considered in the assessment of DEA results were proposed: (a) In the author´s opinion, conclusions from technical performance scores are meaningless when it is unclear whether performance comes from inputs or outputs. Making this visible allows to make inferences about *performance initiators* and the degree of *managerial control* (i.e. risk exposure for instance to a declining public transport market). Firstly, *network changes* combined with *staff adjustments* are the important input measures to impact performance. Secondly, performance in Hamburg and Dresden comes from controllable inputs; Porto seems more exposed to output obligations or demand shocks as performance comes mostly from outputs, which can be curse or blessing. (b) To achieve 0.01 points of efficiency increase just with input cuts, on average Porto would have to dismiss around 70 employees (-2.3%), or sell seven vehicles (-1.4%) or cut the network by 6 km (-1.6%). The input cuts required for this change differ between operators. (c) The data reveals some form of managerial intuition in that common operator problems such as 'overfleeting', 'overstaffing', 'overinfrastructuring' are dealt with by lagged responsive actions or correct anticipation of the market development. (d) Scale efficiency (i.e. optimal operator size) seems much harder to achieve than technical efficiency. However, smaller operators may be more suitable to produce service scale *and* technically efficient than larger operators.

Decision-Performance Link: Y = f(X)

Chapter 7 - as second stage of the two-stage DEA and centrepiece of this work - was concerned with the assessment of determinants/explanatory factors of operator performance. This was achieved by linking *managerial decision time-series* with *performance time-series* via multiple, shifted time-series regressions. *First*, the chapter discussed the theoretical foundations of time-series regression extensively and focused on a Boy-Jenkins-oriented model building procedure, which is essentially centred around achieving stationary time-series and the removal of error auto-correlation. This involved for instance the first-differencing of the explained data, i.e. changing from performance levels to performance growth. *Second*, a holistic and innovative modelling framework was developed allowing to *quantify, visualize* and *compare* the estimated dynamics of effects from managerial decisions on performance growth within a time window of ten years, for three operators and two decision aggregation scenarios and three decision weighting scenarios. *Third,* the key findings of this PhD were synoptically displayed in just two figures. The findings in particular relate to (the similarity of) [C7] decision effect patterns and time-lags, [C8] influential decisions and effect-sizes, [C9] the role of external effects, and [C10] effects on effectiveness and efficiency growth.

[C7] Effects from managerial decisions on operator performance growth appear to change over time, however, differently for each operator. (a) Three distinctive effect patterns were identified: In pattern 'A' effects appear to be always positive (Hamburg). In contrast, pattern 'B' and 'C' (Porto and Dresden) indicated that effects on performance growth tend to become zero or negative at some point in time (later in Porto or sooner in Dresden). This suggests that in Porto and Dresden managerial decisions could not be properly trimmed to be consistently beneficial for the production process over time. Reasons for that might be found in the comparably lower degree of managerial autonomy over time, politically influenced decision-making as well as the lack to adjust decisions more frequently to operator reality. (b) For all three operators comparably strong positive effects on performance growth can be achieved in the short-term within three years after a decision was taken. Over the long term, however, effects are likely to taper off or become negative. These findings appear rather trivial: *First*, they suggest that the nature of managerial decisions in public transport is essentially performance-oriented/-enhancing/-enabling in the first place. *Second*, under certain circumstances, however, managerial decisions might no longer contribute to performance growth and should be therefore revised/adjusted/improved. (c) Depending on the decision variable and performance type, effects might be lagged up to two years, which was found to be similar between operators. More generally, the result implies that in public transport management similar decisions may roughly need the same time to take effect. Operators (as well as users) seem to share similarities concerning the pace to adapt to system changes.

[C8] Effect sizes are consistently small $(\% * 10^{-2})$ and vary in magnitude between decision variables and operators: Overall, Porto accounts for the largest and Dresden for the smallest effect on performance growth. Performance changes seem to occur by the piece. Only a significant large adjustment of decision activities would instantly affect performance growth at reasonable levels. Thus, probably any non-negative short-term effect is a sufficiently valid result from managerial perspective, as decisions would be at least performance preserving/keeping the head above water. For all operators and performance types, SERVICE decisions yield the highest and fastest working effects on performance growth. The results suggest that demand-orientation should be pivotal for public transport managers. One might expect RESOURCE decisions being strongly affiliated with positive *efficiency* growth. This is not the case. However, there are indications that they may correspond to decreasing effectiveness, which would support the claim that efficiency and effectiveness scores occasionally diverge. The study further shows that MANAGEMENT measures - predominantly streamlining and cost-cutting measures - seem to reduce performance growth. Moreover, operative and tactical decision may have a higher impact on performance than strategic decisions.

[C9] The relatively small effects from managerial decisions are contrasted by significantly higher ones from major socio-economic external variables such as *population* and *GDP growth*. The magnitude and direction of these effects depend on the performance type assessed and, most importantly, on the operator. There mechanism of action might more generally be a function of a cities transport system´s general state (quality of service, ridership, accessibility, fares, etc.), the levels of congestion, the operator’s capacity constraints, managerial responsiveness and local political commitment. For instance in Porto, a combination of majorly population and minorly economic growth appears to increase effectiveness significantly, as opposed to Hamburg and Dresden. The only consistent result across operators relates to the positive effects from GDP on effectiveness. In summary, the findings suggest that a large share of (in)efficiency of operators might come from (non-discretionary) external factors and trends. In comparison, managerial practice and decisions (discretionary internal decisions) seems to play a far smaller role concerning their effects on performance growth, rendering operator management supposedly “powerless” (s.t. external factors are not incorporated in decision-making).

[C10] The link between managerial decisions and *effectiveness* growth could be better established than that towards *efficiency* growth: Effects on effectiveness growth are significantly higher and occur most likely in the short term (which cannot be observed clearly for efficiency). This is in line with the suggested strong effects from SERVICE decisions. As these are by definition rather demand-oriented, they have a direct effect on the operator's success in *moving more people* (which eventually translates to effectiveness). In contrast, it was found that managerial measures seem limited to trigger efficiency growth, supposedly because of two reason: *First*, operators cannot always decrease inputs and compensate with technology and training. With already optimal rosters, vehicle routing, schedule, trained staff, incentive contracts etc. resource productivity might be exhausted at some point. *Secondly*, supply levels might be fixed by contracts and other obligations. For bus operators in congested cities probably the most promising efficiency measures remain speed increase (bus prioritization buses, separate lanes) or vehicle size adjustment to off-peak periods. However, an operator might relatively easy increase effectiveness (ridership) through enforced customer acquisition measures, in particular when running on obliged oversupply or SLOs. Thus, the overall gains of managerial action appear to be in favour of *effectiveness growth*, rather than *efficiency growth*. This gives a major argument, why effectiveness should be considered in public transport performance assessment. It further opposes the often applied assumption that efficiency improvements are the only operator objective. Thus, focusing too much or exclusively on the narrower concept of efficiency seems no longer suitable for advanced performance research in public transport.

[OVERALL SUMMARY] The set of operators assessed is neither heterogeneous nor homogenous. When managerial decisions and performance over time are assessed individually, operators appear to show several unexpected similarities. However, the differences indicated in Chapter 5 and 6 as well as the varying effects from managerial decision on performance growth in particular suggest to differentiate Hamburg from Porto/Dresden. For a meaningful benchmarking study/performance analysis on European public transport operators by means of a cross-sectional DEA, it would therefore be recommended for Hamburg and Porto/Dresden to be in different data sets, among operators with *similar* conditions. *Overall, what might be an explanation for the differences?* In Chapter 6 it was learnt that Hamburg's performance curves are rather smooth in contrast to Porto´s and Dresden´s. This indicates a certain level of resilience against external disturbances and appropriate balancing of resources (*quantitative decisions*). This in turn might enable to better plan, fit, adjust, and take *qualitative decision,* as shown in its rather smooth decision curves. Consequently, this "overall smoothness" translates into *steady positive effects* on performance growth as demonstrated in effect pattern A. Accomplishing performance targets as planned then manifests a relatively stable management environment, supposedly reducing also political or public pressures. This can be described as a *virtuous* cycle for Hamburg. In contrast, the more volatile performance in Porto and Dresden corresponds to improper *quantitative* resources adjustment and most likely to rather hasty compensation measures on the *qualitative* decision scale. These might have some performance potential in the short run but might not beneficially for performance growth in the long term (effect pattern B,C) and therefore require frequent adjustment. This in turn might impede the accomplishment of performance targets, increase political and public pressure, management changes, operator makeovers and so on, manifesting a sort of *vicious cycle*. Obviously, in a more global view these inferences might point at a hen-egg like problem in that the causal relation is unclear: does political action, policy-making and governance cause operator behaviour or vice versa?

8.2 Future Research

First, there are several limitations to this work, which might be improved through future research. **[F1]** Decisions categories were assumed given. The decision data was then modelled by manual Content Analysis, since most of the annual reports of the three operators were only available in printed format. However, by using a sufficiently large number of digital sources from other operators, this procedure may be automatized in future research with text-mining methods to allow categories to emerge from data, to assign decisions accordingly and to collect performance data automatically. Similar data from other operators would also help to validate the results and to widen the context of this approach beyond Portugal and Germany.[381] **[F2]** The weights of decisions categories were unknown. Therefore, three weight scenarios were hypothesizing to provide some form of sensitivity analysis. However, these weights might not necessarily represent reality very well, nor was any sophisticated decision hierarchy assumed. Tools like Delphi interviews or Analytic Hierarchy Process (AHP) - both incorporating expertise from the field of public transport management - might be recommended follow-ups to analyse, structure and weight decisions (categories) in a more realistic fashion. For instance, AHP might allow building consistent, weighted decision hierarchies of decision alternatives in a given set, based on the stated pair-wise, relative importance of the expert.

Second, the proposed modelling framework offers substantial room to max out the potential of this work by ‘playing around’ with model configurations. **[F3]** As indicated before one may simply consider a shorter stretch of time (e.g. 30 years) and then assess how effect sizes, patters

[381]Parts of the data source have already been collected and would just have to be processes. See Appendix 19.

etc. change in comparison to the long-term analysis. **[F4]** This can be done similarly by omitting the external factors from the models and supposing that these are inherent to management decisions. **[F5]** One may also want to revert the causal relation in the regression in that *decisions* could be considered a function of *performance*. Then the level of performance (growth) triggers managerial action (which in turn influences performance). This multidirectional approach is used e.g. by Nicholson-Crotty (2005) and Wright et al. (2005). **[F6]** A significant change in the models, however, would be the dynamic interpretation through a *finite distributed lag model* that essentially captures combined decisions effects. It assumes that the effects on performance in a given year is the joint results of multiple decisions over a finite stretch of time. **[F7]** The approach presented, focused mainly on *estimating* the effects sizes of decision on performance. However, the model may also be suitable for *forecasting operator performance*.

Third, extensions to this work would come from alternative methodologies used in the field of performance analysis or innovative 'out-of-the-box' approaches to the subject. **[F7]** A parametric approach, such as stochastic frontier analysis with time-varying inefficiency term could first isolate the factors for the inefficient behaviour over time and then align them in a second step with the proposed or improved decision models. This might enable a comparative assessment with the non-parametric DEA applied herein. **[F8]** Within the DEA portfolio, a *dynamic* DEA as in Färe et al. (1994) would allow to take in temporal links between inputs and outputs, in that supply- or demand-sided outputs of one period would be intermediate inputs in the subsequent period, e.g. to account for user adaption. This is when the demand increases due to the level of supply in the previous period. A DEA with *flexible variables* as proposed in Cook and Seiford (2009) would allow to include variables like 'accessibility' (Ermagun and Levinson, 2015) that can be viewed as a input or output of the public transport production process. A *window DEA* as per Pjevčević et al. (2012) and Yang and Chang (2009) would allow to assess all operators simultaneously. One could also discard the two-stage DEA framework and directly apply a time-series DEA using qualitative decision time-series as productive inputs with conventional (inputs and) outputs to assess the efficiency of decision-making. Or one might apply a three-stage DEA as proposed by Fried et al. (2002), Margari et al. (2007) and García Sánchez (2009) which is essentially another DEA using non-controllable inputs that capture the effects and noise estimated in the second stage (regression). **[F9]** Li et al. (2002) develop a structural equation model for hospital management, linking long-term and intermediate managerial decisions with performance and several constraints. The concept might be adaptable to public transport operators. **[F10]** The role of the operator in a larger system of societal objectives with loops and interlinkages (Figure 8.1) might be an interesting case for system

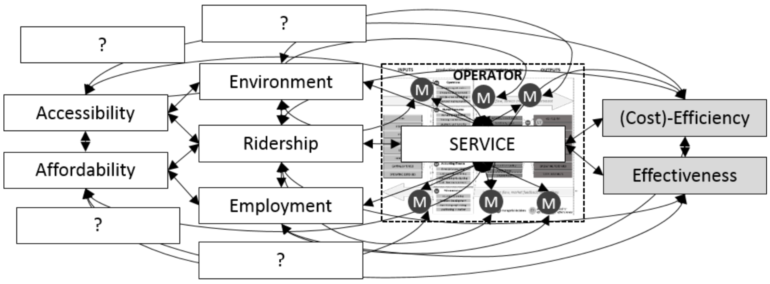

Figure 8.1: System Dynamics and Operator Management. Adapted from van Egmond et al. (2003)

dynamics (SD) to model the relationships between the objectives and how they might influence system behaviour, managerial decision-making over time and *vice versa*. See Wang et al. (2008).

Fourth, several conceptual opportunities of could be identified. **[F11]** One promising research path of DEA could be the consideration of a wider range of inputs/outputs as displayed in Table 3.2, 4.2 and Figure 3.4. These might better describe the underlying production process from different perspectives (user, operator, public) and most importantly promote a broader application of economic efficiency analysis (Daraio et al., 2016). **[F12]** The DEA outputs suggest that the relative importance of input and output variables for the efficiency score change over time. Therefore, one could try test if this is conditional to the performance levels in order to give recommendations to the operator, which input to adjust preferably at which performance level. **[F13]** Another research branch could investigate how to set the right incentives for decision-makers to take the holistically best decision for operator performance and public objectives. This is surely a transversal issue beyond operator management including research on regulatory reforms, contract controlling and reporting mechanisms. **[F14]** Guittat (2016) define three future trajectories leading to higher performance in public transport: *demand maximization*, *optimized operations* and *better business models*. However, the role of the relevant technologies and business models as well as their real impact on operator performance is yet unclear. A next research step could gather recent experience from operators in the field of smart mobility, mobile ticketing, multi-channel marketing, analytics-powered fare systems, on-demand services, multi-agent systems, door-to-door navigation and routing, third party business integration, revenues diversification and more. **[F15]** This work underlined the importance of customer orientation and service-related decisions for operators, which in fact involve large parts of marketing-related measures. As indicated by Borger and Kerstens (2006), this field seems a “seemingly neglected research topic” supposedly due to the preferred focus on efficiency (operations) rather than on effectiveness (business). Therefore one new research avenue could assesses marketing activities of multiple operators over the last ten years and correlate them with their demand-sided output data or effectiveness scores in order to identify the most successful strategies towards users. This would be the extension of economic performance analysis towards its business side. **[F16]** Open questions to be researched: Do city size and mode-mix function as barriers against car-use (probably in combination with economies of scale and density)? A partially rail-based service guarantees higher operational speeds. This might prevent people to switch to individual transport (Hamburg) or it will enable public transport to be considered as a real alternative (Dresden). Pure bus system, however, seem to be more vulnerable. Is the answer to improve the ROW situation for buses to increase speed?

Fifth, the development of a *performance-based decision-support tool* for operators would turn this research in a practical application as tentatively sketched by Costa et al. (2005). Besides the motivation of managers, operators need proper information tools. By knowing, the performance effect of decisions a manager can plan for future actions to achieve certain goals. **[F17]** Due to the economics orientation of this work, the current assessment unit is (only) one year. However, a decisions-support tool in the best case should have to give *ad hoc* information about economic operator performance, potential decisions and their impact. Further, this study assumes that the decisions taken have a value-creating effect, but the direct and indirect costs that arise from it are neglected. Therefore, the tool should incorporate financial information, for instance by assigning monetary values to managerial decisions or by relating the costs of performance improvement to their estimated long-term cost-reduction potential (leverage-effect). In that the tool could indicate, when the costs effect of decisions would outnumber the performance gains. Overall, a decision-support tool would assist the management to locate existing inefficiencies faster (e.g. input excesses, output shortfalls) and to choose the cost-optimal strategy/decision-path to increase performance. With new data collection and processing methods on operator side, this appears feasible to be achieved in future work. From research perspective, it might be a valuable contribution to develop a better understanding of the problem described herein.

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Appendix

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1 CCR-Model of DEA

Input-oriented CCR model with constant returns-to-scale (CRS). Based on Cooper et al. (2007) pp. 21ff and Coelli (2005) pp. 162ff.

Symbol	Definition	Symbol	Definition
x	input	v	input weight vector
y	output	w	output weight vector
p	DMU (year)	e	row vector with all elements unity
θ	efficiency score $[0,1] = \{\theta \in \mathbb{R} \mid 0 \leq \theta \leq 1\}$	λ	semipositive vector in R^n
X, Y	matrices	w_p	scalar, free variable

1.1: THE FRACTIONAL PROGRAM (FP_p)

An intuitive way to introduce DEA is via the *ratio or fractional form*. The optimal weights for a DMU are obtained by solving the following linear programming problem for each DMU.

$$\max_{v,w} \theta_p \quad \frac{\sum_{j=1}^{n} w_j y_{jp}}{\sum_{i=1}^{m} v_i x_{ip}} = \frac{virtual\ output}{virtual\ input} \tag{48}$$

$$s.t.$$

$$\frac{\sum_{j=1}^{n} w_j y_{jp}}{\sum_{j=1}^{m} v_i x_{ip}} \leq 1 \tag{49}$$

$$x_{ip}, y_{jp}, v_i, w_j \geq 0 \tag{50}$$

$$i = 1, \dots, m;\ j = 1, \dots, n;\ p = 1, \dots, Q$$

The ratio should not exceed one for every DMU. The optimal value of θ_p is one. All inputs, outputs and weights are positive. However, fractional programs have infinite solutions, since the solution - optimal weights - can be scaled by any factor α. In order to solve the problem (1) it has first to be reformulated into a linear programming problem. This is done by setting the denominator of the objective as zero and adding a constraint.

1.2: THE LINEAR PROGRAM (LP_p)

$$\max_{v,w} \theta_p \quad \sum_{j=1}^{n} w_j y_{jp} \tag{51}$$

$$s.t. \quad \sum_{i=1}^{m} v_i x_{ip} = 1 \tag{52}$$

$$\sum_{j=1}^{n} w_j y_{jp} - \sum_{i=1}^{m} v_i x_{ip} \leq 0 \tag{53}$$

$$x_{ip}, y_{jp}, v_i, w_j \geq 0 \tag{54}$$

$$i = 1, \dots, m;\ j = 1, \dots, n;\ p = 1, \dots, Q$$

To bypass the problems of the fractional program (FP_p) it is transformed into a multiplier program by adding the constraint $\sum_{i=1}^{m} v_i x_{ip} = 1$. Here, v is the row vector for input multipliers, w is the row vector for output multipliers. (LP_p) is expressed in conventionally as "weights formulation". The fractional program is equal to the linear program. The efficiency measure is independent from the units in which outputs and inputs are measured. (LP_p) can be solved by the simplex algorithm. An optimal solution for each DMU (v_i^*, w_j^*, θ^*) can be achieved dealing with the dual side of (LP_p), (DLP_p) as described below.

Definition 1: CCR-Efficiency

1. DMU_p is CCR-efficient, if $\theta^* = 1$ and there exists at least one optimal (v_i^*, w_j^*) with $v_i^* > 0$ and $w_j^* > 0$.
2. In all other cases DMU_p is CCR-inefficient.

Definition 2: Reference set or peer group or benchmarking

If $\theta^* < 0$ for DMU_p at least one constraint of (6) exists where (v_i^*, w_j^*) produce equality.

$$E'_p = \underset{q=1,\dots,q}{} \left\{ q\colon \sum_{j=1}^{n} w_j^* y_{jq} - \sum_{i=1}^{m} v_i^* x_{iq} \right\} \tag{55}$$

A subset E_p of E'_p consisting of the efficient DMUS form the reference set for DMU_p. The subset is the benchmark and forces DMU_p to be relatively inefficient. The set spanned by E_p forms the efficiency frontier.

Definition 3: Production possibility set P

1. The observed activities (x_j, y_j) belong to P.
2. If (x, y) to P, then (tx, ty) belong to P for any positive scalar t under CRS.
3. For (x, y) in P any semipositive activity $(\bar{x}, \bar{y})$ with $\bar{x} \geq x$ and $\bar{y} \leq$ y is included in P.
4. Any semipositive linear combination of P belongs to P.

$$P = \{(x, y) | x \geq X\lambda, y \leq Y\lambda, \lambda \geq 0\} \tag{56}$$

(LP_p) can also be expressed vector-matrix notation or "multiplier form":

$$\max_{v,w} \quad wy_p \tag{57}$$
$$s.t. \quad vx_p = 1 \tag{58}$$
$$wY - vX \leq 0 \tag{59}$$
$$v, w \geq 0 \tag{60}$$

1.3: THE DUAL PROBLEM (DLP_p)

The corresponding dual formulation of $(\boldsymbol{LP_p})$ - or "envelopment form" - assumes θ to be a scalar and has a feasible solution at $\theta = 1, \lambda_p = 1, \lambda_j = 1, (j \neq p)$. Optimal θ^* is not greater than 1 but greater than 0. λ is forced to be non-zero.

$$\min_{\theta,\lambda} \quad \theta \tag{61}$$
$$s.t. \quad \theta x_p - X\lambda \geq 0 \tag{62}$$

$$Y\lambda \geq y_p \qquad (63)$$
$$\lambda \geq 0 \qquad (64)$$

Definition 4: Slacks

It can be said that $(X\lambda, Y\lambda)$ outperforms $(\theta x_p, y_p)$ when $\theta^* < 1$. Then, slacks are defined:

$$\text{input excess slack } s^- = \quad \theta x_p - X\lambda \qquad (65)$$
$$\text{output excess slack } s^+ = \quad Y\lambda - y_p \qquad (66)$$
$$s^-, s^+ > 0 \text{ for any feasible solution } (\theta, \lambda) \text{ of } (DLP_p) \qquad (67)$$

(DLP_p) is solved in a two stage LP problem: Phase I solves (12) and delivers θ^*; Phase II then uses θ^*as a value and solves another LP using (15) and (16) as constraints. e is a vector of ones = $(1, \dots, 1)$. Phase II intends to maximize the slacks while keeping $\theta = \theta^*$. Coelli (2005) suggest to be aware of two major problems when dealing with slacks: first, the maximization in in phase II refers to the furthest efficient point, not the nearest. Second, the LP problem is not invariant to the units of measurement, thus a unit change e.g. from days to hours could yield different slacks and lambdas.

$$\max_{\lambda, s^-, s^+} \qquad z = es^- + es^+ \qquad (68)$$

Definition 5: Max-slack solution, zero-slack

An optimal solution of Phase II is called max-slack solution. If s^- = s^+ = 0 the solution is called zero-slack.

Definition 6: CCR-Efficiency, Pareto-Koopmans Efficiency

A DMU is CCR-efficient, only when $\theta^* = 1$ (from Phase I) and s^- = s^+ = 0 (from Phase II).

2 BCC-Model of DEA

Input-oriented BCC model with variable returns-to-scale (VRS). Based on Cooper et al. (2007) pp. 89ff and Coelli (2005) pp. 162ff. The notation and optimization steps are equal to that of the CCR model. Generally, CCR-efficiency does not exceed BCC efficiency. The only difference in BCC models is that with $\sum_{j=1}^{n} \lambda_j = 1$ or $e\lambda = 1$ a convexity condition is introduced which imposes how to combine the n DMUs.

Symbol	Definition	Symbol	Definition
x	input	v	input weight vector
y	output	w	output weight vector
p	DMU (year)	e	row vector with all elements unity
θ	efficiency score $[0,1] = \{\theta \in \mathbb{R} \mid 0 \leq \theta \leq 1\}$	λ	semipositive vector in R^{n}
X, Y	matrices	w_p	scalar, free variable

2.1: PRODUCTION POSSIBILITY SET P_{BCC}

$$P_{BCC} = \{(x,y) \mid x \geq X\lambda, y \leq Y\lambda, e\lambda = 1, \lambda \geq 0\} \qquad (69)$$

2.2: BCC LP, ENVELOPMENT FORM (PLP_p^B)

$$\min_{\theta_{BCC},\lambda} \quad \theta_{BCC} \qquad (70)$$

$$s.t. \quad \theta_{BCC} x_p - X\lambda \geq 0 \qquad (71)$$

$$Y\lambda \geq y_p \qquad (72)$$

$$e\lambda = 1 \qquad (73)$$

$$\lambda \geq 0 \qquad (74)$$

2.4: BCC LP, MULTIPLIER FORM (DLP_p^B)

$$\max_{v,w,w_p} z \quad wy_p - w_p \qquad (75)$$

$$s.t. \quad vx_p = 1 \qquad (76)$$

$$wY - vX - w_p e \leq 0 \qquad (77)$$

$$v, w \geq 0, w_p \ free\ in\ sign \qquad (78)$$

2.3: BCC FP, FRACTIONAL FORM (FLP_p^B)

$$\max_{v,w,w_p} z \quad \frac{wy_p - w_p}{vx_p} \qquad (79)$$

$$s.t. \quad \frac{wy_j - w_p}{vx_j} \leq 1 \ (j=1,\ldots,n) \qquad (80)$$

$$v, w \geq 0, w_p \ free\ in\ sign \qquad (34)$$

Similar to the CCR, the primal problem PLP_p^B is solved in two phases where first, the scalar θ_{BCC} is minimized and then slack sums are maximized, assuming that $\theta_{BCC} = \theta^*{}_{BCC}$. The optimal solution for PLP_p^B - which in fact is the optimal solution for each year assessed - is given by $(\theta^*{}_{BCC}, \lambda^*, s^{-*}, s^{+*})$ with the maximal input excesses and outputs shortfalls.

Definition 7: BCC-Efficiency

A DMU is BCC-efficient, only when $\theta^* = 1$ and s^- = s^+ = 0.

Definition 8: Reference set or peer group or benchmarking

For a BCC-inefficient DMU, the reference set E_p is defined in (39). If there are multiple solutions, one can choose any solution to that fit fulfils (40) and (41):

$$E_p = \{j | \lambda_j^* > 0\} \ (\mathrm{j} \in \{1, \dots, n\}) \quad (35)$$

$$\theta^*{}_{BCC} x_p = \sum_{j \in E_p}^{n} \lambda_j^* x_j + s^{-*} \quad (36)$$

$$y_p = \sum_{j \in E_p}^{n} \lambda_j^* y_j - s^{+*} \quad (37)$$

Definition 9: Formula of improvement for inputs and outputs in BCC

This essentially says that performance improvement on the input side can be achieved by reducing as indicated in theta and by reducing the amount of slacks. On the output side we obviously can improve outputs only by the slack (since the managerial power is just on the inputs in an input-oriented BCC model).

$$\widehat{x_p} \Leftarrow \theta^*{}_{BCC} x_p - s^{-*} \quad (38)$$

$$\widehat{y_p} \Leftarrow y_p + s^{+*} \quad (39)$$

2.3: SIMULTANOUSE SOLUTION OF PHASE 1 AND 2

By merging (14) and (21) and entering the convexity constraint the following single model is obtained (see Cooper et al. (2007) p. 73).

$$\min_{\theta_{BCC, s^-, s^+}} \quad \theta_{BCC} \text{-} \ \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_i^+\right) \quad (40)$$

$$s.t. \quad \theta x_{ip} = \sum_{j=1}^{n} x_{ij} \lambda_j + s_i^-, \quad i = 1, \dots, m \quad (41)$$

$$y_{rp} = \sum_{j=1}^{n} y_{rj} \lambda_j - s_r^+, \quad r = 1, \dots, s \quad (42)$$

$$\sum_{j=1}^{n} \lambda_j = 1, \quad j = 1, \dots, n \quad (43)$$

$$\varepsilon \ is \ infinitesimal \ small, \lambda_j, s_r^+, s_i^- \geq 0 \quad (44)$$

3 DEA Results Example p. 46

Table A1: Model input

DMU Name	driver	vehicles	passengers
A	14	7	10000
B	39	13	10000
C	15	5	10000
D	40	3	10000
E	23	5	10000
F	19	8	10000
G	10	29	10000
H	26	4	10000
I	30	20	10000
J	31	8	10000
K	45	3	10000

Table A2: Thetas

DMU Name	Objective Value	Efficient
A	1	Yes
B	0.384615385	
C	1	Yes
D	1	Yes
E	0.897435897	
F	0.760869565	
G	1	Yes
H	1	Yes
I	0.454054054	
J	0.588235294	
K	1	

Table A3: Weights

DMU Name	**driver**	**vehicles**		**passengers**
A	0.057142857	0.028571429	0.5000	1E-04
B	0.005494505	0.06043956	11.0000	3.84615E-05
C	0.014285714	0.157142857	11.0000	0.0001
D	0.012195122	0.170731707	14.0000	0.0001
E	0.012820513	0.141025641	11.0000	8.97436E-05
F	0.043478261	0.02173913	0.5000	7.6087E-05
G	0.06547619	0.011904762	0.1818	1E-04
H	0.014285714	0.157142857	11.0000	0.0001
I	0.02972973	0.005405405	0.1818	4.54054E-05
J	0.008403361	0.092436975	11.0000	5.88235E-05
K	0	0.333333333		1E-04

Table A4: Slacks

DMU Name	driver	vehicles	passengers
A	0	0	0
B	0	0	0
C	0	0	0
D	0	0	0
E	0	0	0
F	0	0	0
G	0	0	0
H	0	0	0
I	0	0	0
J	0	0	0
K	5	0	0

Table A5: Lambdas

DMU Name	A	C	D	G	H
A	1	0	0	0	0
B	0	1	0	0	0
C	0	1	0	0	0
D	0	0	1	0	0
E	0	0.487179487	0	0	0.512820513
F	0.543478261	0.456521739	0	0	0
G	0	0	0	1	0
H	0	0	0	0	1
I	0.905405405	0	0	0.094594595	0
J	0	0.705882353	0	0	0.294117647
K	0	0	1	0	0

4 Database 1 - Decision Text Tables

Network Decisions

HAMBURG

Table A6: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	U-Bahn Ostring Betrieb	new underground segment/link	accessibility	network
2	1951	Bessere Verbindung zum Flughafen	airport connection	accessibility	network
3	1952	Anbindung Innnenstadt	CBD connection	accessibility	network
7	1953	Querverbindungen	cross connection	accessibility	network
10	1954	Anbinung Peripherie	periphery connection	accessibility	network
9	1954	Erweiterung Busnetz	bus network upgrade	accessibility	network
12	1955	Straba: Peripherie	periphery connection	accessibility	network
13	1955	Schiff: neue Anlegestelle	new bus station	accessibility	network
15	1955	Quervervbindung,	cross connection	accessibility	network
25	1960	nach 30 Jahren: U-Bahnnetzerweiterung (Gleis+FZ), Tunnel (Stadt)	new underground segment/link	accessibility	network
26	1960	Bus: Siedlungstätigkeit in den Außenbezirken= Ausdehnung, Verdichtung Netz	periphery connection	accessibility	network
28	1960	U: wohnbautätigkeit in Horn = Linie 4	periphery connection	accessibility	network
30	1962	Bus Großhaltestelle	new bus station	accessibility	network
31	1963	U-Bahn Eröffnung Teilabschnitt	new underground segment/link	accessibility	network
36	1972	B: Erschließung von Wohngebiet	periphery connection	accessibility	network
37	1973	Zubringer Bus and S-Bahn	feeder lines	accessibility	network
38	1973	B: Ausweitung Angebot für Wohngebiete	periphery connection	accessibility	network
39	1973	B: neuer ZOB	new central bus station	accessibility	network
40	1974	B: Anpassung an Siedlingsstruktur	periphery connection	accessibility	network
41	1975	B: Verknüpfung Nord und Südelbegebiet	cross connection	accessibility	network
42	1975	Netz: an Siedlung	periphery connection	accessibility	network
43	1977	sechste OB Bahnhof	new central bus station	accessibility	network
45	1983	Airport Expresslinine (bes. Kennzeichnug, D+Eng, Gepäckmitnahme, Marketing)	airport express connection	accessibility	network
46	1983	B: Fertigstellung Busanlagen (Hubs) zu S-Bahn	new bus station (interchange)	accessibility	network
47	1984	Maßnahmen: Busumsteigeanlagen,	new bus station (interchange)	accessibility	network
48	1985	U: neu Abschnitt	new underground segment/link	accessibility	network
50	1985	Umsteigeanlage	new bus station (interchange)	accessibility	network
51	1986	Focus: Bus infrastruktur (Ausbau Umsteigeanlagen)	new bus station (interchange)	accessibility	network
53	1987	B: neue Umsteiganlage mit Cafe,, Kiosk, Toilette	new bus station (interchange)	accessibility	network
54	1989	B: besser Erschließung Wohngebiete	periphery connection	accessibility	network
55	1990	U: Verlängerung - 30.000 Einwohner erhalten Anschluss	new underground segment/link	accessibility	network
58	1991	U: neuer Abschnitt	new underground segment/link	accessibility	network
59	1996	U: neue Strecke	new underground segment/link	accessibility	network
60	1998	B: bessere Flughafenanbindung	airport connection	accessibility	network
64	2003	neue ZOB	new central bus station	accessibility	network
66	2006	U: Anbbindung an Einkaufspassage in Innenstadt	CBD connection	accessibility	network
67	2009	B: Neuebau umsteigeanlagewn	new bus station (interchange)	accessibility	network
69	2012	Eröffnung wichtigeste Busanlage (interface)	new bus station (interchange)	accessibility	network
70	2012	Eröffnung neue U	new underground segment/link	accessibility	network
4	1953	Bus: Schnelllinine mit Tarifstützung von Außenbezirken	subsidized express line to periphery	other innovations	network
5	1953	O-BUS netz: neu O4, Sprunghafter Anstieg	new mode/network (trolleybus)	other innovations	network
6	1953	Bus: Sonderlinine mit Tarifstützung von Außenbezirken, Querverbindungen	subsidized express line to periphery	other innovations	network
11	1955	Schnelllinien Busverkehr	upgrade express lines	other innovations	network
14	1955	Sonderlinien Busverkehr	dedicated lines	other innovations	network
16	1956	Bus: Ausbau Schnelliniennetz	upgrade express lines	other innovations	network
17	1956	B: Nacht-Schnellbusse	express night lines	other innovations	network
18	1957	Erweiterung Schnellbus, Citybusse: 4,2 Mio (von 1,8)	upgrade express lines	other innovations	network
19	1957	SB: Erweiterung Nachtnetz (Grafik)	extension night lines	other innovations	network
20	1957	B: Ausbau Sonderlinien	upgrade nightlines	other innovations	network
21	1957	Umstell SB auf Bus+	tram replacement	other innovations	network
22	1958	Erweiterung Schnellbus, Citybusse auf 7,9 Mio von 4,2 Mio (von 1,8)	upgrade express lines	other innovations	network
23	1958	B: Citybus Einführung: Kleinbusse, 13 Sitz, 5 Stehbusse, 5 min takt, 50 Pfg.)	new product (citybus)	other innovations	network
24	1959	SB: Stillegungen, Ersatz druch Bus	tram replacement	other innovations	network
29	1961	neue Angebote Busnetz	upgrade bus service	other innovations	network
32	1964	B: Spätdienst/linie	introduction late line	other innovations	network
34	1970	Nachtlininen Bus	upgrade nightlines	other innovations	network
35	1972	B: Eilbuslinien	upgrade express lines	other innovations	network
57	1990	Ereignislinine (Einkauf, Tanz, Bundesliga etc)	introduction express lines	other innovations	network
63	2001	B: Kleinbuslinie - Ein-Austige auf Wunsch	new product (on demand lines)	other innovations	network
65	2005	Verbundraumausweitung (Netz)	upgrade transport association network	other innovations	network
8	1953	Bus: Umbenennung Linien	change line labeling	(re)organization	network
27	1960	B: Optimierung Schnellbusnetz	optimization express bus network	(re)organization	network
33	1966	Netzumbildung durch Verbund	remodelling due to transport association intorduction	(re)organization	network
44	1983	Anpassung an S-Bahn	remodelling due to competition (S-Bahn)	(re)organization	network
52	1987	Optimierung Netze	network optimization	(re)organization	network
56	1990	B: anpassung an U	remodelling due to underground	(re)organization	network
61	1999	Optimierung Nachtnetz = Kundenbindung bei jungen Leuten	optimization night lines	(re)organization	network
62	2001	B: Angebotsverbesserungen, Linienanpassung	general line optimization	(re)organization	network
68	2009	B: Optimierung Liniennetz	general line optimization	(re)organization	network

PORTO

Table A7: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
2	1952	anbindung stadion	connection stadium	accessibility	network
8	1961	neuer Stadtteil Bairro Pasteleleira	connection periphery	accessibility	network
9	1963	umstieg	new station (interchange)	accessibility	network
13	1965	neuer umstieg	new station (interchange)	accessibility	network
14	1965	bau haltestelle	new station (interchange)	accessibility	network
21	1972	neue stops aliados	new bus station (interchange)	accessibility	network
24	1978	hubs	new station (interchange)	accessibility	network
25	1979	hubs	new station (interchange)	accessibility	network
29	1980	anbindung airport	connection airport	accessibility	network
28	1980	hubs	new station (interchange)	accessibility	network
30	1981	Hub Gaia	new station (interchange) Gaia	accessibility	network
33	1988	anbindung krankenhaus	connection hospital	accessibility	network
35	1990	anbindung krankenhaus	connection hospital	accessibility	network
36	1991	New Bus Station	new station (interchange)	accessibility	network
38	1996	Establishment of new bus stops (32)	bus stop program	accessibility	network
42	1996	anbindung an shoppingcenter	connection shopping mall	accessibility	network
41	1996	32 neue haltestellen	bus stop program	accessibility	network
47	1999	New Line (Aerobus Service)	connection airport	accessibility	network
48	2000	anschluss an neue siedlungsgebiete	connection periphery	accessibility	network
49	2001	Inauguration of Bom Sucesso's Bus Terminal;	new station (interchange) (Bom Sucesso)	accessibility	network
57	2005	new hub	new station (interchange)	accessibility	network
62	2010	anbindung siedlungsgebiet	connection periphery	accessibility	network
63	2010	anpassung an haltestellwünsche	bus stop program	accessibility	network
64	2010	anbindung krankenhaus	connection hospital	accessibility	network
66	2011	bus stop location program hospital	bus stop program	accessibility	network
67	2011	anbindung flughafen nachts	connection airport at night	accessibility	network
10	1964	night lines	introduction nightlines	other innovations	network
11	1965	network innovation	network innovation	other innovations	network
12	1965	New network for trolley-cars	new product (trolley cars)	other innovations	network
15	1966	New lines (early morning)	new lines (early morning)	other innovations	network
17	1969	Removal of rails	removal of rails	other innovations	network
23	1977	neues nachtnetz	introduction of new night network	other innovations	network
26	1980	Reduction of the Electric Tram Network	bus replaces tram	other innovations	network
27	1980	New Line (Campanhã Train Station - Airport)	connection airport	other innovations	network
31	1983	Network innovation	network innovation	other innovations	network
32	1985	New Night Lines	upgrade night network	other innovations	network
34	1988	night lines	upgrad night network	other innovations	network
37	1992	schnellbuslinien	express lines	other innovations	network
39	1996	closure of bus stops (82)	closure of bus stops (82)	other innovations	network
40	1996	night lines	upgrade night network	other innovations	network
43	1997	Closure of a Station	closure of a station	other innovations	network
46	1998	Re-establishment of the electric car network	remodelling network due to tram revival	other innovations	network
50	2001	Tram zurück	full revival tram	other innovations	network
53	2003	weihnachtslinie	dedicates Xmas line	other innovations	network
54	2003	mininetz low floor only (elderly people)	network innovation (mini-low floor network only for elderly people)	other innovations	network
56	2005	neues nacht netz nova rede	upgrade night network (nova rede)	other innovations	network
60	2006	ausbau social linien	extension social lines	other innovations	network
65	2011	neues nacht netz	upgrade night network	other innovations	network
1	1950	Kreuzung (netz)	improvement of nods	(re)organization	network
3	1953	network change	remodelling entire network	(re)organization	network
4	1956	änderung verkehrsführung (gut)	remodelling traffic routing in favour for PT	(re)organization	network
5	1960	Railway network reorganisation	remodelling due to competition (train)	(re)organization	network
6	1960	restrukturierung SB Netz	remodelling tram network	(re)organization	network
7	1961	Electric network reorganisation	remodelling power provision network	(re)organization	network
16	1968	Network change	remodelling entire network	(re)organization	network
18	1969	änderung verkehrsführung	remodelling traffic routing in favour for PT	(re)organization	network
19	1970	Bus Network Changes	remodelling bus network	(re)organization	network
20	1972	änderung verkehrsführung	remodelling traffic routing in favour for PT	(re)organization	network
22	1977	Network changes	remodelling entire network	(re)organization	network
45	1998	Modification of Lines	remodelling lines	(re)organization	network
44	1998	wiederbelebung tram	revivial tram network	(re)organization	network
51	2002	integriertes netz	integrated network	(re)organization	network
52	2003	start intermodal system	intermodal network	(re)organization	network
55	2004	network restrukturing	remodelling entire network	(re)organization	network
58	2005	nova rede 1. phase	new network (nove rede)	(re)organization	network
59	2006	nove rede II	new network (nove rede)	(re)organization	network
61	2007	nova rede 24h complet	new network (nove rede) 24h	(re)organization	network

DRESDEN

Table A8: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1961	spike	spike (connection periphery)	accessibility	network
2	1962	spike	spike (connection periphery)	accessibility	network
3	1965	spike	spike (connection periphery)	accessibility	network
4	1969	Verbindung der Industrie und Einwohnerzentren	connection industry - periphery	accessibility	network
6	1972	spike	spike (connection periphery)	accessibility	network
7	1976	Anbindung an Wohngebiete Li 16/26	connection periphery	accessibility	network
8	1977	spike	spike (connection periphery)	accessibility	network
10	1980	spike	spike (connection periphery)	accessibility	network
11	1982	neue Straßenbahntrasse nach Prohlis	connection periphery (Prohlis)	accessibility	network
12	1984	Verkehrserschließung Gorbitz	connection periphery (Gorbitz)	accessibility	network
14	1986	Anbindung Neubaugebiet Reick durch Haltestelle	connection periphery (Reick)	accessibility	network
15	1987	weiterer Ausbau Gorbitz	connection periphery (Gorbitz)	accessibility	network
16	1988	Gleisschleife Gorbitz = Linienänderung = neubaugebiet erschlossen	connection periphery (Gorbitz)	accessibility	network

24	1998	0. Juni 1999 die Neubaustrecke von Plauen nach Coschütz in Betrieb genommen werden	connection periphery (Plauen)	accessibility	network
26	2000	Rangebiete/Neueingemeindungen erschlöossen	connection periphery (Plauen)	accessibility	network
27	2002	neue Zentralhaltestellen	new station (interchange)	accessibility	network
28	2003	Linie 74: Krankenhaus	connection hospital	accessibility	network
29	2003	Elbepark	connection shopping mall	accessibility	network
30	2008	Anbindung Peripherie	connection periphery	accessibility	network
31	2009	Linie 85. Sie erschließt erstmals den südlichen Rand des TU-Geländes.	connection university	accessibility	network
32	2010	Leistungsfähigkeit des Knotenpunktes aus ÖPNV-Sicht am Pirnaischen Platz	new hub (Pirnaischer Platz)	accessibility	network
33	2011	verbessertes Nahverkehrsangebot im Schönfelder Hochland am östlichen Stadtrand: PERIPHERIE; dünnbesiedelte gebiete	connection periphery (Schönfelder Hochland)	accessibility	network
18	1990	spike	spike (network reduction, remodelling)	other innovations	network
19	1991	spike	spike (network reduction, remodelling)	other innovations	network
20	1992	spike	spike (network reduction, remodelling)	other innovations	network
21	1993	spike	spike (network reduction, remodelling)	other innovations	network
5	1969	neues Liniennetz: Zentrumsoirnetierung, Direktanschlüsse an Stadtmitte, Anbindung Peripherie, (Linie 11)	remodelling	(re)organization	network
9	1978	Optimierung: Neubau und Stadtmitte	remodelling	(re)organization	network
17	1989	Optimierung: Verbesserung Endpunktverküpfungen	remodelling	(re)organization	network
22	1995	Liniennmetzumstellung (=Kosteneinsparung - Abschöpfung Fahrgastpotential, Fahrzeugeinsatz anhand Topgraphie)	remodelling	(re)organization	network
23	1998	ÖV Konzept Plauen	remodelling (Plauen)	(re)organization	network
25	2000	Liniennetzumstellung, 23km neues Streckennetz: Linie 2000	remodelling	(re)organization	network
34	2013	Eröffnung der Waldschlößchenbrücke	connetion periphery (new bridge)	(re)organization	network

Fleet Decisions

HAMBURG

Table A9: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	FZ Typ V 6 neu, V7	vehicle type V6 + V7	fleet upgrade	fleet
2	1951	Großraumwagen - mehr platz	high capacity cars	fleet upgrade	fleet
3	1951	Einführung Typ V7	vehicle type V7	fleet upgrade	fleet
5	1952	2 GRW=3 alte Wagen	high capacity cars	fleet upgrade	fleet
8	1953	Obus=doppelgeschossig	double decker - trolley bus	fleet upgrade	fleet
6	1953	Ausbau Großraumwagenprogramm (Strba, Bus)	high capacity cars	fleet upgrade	fleet
9	1954	Großraumbusse	high capacity buses	fleet upgrade	fleet
13	1965	B: neue schnellbusserie	express buses	fleet upgrade	fleet
16	1968	Einsatz VÖV Standard Lininebus	vehicle type "VÖV Standard Lininebus"	fleet upgrade	fleet
15	1968	U: DT 3- Bahn	vehicle type DT 3	fleet upgrade	fleet
17	1971	neuer IKARUS Standarlininenbus	vehicle type "IKARUS Standarlininenbus"	fleet upgrade	fleet
18	1972	neuer Bustyp: urbanbus	vehicle type "Urbanbus"	fleet upgrade	fleet
22	1976	SB alle Beiwagen raus, nur noch triebwagen	rail cars only (no trailers)	fleet upgrade	fleet
23	1977	B: alle Typen O305	vehicle type (O305)	fleet upgrade	fleet
24	1977	Einführung Flüsterbusse	whisper engines	fleet upgrade	fleet
29	1979	B: neue Schulbusse	school bus upgrade	fleet upgrade	fleet
28	1979	Gelenkbus O305 G (35), Niederflurbus	vehicle type (O305 G), low floor, articulated	fleet upgrade	fleet
30	1980	Umweltfreundlich bus 891/918	environmentally friendly vehicle type 891/918	fleet upgrade	fleet
32	1982	B: Einsatz von Gelenkbusen,	articulated buses	fleet upgrade	fleet
35	1984	B: neue Busflotte Stadtlininenbus II	new urban bus (Stadtlinienbus)	fleet upgrade	fleet
38	1987	B: 4 Stadtlinien auf Gelenkbusse	articulated buses	fleet upgrade	fleet
37	1987	Typ DT4	vehicle type DT 4	fleet upgrade	fleet
40	1988	Gelenkbusse=seatkm hoch	articulated buses	fleet upgrade	fleet
43	1991	S: niederflurbusse,	low floor buses	fleet upgrade	fleet
50	1997	Citaro Stadtbusse (neue Geneartion Busse)	new urban bus (Citaro, next generation)	fleet upgrade	fleet
51	2001	Kleinbus	minibuses	fleet upgrade	fleet
52	2002	DT4.5 und	vehicle type DT 4.5	fleet upgrade	fleet
53	2002	DT4.6	vehicle type DT 4.6	fleet upgrade	fleet
55	2003	Doppelgelenkbusse	bi-articulated buses	fleet upgrade	fleet
54	2003	3 schadstofffreie Busse (Wasserstoff)	hydrogen buses	fleet upgrade	fleet
56	2004	Doppelgelenkbus van hool	bi-articulated buses	fleet upgrade	fleet
57	2004	Dauereinsatz Wasserstoffbusse	hydrogen buses	fleet upgrade	fleet
58	2005	XXL Busse regulär	bi-articulated buses	fleet upgrade	fleet
59	2005	6 weitere Wasserstofffahrtzzeuge	hydrogen buses	fleet upgrade	fleet
60	2005	Bus: Midi Busse in dicht besiedelten Wohngebieten, Ein - Aus an jeder Stelle	midi buses	fleet upgrade	fleet
62	2007	wasserstoff schiff	hydrogen ship	fleet upgrade	fleet
65	2008	Reduzierung E-Bus	e-bus reduction	fleet upgrade	fleet
67	2010	neue Brennstoffzellenbusse	hydrogen buses	fleet upgrade	fleet
68	2011	Dieselhypridbusse im Linienbetrieb: nur 16% Treibstoffersparnis	diesel-hyprid buses	fleet upgrade	fleet
69	2011	Brenstoffzellenhypridbusse: 50% Ersparnis	diesel-hyprid buses	fleet upgrade	fleet
70	2012	DT5 Linie	type DT 5	fleet upgrade	fleet
71	2013	ausbau hypridflotte	diesel-hyprid buses	fleet upgrade	fleet
4	1951	Schiff: dieselelektrischer Antrieb	diesel electric engines	technology upgrade	fleet
7	1953	neue Motoren U-bahn = höhere Geschwindigkeit	propulsion upgrade	technology upgrade	fleet
10	1955	Sicherheitsglas bei Bussen	safety glass	technology upgrade	fleet
11	1958	Fahrkomfort Ubahn: federung	suspension upgrade	technology upgrade	fleet
12	1960	U: Test Doppelwagen = 20% weniger Gewicht, wenigre Strom, vollelektrische Bremse	double carts	technology upgrade	fleet
14	1966	Busdesign (energy)	bus desing ugbrade	technology upgrade	fleet
19	1973	gestiegen Anforderungen an Umweltschutz an Flotte	improvement of environmental performance	technology upgrade	fleet
20	1974	B: automatik, gekapselter Motor (Kraftstoffsparend + gedämmt)	automative gearbox, insulated engines	technology upgrade	fleet
21	1975	Flotte: Sparsamkeit	environmental improvements	technology upgrade	fleet
25	1978	Entwicklung Drehstromantrieb (techn./wirt Vorteile)	three-phase drive	technology upgrade	fleet
26	1978	Geräuschminimierung	improvement of environmental performance	technology upgrade	fleet
27	1979	Geräuschminimierunt	improvement of environmental performance	technology upgrade	fleet
31	1982	Selbstfahrende Züge, Test	driverless underground (test)	technology upgrade	fleet
33	1983	U: Anpassung Platzangebot	high capacity trailers	technology upgrade	fleet

34	1984	Geräuschdämpfung	improvement of environmental performance	technology upgrade	fleet
36	1986	Bus: Verwendung Leichtlauföle = Verlängerung Wechselintervall	low-friction oil	technology upgrade	fleet
39	1987	Erhöhung Generalüberholungsintervall durch Erhöhung Wartung und Schwachstellenanalyse = Schdenrückgang 12%	upgrade maintenance interval	technology upgrade	fleet
41	1990	Rußpartikelfilter 10 Busse,	soot particle filters	technology upgrade	fleet
42	1991	Umwelt: schwefelarmer Dieselkraftstoff = EURO II	EURO 2 standard	technology upgrade	fleet
44	1993	neue Standards Abgasuntersuchung	new exhaust evaluation standards	technology upgrade	fleet
45	1993	Umweltfokus flotte	improvement of environmental performance	technology upgrade	fleet
46	1994	Umweltmaßnahme	improvement of environmental performance	technology upgrade	fleet
47	1995	U: Ausbau Telematik	telematics	technology upgrade	fleet
48	1995	Umweltmaßnahme	improvement of environmental performance	technology upgrade	fleet
49	1996	Umwelt: Stromeinsparung U,, senkung Kraftstoffverbrauch (41,6 auf 40,9 l/100km in 4 Jahren, Reduzierung Emmissionen, programm kommunale Agenda 21	improvement of environmental performance	technology upgrade	fleet
61	2006	EURO 5 Norm ausbau	EURO 5 standard	technology upgrade	fleet
63	2007	Emmisionsarme Dieselmotoren	low-emission Diesel engines	technology upgrade	fleet
64	2007	U: 28% Fahrleistung nur 6% Steigerung Stromverbrauch	improvement of environmental performance	technology upgrade	fleet
66	2008	Umweltmaßnahme	improvement of environmental performance	technology upgrade	fleet

PORTO

Table A10: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1956	Auschreibung Trolleybos Installation	trolley bus preparations	fleet upgrade	fleet
2	1959	Growth in bus use	bus fleet upgrade	fleet upgrade	fleet
3	1959	introduction trolleybus	trolleybus introduction	fleet upgrade	fleet
5	1962	Doppeldecker	double decker buses	fleet upgrade	fleet
6	1962	Ambulanzfahrzeug	ambulance vehicle	fleet upgrade	fleet
7	1967	Fleet changes	bus fleet upgrade	fleet upgrade	fleet
8	1983	Fleet Redistribution (for night service)	bus fleet upgrade (set up for night service)	fleet upgrade	fleet
9	1983	articulated buses	articulated buses	fleet upgrade	fleet
10	1984	ausbau articulates buses	articulated buses	fleet upgrade	fleet
11	1987	Electric Car Fleet Reduction (40%)	electric car fleet reduction (40%)	fleet upgrade	fleet
12	1989	Leyland Fleet Elimination	Leyland fleet elimination	fleet upgrade	fleet
13	1990	New Fleet (for disabled people)	upgrade fleet (accessible)	fleet upgrade	fleet
15	1992	GLP inroduction	GLP introduction	fleet upgrade	fleet
16	1992	hyprid introduction	Hyprid introduction	fleet upgrade	fleet
18	1993	Electric Car Fleet Elimination	electric car fleet elimination	fleet upgrade	fleet
20	1995	Trolley Cars Fleet Elimination	trolleybus elimination	fleet upgrade	fleet
21	1995	New Fleet (mini)	mini buses	fleet upgrade	fleet
22	1999	Experimental Natural Gas Fleet	LPG test	fleet upgrade	fleet
23	1999	GLP in action	LPG introduction	fleet upgrade	fleet
25	2000	Increase of Natural Gas Fleet (conversion of 75 buses)	LPG buses	fleet upgrade	fleet
27	2001	Increase of Natural Gas Fleet	LPG buses	fleet upgrade	fleet
28	2001	ausbau GLP	LPG buses	fleet upgrade	fleet
30	2004	hydrogen bus	Hydrogen buses	fleet upgrade	fleet
32	2006	betankung von erdgastaxis	LPG taxis	fleet upgrade	fleet
33	2006	ausbau CNG	CNG buses	fleet upgrade	fleet
4	1960	mehr plätze	capacity increase	technology upgrade	fleet
14	1991	Access	accessible fleet	technology upgrade	fleet
17	1992	Access	accessible fleet	technology upgrade	fleet
19	1993	Access	accessible fleet	technology upgrade	fleet
24	1999	EUR2 Norm	EURO 2 standard	technology upgrade	fleet
26	2000	EUR2 Norm	EURO 2 standard	technology upgrade	fleet
29	2001	EUR2 Norm	EURO 2 standard	technology upgrade	fleet
31	2006	neue oberleitungstechnology tram	catenary upgrade	technology upgrade	fleet

DRESDEN

Table A11: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1957	Auslieferung der Gotha-Einheitsstraßenbahnwagen vom Typ ET57	vehicle type ET57	fleet upgrade	fleet
2	1957	Ikarus-Bus vom Typ 60	vehicle type "Ikarus 60"	fleet upgrade	fleet
4	1959	Ikarus 66	vehicle type "Ikarus 66"	fleet upgrade	fleet
5	1961	Die ersten neuen Busse aus Ungarn vom Typ Ikarus 30	vehicle type "Ikarus 30"	fleet upgrade	fleet
6	1962	Modern: Großraumzüge (Triebwagen und Beiwagen) des Typs T4-62	vehicle type "T4-62"	fleet upgrade	fleet
7	1962	Skoda 706 RO, der Ikarus 60 und aus der eigenen Fahrzeugindustrie der IFA H6B	vehicle type "Skoda 706 RO"	fleet upgrade	fleet
8	1963	Modern Großraumzüge (Triebwagen und Beiwagen) des Typs T4-62	vehicle type "T4-62"	fleet upgrade	fleet
9	1964	Ikarus Typ 630	vehicle type "Ikarus 630"	fleet upgrade	fleet
10	1967	Typs 180	vehicle type "Type 180"	fleet upgrade	fleet
11	1968	neue Straßenbahnwagenb	trailer upgrade	fleet upgrade	fleet
12	1968	Ikarus 180	vehicle type "Ikarus 180"	fleet upgrade	fleet
13	1969	Start: neuer Straßenbahntyp T4D (Anfangs Einführungsprobleme)	vehicle type "T4D"	fleet upgrade	fleet
14	1970	Ausweitung Furhpark StrabA auf T4D B4D + 84	vehicle type "T4D" and "B4D"	fleet upgrade	fleet
15	1971	analogen Zweiachser vom Typ 556	vehicle type "Ikarus 556"	fleet upgrade	fleet
16	1972	Ausweitung Furhpark StrabA auf T4D B4D +87+17	vehicle type "T4D" and "B4D"	fleet upgrade	fleet
18	1973	200er Reihe	vehicle type "Ikarus 200"	fleet upgrade	fleet
19	1975	Types IKARUS 280	vehicle type "Ikarus 280"	fleet upgrade	fleet
24	1986	neuer Fahrzeugtyp, Erprobung: T6A2	vehicle type "T6A2"	fleet upgrade	fleet
25	1989	Typs 260.02	vehicle type "Ikarus 260.02"	fleet upgrade	fleet
26	1990	Mercedes-Benz O 305	vehicle type "Mercedes Benz O305"	fleet upgrade	fleet
27	1991	Typ T4D-M	vehicle type "T4D-M"	fleet upgrade	fleet
28	1993	moderniz: 11% neue Straba	vehicle type "T4D-M"	fleet upgrade	fleet
29	1993	Busse: Ikarus gegen MAN/Mercedes	vehicle type "Mercedes Benz O305+MAN"	fleet upgrade	fleet
30	1993	Flotte: 53 neue Busse	vehicle type "Mercedes Benz O305+MAN"	fleet upgrade	fleet
31	1994	Flotte: +99 Strababeiw, +13 NFL B	vehicle type "T4D-M"	fleet upgrade	fleet
33	1995	erste NF Straba NGT6DD (2501)	vehicle type "NGT6DD" (low-floor)	fleet upgrade	fleet

34	1995	55 Triebwagen zu Triebbeiwagen (TB4D)	vehicle type "T4D-M"	fleet upgrade	fleet
36	1997	Ausbau Flotte (weniger Verbrauch/Unterhalt)	improvement of environmental performance	fleet upgrade	fleet
38	1999	60m Straba	60 m tram	fleet upgrade	fleet
39	2001	NGT 8 Einführung	vehicle type "NGT8" (low-floor)	fleet upgrade	fleet
40	2003	Flotte: NGT 12 = 45 m	vehicle type "NGT12"	fleet upgrade	fleet
41	2003	4 türige Busse Solaris und MB	vehicle type "Solaris Urbino + MAN" (4 doors)	fleet upgrade	fleet
43	2009	Citaro O 530 G des Herstellers EVO: -5% Verbrauch	vehicle type "O530G"	fleet upgrade	fleet
44	2010	Zweiter Hybridbus für Dresden	hyprid buses	fleet upgrade	fleet
45	2011	18 hybridbusse: Hybrid-Fahrzeuge fahren dort, wo sie den größtmöglichen Nutzen für die Dresdner Luft stiften. Die Gelenkbusse werden auf den nachfragestarken 60er-Linien, vor allem auch in der Innenstadt, eingesetzt	hyprid buses	fleet upgrade	fleet
3	1958	Verstärkung Kontrolle durch Meister	mainten	technology upgrade	fleet
17	1972	Instandhaltungszyklen Tatra verbessern	upgrade maintenance interval	technology upgrade	fleet
20	1984	Einführung: Zweirichtungswagen	upgrade maintenance interval (Tatra)	technology upgrade	fleet
21	1984	Instandhaltungstechnogien: Verbesserung	upgrade maintenance technology	technology upgrade	fleet
22	1985	Wendegroßzüge	push-pull train technology	technology upgrade	fleet
23	1986	Generalreparatur der Hauptachsen	upgrade main axes	technology upgrade	fleet
32	1994	Modernisierung: Thyristorsteuerung (TV8)	upgrade to thyristor control	technology upgrade	fleet
35	1996	90 modernisierte Triebwagen der ersten Serie ebenfalls eine Thyristorsteuerung	upgrade to thyristor control	technology upgrade	fleet
37	1997	90 modernisierte Triebwagen der ersten Serie ebenfalls eine Thyristorsteuerung	upgrade to thyristor control	technology upgrade	fleet
42	2007	Bus: EURO5/EEV Norm	EURO 5 standard	technology upgrade	fleet
46	2011	Neue Messanlage erkennt unrunde Räder	upgrade maintenance technology	technology upgrade	fleet
47	2012	Im Luftreinhalteplan der Landeshauptstadt Dresden ist das Ziel formuliert, dass bis 2012 mindestens 69 Prozent aller DVB-Busse die grüne Plakette tragen. Dieses Ziel konnten wir mit 68 Prozent nicht ganz erfüllen.	improvement of environmental performance	technology upgrade	fleet

Personnel Decisions

HAMBURG

Table A12: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
7	1954	Lohn/Gehaltserhöhungen + 4,5%	salary increase	incentives	personnel
10	1956	Weihnachtszuwendung	christmas bonus	incentives	personnel
12	1957	45h Woche (von 48 gesenkt) - Manteltarifvertrag	work time reduction (48 to 45)	incentives	personnel
13	1957	Manteltarifvertrag	framework agreement on employment conditions	incentives	personnel
15	1959	Gehaltserhöhung +7,5%	salary increase	incentives	personnel
24	1965	9% Lohnerhöhung	salary increase	incentives	personnel
26	1966	4% Lohnerhöhung	salary increase	incentives	personnel
28	1973	Lohn-Gehalterhöhung	salary increase	incentives	personnel
29	1973	Erhöhung Ulraubsgeld	holiday bonus increase	incentives	personnel
30	1973	Urlaubszeit	increase vactation time	incentives	personnel
31	1973	Zuschläge Sonn, Nachtschicht, Feiertag	dedicated bonuses for overtime	incentives	personnel
32	1974	40 Stundenwoche	work time reduction (45 to 40)	incentives	personnel
33	1975	vermögenswirksame Leistung 26 €/Monat	capital-forming benefits	incentives	personnel
34	1975	Verbesserung Arbeitsbedingungen	improved working conditions	incentives	personnel
35	1975	Lohnerhöhun 5%	salary increase	incentives	personnel
37	1978	Lohnerhöhung+5,4%	salary increase	incentives	personnel
39	1980	Lohnerhöhung 6,5%	salary increase	incentives	personnel
41	1981	Lohnerhöhung 7,2%	salary increase	incentives	personnel
42	1983	Lohnerhöhung 4,5	salary increase	incentives	personnel
43	1984	Lohnerhöhung 5,7	salary increase	incentives	personnel
46	1985	Lohn+ 2,5%	salary increase	incentives	personnel
48	1986	38h Woche	work time reduction (40 to 38)	incentives	personnel
49	1986	4,5% Lohnsteigerung	salary increase	incentives	personnel
71	1996	bezahlte pausen	salary increase (paid break time)	incentives	personnel
75	1996	präsenzprämie VS	bonus for minimal sick days	incentives	personnel
76	1997	Arbeitszeitflexibilisierung Verwaltung	flexible work time (administration)	incentives	personnel
77	1998	neuer Tarifvertrag: Leistungorientierte Vergütung	performance bonuses	incentives	personnel
79	1998	(Teamorientiertes Prämiensystem)	performance bonuses	incentives	personnel
81	1999	Arbeitszeitflexibilisierung	flexible work time	incentives	personnel
86	2001	Sportzentrum MA	sport centre for employees	incentives	personnel
91	2003	Ausschlussb betriebsbedingter Kündigungen	elimination of termination of employment for operational reasons	incentives	personnel
92	2003	Absicheruungsmaßnahmen Personal	insurances for employees	incentives	personnel
93	2004	Führungskräfteprogramm	incentivation of executives	incentives	personnel
97	2006	neues vergütungssystem	new payment systems	incentives	personnel
98	2006	Ausbau Weiterbildungsangebot	increased range of training and qualification measures for employees	incentives	personnel
99	2006	Ausbau Ausbildung un Studium	increased range of training and qualification measures for employees	incentives	personnel
102	2007	Allienaz 50 plus Engagement	programs for elder staff	incentives	personnel
103	2007	Program Freizeit plus (Seminare, Weiterbildung, PC Führerschein)	increased range of training and qualification measures for employees	incentives	personnel
104	2008	Tarifvertrag +1,3 %	salary increase	incentives	personnel
108	2010	Anpassung Personalstrategie Familie&Beruf,	job and family programs	incentives	personnel
109	2010	Frauenförderun	promotion of femal worker program	incentives	personnel
113	2013	fahrgastpreis für MA	employee of the month/year	incentives	personnel
114	2013	neuer Tarifvertrag	salary increase	incentives	personnel
40	1980	Schulungen Personal im Umgang mit Kunden	service training (general)	training	personnel
44	1984	Kundendienstschulung Busfahrer	service training drivers	training	personnel
45	1984	Fahrerschulung	service training drivers	training	personnel
47	1985	Busfahrer: Kundendienstschulung	service training drivers	training	personnel
50	1986	Kundendienstschulung	service training (general)	training	personnel
55	1989	Kundendiesntschulung	service training (general)	training	personnel
65	1992	Weiterbildung	postgraduate training	training	personnel
66	1993	Kundendienstschulung für Busfahrer	service training drivers	training	personnel
78	1998	Aus- und Weiterbildung Schwerpunkt EDV^, Computer-based Training, Simualtoren (Betriebsabläufe)	postgraduate IT training	training	personnel

83	1999	Schulung	postgraduate training	training	personnel
87	2001	Schulung Kundenorientierung	service training (general)	training	personnel
89	2002	Deseskalationstraining	deescalation training	training	personnel
90	2003	Kundendienstschulung	service training (general)	training	personnel
107	2009	Ecodriving Busfahrer Weiterbildung	ecodriving training	training	personnel
111	2013	führungskräftekonferenz/schulung	executive training	training	personnel
116	2013	Fokus ausbildung	enforced vocational training programs	training	personnel
1	1950	orga wegen Einmannbetrieb (B,C,E)	reorganization due to single agent/ one man operation policy	other	personnel
2	1951	orga wegen Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
3	1952	orga wegen Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
4	1953	Einbau von Abgangssperren=Abbau von Kontrollpersonal = Orga	reorganization due to turnstiles implementation	other	personnel
5	1953	orga wegen Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
6	1954	B: Orga Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
8	1955	B: orga wegen Einmannbetrieb bis auf 4 Linien	reorganization due to single agent/ one man operation policy	other	personnel
9	1956	B:orga wegen 2 weitere Linien Einmannbetrieb (noch 3 bleiben)	reorganization due to single agent/ one man operation policy	other	personnel
11	1956	Ausdehnung Schicht im Gelegenheitsverkehr	extension of shifts	other	personnel
14	1958	B: orga wegen Einmannbetrieb (41,44)	reorganization due to single agent/ one man operation policy	other	personnel
16	1959	Orga wegen Rationalisierung in Werkstätten, Optimierung der Abläufe Verwaltung= setzt Personal frei	reorganization due to rationalisation in various departments	other	personnel
17	1959	Orga wegen U: Zugabfertigungen nach Bildschirm, bei gekrümmten Bahnhöfen Personaleinsparungen	reorganization due to automatic train despatching	other	personnel
18	1959	Orga wegen B: Einmannbetrieb (41,44)	reorganization due to single agent/ one man operation policy	other	personnel
19	1960	Orga U: Ultraschallgerät zur Schienenprüfung = Einsparung Streckenläufer	reorganization due to automatic rail inspection	other	personnel
20	1960	Orga B: Standschaffner Wiedereinführung zu Peak	reintroduction of conductor during peak	other	personnel
21	1960	Orga B: Einmannbedienung abgeschlossen	reorganization due to single agent/ one man operation policy	other	personnel
22	1964	SB: Orga wegen Einmannbetrieb, Test: Triebwagen ohne Schaffner = Zeitkarten, Beiwagen mit Schaffner	reorganization due to single agent/ one man operation policy	other	personnel
23	1965	S: Orga wegen Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
25	1966	Orga Einmannbetrieb Straba	reorganization due to single agent/ one man operation policy	other	personnel
27	1967	SB: Orga letze Linien auf Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
36	1977	Schiffe: Orga Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
38	1980	Frauen als Fahrerinnen	female employees = drivers	other	personnel
51	1986	Fahrgastbetreuer eingestellt	customer service employee	other	personnel
52	1986	Zugbegleiter für Sicherheitsgefühl	partial reintroduction of conductors (security)	other	personnel
53	1988	Orga: Streichen Haltestellenwärter	dismissal of station masters	other	personnel
54	1988	Orga: Abzug ständige Besetzung Reserve,	dismissal of reserve pool staff	other	personnel
56	1990	Kosten: Studenten zur Fahrkartenprüfung,	student = ticket inspectors	other	personnel
57	1990	Orga wegen HS ohne stationäres Personal	reorganization du dismissal of station masters	other	personnel
58	1990	Arbeitskreis Gesundkeit um Krankenstand niedrig zu halten: ernährung, Bewegung, richtiges Sitze etc	focus: staff health	other	personnel
59	1991	Reduzierung Zugfahrermehrbedarf	dismissal of reserve pool drivers	other	personnel
60	1991	Vorbeotungs- Abschußzeiten nicht mehr Dienstzeit,	preparation and break time no long paid	other	personnel
61	1991	Zugfahrerselbstabfertigung Ausbau	reorganisation due automatic train despatchment (dismissal of workers)	other	personnel
62	1992	Mitarbeiterbefragung	employee surveys	other	personnel
63	1992	Einführung Personalgespräche	appraisal interview	other	personnel
64	1992	Konzept: Gruppenstruktur im Fahrdienst	restructuring drivers (group model)	other	personnel
67	1994	Ausbau: Gruppenmodell Fahrer	restructuring drivers (group model)	other	personnel
68	1994	Zugselbtabfertigung	reorganisation due automatic train despatchment (dismissal of workers)	other	personnel
69	1995	200 Ma in Qualitätsgruppen mit Anreizen	quality/staff performance tracking (group model)	other	personnel
70	1996	Tarifervertrag: Besserstellung HHA (wettberwrbsfähigkeit)	labour aggreement in favour for HHA	other	personnel
72	1996	Erhöhung Arbeitszeit +1,5 pro Woche	increase work time	other	personnel
73	1996	Streichung Zulagen	cut in benefits	other	personnel
74	1996	neuverträge verdiene weniger	less salary for newly contracted staff	other	personnel
80	1999	neuer Tarifvertrag: Bus: Besserstellung HHA, wegen Wettbewerbsfähig	labour aggreement in favour for HHA	other	personnel
82	1999	Aushänge von Firmenposts	internal communciation	other	personnel
84	2000	Traineeprogram	trainee position	other	personnel
85	2000	Tarifabschluss (+1,2% = Besserstellung HHA)	labour aggreement in favour for HHA	other	personnel
88	2002	Mitarbeiterbefragung (über Unternehmen , Wettbewerb, Strategi, etc)	employee surveys	other	personnel
94	2004	neues Beurteilungssystem	staff performance assessment	other	personnel
95	2004	Verstärkte Ausbildung (Azubis, Studenten)	enforced vocational training programs	other	personnel
96	2005	MA Vollbefragung	employee surveys	other	personnel
100	2006	Kampagne zum Arbeitsalltag des Busfahrers = Akquise gutes Personal	information campaign to attract drivers	other	personnel
101	2006	Rückgang Arbeitunfälle /durch ausbildung)	safety training to reduce work accidents	other	personnel
105	2009	online MA Portal	internal communciation (staff portal)	other	personnel
106	2009	neues Ideenmanagement	ideas management	other	personnel
110	2010	Gesundheitsförderung	focus: staff health	other	personnel

PORTO

Table A13: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
2	1951	, sitzplätze fahrer, kontrolleur	improved working conditions (driver and conductors)	incentives	personnel
8	1957	New dining-hall	improved working conditions (facilities)	incentives	personnel
9	1959	Salary increase	salary increase	incentives	personnel
11	1960	Lohn +	salary increase	incentives	personnel
15	1961	umkleide personal	improved working conditions (facilities)	incentives	personnel
16	1961	Lohn +	salary increase	incentives	personnel
17	1962	Transport services and privileges	transport services and privileges for staff	incentives	personnel
18	1962	salary increase	salary increase	incentives	personnel
19	1962	premium	bonuses	incentives	personnel
20	1962	holiday	increased number of vacation days	incentives	personnel
21	1962	paid holidays	paid holidays	incentives	personnel
23	1964	warteraum	improved working conditions (facilities)	incentives	personnel
24	1965	Salaries readjustment	salary increase	incentives	personnel
25	1966	Lohn+	salary increase	incentives	personnel
26	1967	lohn+	salary increase	incentives	personnel
28	1968	lohn +	salary increase	incentives	personnel
30	1969	pension payments	pension payments	incentives	personnel
31	1969	lohn+	salary increase	incentives	personnel
34	1971	lohn+	salary increase	incentives	personnel
35	1972	Supplementary allowances	bonuses	incentives	personnel
40	1975	Salary Increase	salary increase	incentives	personnel
41	1975	New privileges	transport services and privileges for staff	incentives	personnel
46	1977	Lohn+	salary increase	incentives	personnel
54	1979	personaltarif	transport services and privileges for staff	incentives	personnel
67	1983	ventilatoren	improved working conditions (facilities)	incentives	personnel
72	1984	Lohn+	salary increase	incentives	personnel
89	1991	reduzierung wochenarbeitszeiz 45 auf 43	work time reduction (45 to 43)	incentives	personnel
96	1994	rewar for best driver	driver of the month/year award	incentives	personnel
97	1994	incentives aufstieg/leistungsbezogen	performance oriented payment	incentives	personnel
98	1995	Reduced Work Time (42 hours per week)	work time reduction (43 to 42)	incentives	personnel
99	1995	incentive aufstieg	carreer options	incentives	personnel
100	1996	Reduced Work Time (40 hours per week)	work time reduction (42 to 40)	incentives	personnel
103	1996	aufstiegsincentives	carreer options	incentives	personnel
104	1997	40h woche (complete)	work time reduction (42 to 40) complete	incentives	personnel
107	1998	Establishment of pension funds	establishment of pension funds	incentives	personnel
108	1998	better operation conditions for workers	improved working conditions (operations)	incentives	personnel
109	1998	work comfort ++	improved working conditions	incentives	personnel
113	1999	Reduction of overtime work	reduction of overtime work	incentives	personnel
114	1999	working condtions improved	improved working conditions	incentives	personnel
115	1999	sportangebote staff	sport facilities staff	incentives	personnel
116	1999	anlage für urlaub	holiday facilities staff	incentives	personnel
117	1999	pension fonds	upgrade pension funds	incentives	personnel
118	1999	boni	bonuses	incentives	personnel
127	2006	bester fahrer auszeichnung	driver of the month/year award	incentives	personnel
129	2006	verbesserung arbeitsbedingungen	improved working conditions (operations)	incentives	personnel
134	2007	verbesserung Arbeitsbedingungen	improved working conditions (operations)	incentives	personnel
135	2007	MA tickets	transport services and privileges for staff	incentives	personnel
139	2008	verbesserung der Arbeitsbedingungen	improved working conditions	incentives	personnel
140	2008	MA tickets	transport services and privileges for staff	incentives	personnel
142	2008	MA Sportzentrum	sport facilities staff	incentives	personnel
143	2009	MA (Fahrer) auszeichnung	driver of the month/year award	incentives	personnel
144	2009	würdigung langzeit Arbeiter	award for long term employees	incentives	personnel
146	2009	belohnung d leistung	performance oriented payment	incentives	personnel
149	2010	auszeichnung fahrer	driver of the month/year award	incentives	personnel
152	2010	effective drinving bonus	effective driving bonus	incentives	personnel
156	2011	job und familie	work and family program	incentives	personnel
160	2012	auszeichnung langjährige MA	award for long term employees	incentives	personnel
163	2013	salary	salary increase	incentives	personnel
165	2013	auszeichnung bester faher	driver of the month/year award	incentives	personnel
167	2013	out of office day (incentive)	out of office day	incentives	personnel
1	1951	training	training	training	personnel
3	1953	training service	service training	training	personnel
4	1976	fokus formacao	training	training	personnel
5	1978	training	training	training	personnel
6	1978	training staff	training	training	personnel
7	1979	traing fahrer	training driver	training	personnel
10	1979	fahrtraing	training driver	training	personnel
13	1980	training für manager	executive training	training	personnel
14	1981	training	training	training	personnel
27	1991	training personal neue technologien = zusammenarbeit mit uni	IT training	training	personnel
29	1996	training staff neue technologien	IT training	training	personnel
32	1998	inhouse training customer relation	inhouse training customer relation	training	personnel
33	1998	massive training staff	training	training	personnel
36	2000	staff training	training	training	personnel
37	2004	training	training	training	personnel
38	2005	training	training	training	personnel
39	2006	training neue technologien	IT training	training	personnel
42	2007	training fahrer	training driver	training	personnel
43	2007	training MA Kundenorientierung	service training	training	personnel
44	2008	Training und Motivation: 5	service training	training	personnel
45	2010	management training staff	executive training	training	personnel
47	2010	driver training	training driver	training	personnel
48	2011	lectures from Professors	lectures from professors	training	personnel
49	2011	training energy efficiency	training energy efficiency	training	personnel
50	2012	eco driving traing	eco driving training	training	personnel
51	1952	new regime for future personnel	new regime for future personnel	other	personnel
52	1953	Agreement with 1952	agreement with 1952	other	personnel
53	1953	Centrum Arbeitsunfälle	centre for work accidents	other	personnel
55	1954	Modification of healthcare services	modification of healthcare services	other	personnel

56	1960	ausbau Gesundheitswesen	upgrade health care	other	personnel
57	1961	Driving tests	driving tests	other	personnel
58	1961	and inquiry	driving assessment	other	personnel
59	1961	evaluation of staff	performance assessment	other	personnel
61	1962	Ambulanzdienst	ambulance treatment	other	personnel
62	1967	medizincheck personal	medical	other	personnel
63	1968	personal reduction	reorganistation due to staff dismissal program	other	personnel
64	1970	Personnel Expansion/ Hiring Schemes	reorganistation due to hiring program	other	personnel
65	1970	Vocational Training	vocational training	other	personnel
66	1972	Einmannbetrieb start	reorganization due to single agent/ one man operation policy	other	personnel
68	1973	Orga Einmann	reorganization due to single agent/ one man operation policy	other	personnel
69	1974	Salario Mínimo Nacional (SMN)	minimum wage	other	personnel
70	1974	Orga Einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
71	1975	Abkommen Arbeiter ACT	framework agreement on employment conditions	other	personnel
73	1975	Personalabbau	reorganistation due to staff dismissal program	other	personnel
75	1976	orga einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
76	1977	Mitarbeiterzeitschrift	internal communication	other	personnel
77	1978	orga einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
78	1978	Change of selling points' working hours	reorganization due to reduced opening hours of customer service points	other	personnel
79	1979	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
60	1980	neues gehaltsschema	new payment system	other	personnel
12	1980	verkäufer zu fahrern	internal job market (vendors to drivers)	other	personnel
80	1980	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
81	1980	psychologische betreuung	psychological advisory service for staff	other	personnel
82	1981	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
22	1982	umschulung: fahrer zur wartung	internal job market (drivers to engineers)	other	personnel
83	1982	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
84	1982	mehr psychologische bereuung	psychological advisory service for staff	other	personnel
85	1983	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
86	1983	einmannpolitik	reorganization due to single agent/ one man operation policy	other	personnel
90	1983	Neueinstellungen	reorganistation due to hiring program	other	personnel
91	1983	mitarbeiterbetreuung psychologisch	psychological advisory service for staff	other	personnel
92	1984	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
74	1985	vermeidung von neueintritten personal; interne besetzung	internal job market	other	personnel
93	1985	Limited Levels of Personnel Recruitment	hiring limitation	other	personnel
94	1985	einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
95	1985	behinderte arbeiter	handicapped employees program	other	personnel
101	1986	Single Agent (in bus network)	reorganization due to single agent/ one man operation policy	other	personnel
102	1986	Topziel: personalplanung	improved staff management schemes	other	personnel
105	1986	behinderte arbeitnehmer	handicapped employees program	other	personnel
106	1987	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
110	1988	Personnel Downsizing	reorganistation due to staff dismissal program	other	personnel
111	1988	Single Agent (continued implementation)	reorganization due to single agent/ one man operation policy	other	personnel
112	1989	einmannbetrieb	reorganization due to single agent/ one man operation policy	other	personnel
87	1990	band	team building measure	other	personnel
88	1990	interner arbeitmarkt	internal job market	other	personnel
119	1990	Personnel Downsizing	reorganistation due to staff dismissal program	other	personnel
120	1990	Single Agent (full implementation on bus network)	reorganization due to single agent/ one man operation policy	other	personnel
121	1990	schulen (ausbildung)	enforced vocational training (information campaigns in schools)	other	personnel
122	1992	Personnel Downsizing	reorganistation due to staff dismissal program	other	personnel
123	1992	Limited Levels of Bus Drivers Recruitment	hiring limitation for drivers	other	personnel
124	1992	performanceorientierung (weiterbildun)	assessment of training measures	other	personnel
125	1993	Personnel Downsizing	reorganistation due to staff dismissal program	other	personnel
126	1994	Personnel Downsizing	reorganistation due to staff dismissal program	other	personnel
128	1996	fortbildungsplan	training schedules	other	personnel
130	1998	Increase of overtime work	increase of overtime work	other	personnel
131	1998	Personnel readjustment	reorganistation due to hiring program	other	personnel
132	1999	Personnel Expansion	reorganistation due to hiring program	other	personnel
133	2000	Personnel readjustment	reorganistation due to hiring program	other	personnel
136	2001	Personnel Recruitment	reorganistation due to hiring program	other	personnel
137	2002	MA umfrage	employee survey	other	personnel
138	2005	abkommen mit gewerkschafften	framework agreement on employment conditions	other	personnel
141	2006	MA information	staff information campaign	other	personnel
145	2007	Coop mit Bildungsinstitution (für MA)	cooperation with universities (training)	other	personnel
147	2007	Vergabe von Praktikas	internships	other	personnel
148	2007	neuer Tarifvertrag	framework agreement on employment conditions	other	personnel
150	2008	Nachwuchsaquise	enforced vocational training (information campaigns in schools)	other	personnel
151	2008	Certifizierung Arbeitssicherheit und Gesundheit	certification of employees (health, security)	other	personnel

153	2009	praktikas	internships	other	personnel
154	2009	eröffnungn behandlungsräume	opening of medical and treatment facilities	other	personnel
155	2009	MA monitoring und	performance assessment	other	personnel
157	2010	internship	internships	other	personnel
158	2010	contractiong of drivers	reorganistation due to hiring program (drivers)	other	personnel
159	2011	reduction of limits for fuel and mobil phone use board	reduction of limits for fuel and mobil phone use board	other	personnel
161	2012	ausbau internship	internships	other	personnel
162	2012	bus driver manual	bus driver manual	other	personnel
164	2013	arbeitssport	workers' sports (focus health)	other	personnel
166	2013	praktika	internships	other	personnel

DRESDEN

Table A14: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1957	45h Woche	work time reduction (47 to 45)	incentives	personnel
5	1958	Aufenthaltsräume Personal	improve working conditions (facilities)	incentives	personnel
10	1959	Aufenthaltsräume + Toiletten Personal	improve working conditions (facilities)	incentives	personnel
13	1960	Lohnerhöhung,	salary increase	incentives	personnel
14	1960	Schichtprämie	bonuses for shift work	incentives	personnel
19	1962	Aufenthaltsträume	improve working conditions (facilities)	incentives	personnel
28	1967	5 Tage Woche	work time reduction (5 day week)	incentives	personnel
29	1967	Prämiensystem	bonus system	incentives	personnel
33	1970	Feierabendarbeitsverbot	overtime protection for workers	incentives	personnel
35	1972	Lohnsteigerung	salary increase	incentives	personnel
38	1976	Kantinenrenovierung	improve working conditions (facilities)	incentives	personnel
39	1977	40h Woche Fahrdienst + Urlaubsverlängerung	work time reduction (45 to 40)	incentives	personnel
42	1981	Arbeitszeitsenkung	work time reduction	incentives	personnel
43	1986	Schichtgeld	bonuses for shift work	incentives	personnel
44	1986	Leistungsprämie	performance bonus	incentives	personnel
45	1987	Schichtzuschlag	bonuses for shift work	incentives	personnel
46	1987	Lohn: Weiterführung Leistungsorientierung	performance bonus	incentives	personnel
48	1989	Verbesserung der Arbeitsbedingungen,	improve working conditions (facilities)	incentives	personnel
52	1997	Jahresarbeitszeit (-52h)	work time reduction (annually -52h to 39 per week)	incentives	personnel
58	2007	Spartentarifvertrag	framework agreement on employment conditions	incentives	personnel
60	2008	Altersteilzeitverträge	part-time work for older employees	incentives	personnel
61	2008	familienfreundliche Flex-Turnus Dienstplan	work and family program (fexibleduty roster scheduling)	incentives	personnel
72	2011	Jobtickets für DVB-Mitarbeiter	transport services and privileges for staff (job-ticket)	incentives	personnel
84	2013	Fahrdienstgebäude	improve working conditions (facilities)	incentives	personnel
86	2013	Tarifvertrag	framework agreement on employment conditions	incentives	personnel
6	1958	Qualifizierung Fahrschulwagen	training	training	personnel
8	1959	Qualifizierung	training	training	personnel
16	1961	Qualifizierung,	training	training	personnel
32	1969	Vorbereitung EDV einführung	IT training	training	personnel
34	1970	Vorbereitung Rechenzentrum+EDV	IT training	training	personnel
40	1977	Qualifizierung EDV	IT training	training	personnel
41	1979	Erziehung Fahrpersonal	training driver	training	personnel
49	1996	Schulungen für Service, Kontakt zu Kunden, innerbetr. Kommunikation)	service training	training	personnel
59	2007	Anstieg Weiterbildung	training	training	personnel
62	2008	Weiterbildungsangeboten der DVB AG deutlich gestiegen	training	training	personnel
64	2009	Anstieg Weiterbildung	training	training	personnel
65	2010	ProVes ab 2011 in wichtigen Unternehmensbereichen Workshops mit Führungskräften und Mitarbeitern zum demografischen Wandel statt.	executive training on ProVes	training	personnel
68	2010	anstieg weiterbildung	training	training	personnel
70	2011	Fahrer und Werkstattmitarbeiter mussten im Umgang mit der neuen Technik geschult werden. Die Dieseleinsparung hängt stark von der Fahrweise ab und auch die Instandhaltung der elektrischen Komponenten erfordert besonderes Know-how. Nur speziell ausgebildete Fachkräfte dürfen an der Hochvoltanlage arbeiten_ Schulungen des Fahr- und Werkstattpersonals, spezielle Werkstattausrüstungen und die wissenschaftliche Begleitung	IT training driver and maintenance	training	personnel
71	2011	Fahrsicherheitstraining für alle Busfahrer	drivers' orientation and safety training	training	personnel
74	2011	anstieg weiterbildung	training	training	personnel
79	2012	Hypridbusausbildung	training drivers on hyprid buses	training	personnel
89	2013	Anstieg Weitbildung		training	personnel
2	1957	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
3	1958	Fahrerlaubnis für Fahrer/Stempel und Überwachung	driver license monitoring	other	personnel
4	1958	Einführung Disziplinarbefugnis	introduction of disciplinary procedure	other	personnel
7	1958	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
9	1959	Einbau der Schienenbremse entlastet Personal	reorganization due to rail brake technology	other	personnel
11	1959	Kassierschaffner an Bahnhöfen	conductor at station only	other	personnel
12	1959	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
15	1960	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
17	1961	Standschaffner	conductor at station only	other	personnel
18	1961	Schaffner = Frauen	female employees = conductors	other	personnel
20	1962	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
21	1963	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel

22	1963	Teilnahme Personal an Entscheidungen	participation of workers in decision making	other	personnel
23	1964	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
24	1965	neue Lohnform	new payment system	other	personnel
25	1965	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
26	1966	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
27	1967	neue Lohnform	new payment system	other	personnel
30	1967	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
31	1968	orga: EB	reorganization due to single agent/ one man operation policy	other	personnel
36	1973	Arbeitsschutzwachen	work safty and security guards	other	personnel
37	1975	Beschwerdemanagement	staff complaint management	other	personnel
47	1989	Einheitl Lpohnbasis,	new payment system	other	personnel
50	1996	Fahrgruppenleiter (4Tage fahren - 1 Tag für Gruppe)	group model for drivers (4 day driving, 1 day group admin)	other	personnel
51	1996	Umstrukturierung	reorganization due to company restructuring	other	personnel
53	1997	Beginn Ausbildung Auszubildende	start vocational training	other	personnel
54	2000	Anhebuung 38 auf 40h WAZ	increased work time (40h)	other	personnel
55	2000	neue Fahr und Dienstpläne	improved duty rosters	other	personnel
56	2005	Flexplan Dienstplanung	flexible duty rosters	other	personnel
57	2006	Start Weiterbildung VDV Kompetenzzentrum	enforced vocational training (school of competence)	other	personnel
63	2009	MA fest	employee motivation schemes (party)	other	personnel
66	2010	Studenten im Fahrdienst	student = drivers	other	personnel
67	2010	Neuer Betriebsrat gewählt	new employee organization	other	personnel
69	2010	beteiligung staff	participation of workers in decision making	other	personnel
73	2011	plattform zum MA Austausch	internal communication (staff portal)	other	personnel
75	2011	ProVes ab 2011	Proves programm	other	personnel
76	2011	beteiligung staff	participation of workers in decision making	other	personnel
81	2012	Ausbildung Quereinsteiger	hiring and training of lateral entry employee	other	personnel
77	2012	Gesundheitsaktionen für Mitarbeiter	focus: staff health	other	personnel
78	2012	Projekt ProVes abgeschlossen: Mischarbeit Fahrdienst, Kundendienst und Ausbildung Quereinsteiger	Proves programm	other	personnel
80	2012	Mischarbeit Fahrdienst, Kundendienst	driving and service: mixed job profile	other	personnel
82	2012	beteiligung staff	participation of workers in decision making	other	personnel
83	2013	Ausbau Intranet (von Zuhause)	internal communication (staff portal from home)	other	personnel
85	2013	MA fest,	employee motivation schemes (party)	other	personnel
87	2013	Gesundheitspakt AOK	focus: staff health (cooperation with AOK)	other	personnel
88	2013	Team Challenge	employee motivation schemes (team challenge)	other	personnel

Schedule Decisions

HAMBURG

Table A15: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	Takverdichtung (15 auf 7,5)	frequency increase	frequency changes	schedule
2	1951	U-Bahn Verdichtung Takt 5 min	frequency increase underground	frequency changes	schedule
5	1953	U:Takverdichtung auf 2,5min	frequency increase underground	frequency changes	schedule
6	1953	Taktverdichtung: L2	frequency increase tram	frequency changes	schedule
7	1955	SB: Verdichtung: 7,5 auf 5	frequency increase tram	frequency changes	schedule
9	1957	SB: Taktverdichtung	frequency increase tram	frequency changes	schedule
10	1957	u: Taktverdichtung	frequency increase underground	frequency changes	schedule
11	1958	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
12	1959	U: Taktverdichtung,	frequency increase underground	frequency changes	schedule
13	1960	B: Taktverdichtung, Verlängerungen	frequency increase bus	frequency changes	schedule
14	1963	SB: Taktverdichtung	frequency increase tram	frequency changes	schedule
15	1963	B: Verdichtung Wagenfolge	frequency increase bus	frequency changes	schedule
16	1963	U: Verdichtung auf 2,5 min peak (sonst 5)	frequency increase underground	frequency changes	schedule
17	1964	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
18	1964	SB: Taktverdichtung	frequency increase tram	frequency changes	schedule
19	1964	B: Fahrplanverdichtung, Zugfolge	frequency increase bus	frequency changes	schedule
20	1965	U: Taktverdichtichtung	frequency increase underground	frequency changes	schedule
21	1967	B: Taktverdichtung	frequency increase bus	frequency changes	schedule
22	1972	B: Taktstreckungen	frequency reduction bus	frequency changes	schedule
23	1973	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
24	1974	U: Verdichtung	frequency increase underground	frequency changes	schedule
25	1979	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
26	1979	B: Taktverdichtung	frequency increase bus	frequency changes	schedule
27	1980	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
28	1982	U: Taktdehung am WE, Spätverkehr auf 10min (von 5)	frequency reduction bus weekend, after work hours	frequency changes	schedule
29	1982	Alsterlininen für Berufsverkehrs unbedeutend. Eher für gelegenheitsfahrten: daher Takdehnung	frequency reduction bus	frequency changes	schedule
30	1987	B: Taktdehnung	frequency reduction bus	frequency changes	schedule
31	1988	Taktdehnung	frequency reduction	frequency changes	schedule
32	1988	Herausnehmen von Zügen	frequency increase underground	frequency changes	schedule
33	1990	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
34	1991	U: Taktverdichtung	frequency increase underground	frequency changes	schedule
35	1991	U: Verdichtung Fahrplan,	frequency increase underground	frequency changes	schedule
36	1992	U: Taktverdichtung,	frequency increase underground	frequency changes	schedule
37	1992	B: Verdichtung auf 3,5 min in Innenstadt	frequency increase bus	frequency changes	schedule
38	1993	B: Verdichtung auf 20min in Abendstunden bis 23h	frequency increase bus	frequency changes	schedule
39	1993	B: Taktdehnung abends	frequency decrease bus evening	frequency changes	schedule

40	1993	B: Tagsüber Taktverdichtung Schnellbus 20 auf 15	frequency increase express bus	frequency changes	schedule
41	1995	B: Taktverdichtung	frequency increase bus	frequency changes	schedule
42	2002	Verdichtung Metrobus	frequency increase metrobus	frequency changes	schedule
47	2006	B: Taktverdichtung	frequency increase bus	frequency changes	schedule
43	2007	B: taktverdictung	frequency increase bus	frequency changes	schedule
45	2008	B: Taktverdichtung	frequency increase bus	frequency changes	schedule
46	2008	Taktverdichtungen	frequency increase bus	frequency changes	schedule
48	2013	Taktverdichtung	frequency increase	frequency changes	schedule
3	1952	U-Bahn: Verlänmgerung Taktzeit 5 min	schedule extension underground	other	schedule
4	1952	Bus: Verlängerung, Takverdichtung,	schedule extension bus	other	schedule
49	1953	Fahrlanverbesserungen	schedule optimization	other	schedule
8	1955	Straba: Verdichtung, Dauerbetrieb	24h schedule	other	schedule
50	1970	Fahrplananschlüsse	schedule optimization (connections)	other	schedule
51	1972	generell Fahrplaneinschränkungen wegen Nachfragemangel	schedule optimization (reduced demand)	other	schedule
52	1974	Fahrplan: kostensparende Maßnahmen: Streichung SB, enge Anpassung Angebot-Nachfrage = Leistungsverbesserung in peaks, Einschränkungen in off-peaks	schedule optimization (reduced demand)	other	schedule
53	1975	Fahrplan: an Nachfrage	schedule optimization (reduced demand)	other	schedule
59	1982	Sommerferienfahrplan	summer schedule	other	schedule
54	1984	U: Ferien = Taktdehnung	schedule optimization (reduced demand)	other	schedule
55	1985	B: Fahrplananpassung an abschnitte mit geringer Nachfrage	schedule optimization (reduced demand)	other	schedule
56	1987	OptimierungFahrpläne	schedule optimization (reduced demand)	other	schedule
57	1992	Längere Bedienungzeiten	schedule extension	other	schedule
58	2005	U: Ausweitung Nachtangebot, 20min Takt	schedule extensionnight service	other	schedule
34	2007	U: taktverlängerung bis 21 ur	schedule extension with higher frequency	other	schedule
52	2007	B: verängerung betriebszeit metrobus	schedule extension metrobus	other	schedule
44	2008	Verlängerung verdichtet Takt	schedule extension with higher frequency	other	schedule

PORTO

Table A16: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	taktverdichtung	frequeny increase	frequency changes	schedule
2	1950	taktverdichtung	frequeny increase	frequency changes	schedule
3	1950	taktverdichtung	frequeny increase	frequency changes	schedule
4	1950	taktverdichtung	frequeny increase	frequency changes	schedule
6	1951	Taktverdichtung	frequeny increase	frequency changes	schedule
7	1951	Taktverdichtung	frequeny increase	frequency changes	schedule
8	1951	Taktverdichtung	frequeny increase	frequency changes	schedule
10	1952	ausdünnung	frequency reduction	frequency changes	schedule
15	1961	taktverdichtung	frequency reduction	frequency changes	schedule
16	1962	Frequency increase (Gaia)	frequeny increase	frequency changes	schedule
18	1963	Taktverdichtung	frequeny increase	frequency changes	schedule
21	1985	Service Reduction at Sundays	frequency reduction sundays	frequency changes	schedule
25	1997	taktverdichtuzng	frequency reduction	frequency changes	schedule
27	1998	increased frequency	frequeny increase	frequency changes	schedule
28	2003	Frequency increase	frequeny increase	frequency changes	schedule
29	2004	frequency increase	frequeny increase	frequency changes	schedule
30	2004	Kapazitäsanpassung (Taktstreckung)	frequency reduction	frequency changes	schedule
31	2005	frequency increase	frequeny increase	frequency changes	schedule
32	2007	takverdichtung	frequeny increase	frequency changes	schedule
34	2008	anpassung frequenzen (nach unten)	frequency reduction	frequency changes	schedule
35	2010	taktverdichtung	frequeny increase	frequency changes	schedule
37	2011	taktstreckung/	frequency reduction	frequency changes	schedule
42	2012	taktanpassung (streckung) 2	frequency reduction	frequency changes	schedule
44	2012	taktanpassung (streckung) 2	frequency reduction	frequency changes	schedule
45	2013	taktstreckung	frequency reduction	frequency changes	schedule
5	1951	Änderung fahrplan	schedule optimization	other	schedule
9	1952	ausdehnung peak	extension peak frequency time	other	schedule
11	1953	Itinerary changes	schedule optimization	other	schedule
12	1954	Alteration of opening and closing timetable	schedule optimization (opening and closing time)	other	schedule
13	1956	high schools timetables modification	schedule optimization (according to highschool time changes)	other	schedule
14	1960	fahrplanänderung	schedule optimization	other	schedule
17	1963	Ausbau Nachfahrplan	extension night operation time	other	schedule
19	1964	nachtverkehrs/linien	extension night operation time	other	schedule
20	1966	nachverkehr	extension night operation time	other	schedule
22	1985	Sommerfahrplan	summer schedule	other	schedule
23	1986	Service Reduction	schedule optimization (reduced demand)	other	schedule
24	1997	fahrplanänderung	schedule optimization	other	schedule
26	1998	new schedules	schedule optimization	other	schedule
33	2007	fahrplanausdehnung	schedule extensions	other	schedule
36	2010	anpassung an stundenpläne	schedule optimization (according to highschool time changes)	other	schedule
38	2011	sommerfahrplan neu	summer schedule	other	schedule
39	2011	neue schulfahrpläne	schedule optimization (new school schedules)	other	schedule
40	2011	neue nachtfahrpläne	schedule optimization (new night schedules)	other	schedule
41	2012	fahrplan kürzung 2	schedule optimization (cutback)	other	schedule
43	2012	fahrplan kürzung 2	schedule optimization (cutback)	other	schedule
46	2013	fahrplankürzungen	schedule optimization (cutback)	other	schedule

DRESDEN

Table A17: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1957	+ Takt 5min	frequeny increase	frequency changes	schedule
2	1959	Obus: Verkürzung Wendezeiten --> Verdichtung Zugfolge 6 auf 5 min	frequeny increase	frequency changes	schedule
3	1959	Bus: Linei B Wagenfolge verdichtet	frequeny increase	frequency changes	schedule

4	1961	Zugfolge: Linie 31	frequency reduction	frequency changes	schedule
5	1962	Verringerung Takt	frequeny increase	frequency changes	schedule
7	1974	Linie 75: Takterhöhiung	frequeny increase	frequency changes	schedule
8	1974	L94: Verlängerung, Takthalbierung	frequency reduction	frequency changes	schedule
9	1975	Zugfolgeverdichtung (Li12/14)	frequeny increase	frequency changes	schedule
10	1975	Verknüpfung + Verdichtun 15 auf 7(75+94)	frequeny increase	frequency changes	schedule
12	1986	Verlängerung und Verdichtung Zugfolgezeiten L42	frequeny increase	frequency changes	schedule
14	1989	Veränderung der Zugfolge	frequeny increase	frequency changes	schedule
15	1993	Takterhöhung von 15 auf 10min	frequeny increase	frequency changes	schedule
23	2001	Abend/Nachtfahrtakt bis 23h: 15min	frequeny increase	frequency changes	schedule
25	2003	neue Strabatyp erlaubt Taktdehnung	frequency reduction	frequency changes	schedule
26	2004	Taktstreckung wegen Angebotsanpassung	frequency reduction	frequency changes	schedule
29	2008	Taktsteigerung für Peripherie (+300 FG/d)	frequeny increase	frequency changes	schedule
6	1973	Fahrplanoptimierung	schedule optimization	other	schedule
11	1982	Fahrplanstabilität	schedule optimization	other	schedule
13	1989	Verlängerung Einsatzzeit L16	schedule extension	other	schedule
16	1993	Orga: 50% vrbesserter Fahrplan	schedule optimization	other	schedule
17	1994	Ferienfahrpläne	summer schedule	other	schedule
18	1994	Sommerfahrplan	summer schedule	other	schedule
19	1994	Feiertagstakt: 20min	holiday schedule	other	schedule
20	2000	Einheitl Grundtaktsystem: Strab/Bus 10min	basic frequency 10-min for tram and bus	other	schedule
21	2000	Verlängerung Einsatzzeiten	schedule extension	other	schedule
22	2000	Nachtfahrplan	night schedule	other	schedule
24	2003	Ferienzeit: Taktänderung 15 bzw 30min	summer schedule	other	schedule
27	2007	Anpassung Takt an Einkaufszeiten (tägl 20, sams 18) in innenstadt	schedule optimization (according to shopping malls)	other	schedule
28	2007	innenstadt: bis 22:30 15min bis 2:00 30min	schedule optimization (according to shopping malls)	other	schedule
30	2008	Linie 2 fährt durchgängig	24 schedule	other	schedule

Fare Decisions

HAMBURG

Table A18: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	Tariferhöhung, Verschonung Berufsverkehr von Preiuerhöhungen	fare increase	fare change	fares
4	1952	Preiserhöhung bei Bus	fare increase	fare change	fares
9	1957	Tariferhöhung=Fahrgastabwanderung	fare increase	fare change	fares
11	1960	Tariferhöhung, Verfeinerung Angebot	fare increase	fare change	fares
20	1971	Tariferhöhung	fare increase	fare change	fares
23	1973	Tarifanspassung	fare increase	fare change	fares
24	1976	Tariferhöhung	fare increase	fare change	fares
28	1977	Tariferhöhun	fare increase	fare change	fares
29	1978	Tariferhöhung	fare increase	fare change	fares
32	1979	Tariferhöhung 5,5%	fare increase	fare change	fares
34	1980	Tariferhöhung 4,9%	fare increase	fare change	fares
35	1981	Tariferhöhnh	fare increase	fare change	fares
38	1982	Tarif: +5,5%	fare increase	fare change	fares
41	1983	Tarif: + 9,8	fare increase	fare change	fares
42	1984	Tarif: 8,8+	fare increase	fare change	fares
48	1992	Tariferhöhung (2,2%(	fare increase	fare change	fares
49	1993	Tariferhöhung (5,8%)	fare increase	fare change	fares
51	1994	Tarierhöhung 3,2	fare increase	fare change	fares
54	1995	Tariferhöhung 4	fare increase	fare change	fares
55	1996	Tarif: +2,9%	fare increase	fare change	fares
56	1997	Tariferhgöhung 2,8%	fare increase	fare change	fares
59	2007	Tariferhöhung	fare increase	fare change	fares
60	2012	Tariferhöhung 2,8%	fare increase	fare change	fares
2	1950	Gemeinschaftstarif	integrated fare	other	fares
3	1952	Tarifänderung/Tarifreform: Reiselänge wird berücksichtig	new fare system	other	fares
5	1953	Einführung Jahreskarte (260M)	annual ticket	other	fares
6	1953	Sonderlinine mit Tarifstützun	social fares / subsidization	other	fares
7	1955	Bus: Sonderlinien auf verkehrsnachfragearmen linien (mit güstigem tarif)	social fares / subsidization	other	fares
8	1957	Senkung der Schnellbustarife	social fares / subsidization	other	fares
10	1958	Studentenkarte=Nachtverkehr	student fares	other	fares
12	1961	Tarifinnovation	other fare innovation	other	fares
13	1963	komplette Tarifumstellung (!)	new fare system	other	fares
14	1963	Tariggemeinsschaft mit HafenDAmplfschifffahrt HADAG; freizügiges Umsteigen	integrated fare (with ferries)	other	fares
15	1966	Gemeinschaftstarif Verbund Hamburg	integrated fare (transport association)	other	fares
16	1968	befristete Sondertarife um Anreize zu setzen (Touristenkarten, Wochenedvergünstigungen, Weihnachtseinkausschein	fare diversification	other	fares
17	1968	Steigerung: integriete Leistungs und Tarifangebot, Werbung um Kunden, Produktdiversifikation	fare diversification	other	fares
18	1969	Tarif: neue Angebote (Seniorekarte, Ausflugskarte, Ferienkarte, Partykarte, Einkaufsfahrscheine, Touristenkarte)	fare diversification	other	fares
19	1970	Sonderangebotskarten: Seniorenkarte, Touristenkarte, Familienausflugskarte, Tourenanschlusskarte, Famileneinkaufskarte)	fare diversification	other	fares
21	1971	Tarifänderung + Ausdehnung Zonen,Produktdiffersifiztierung, Kindermonatskarte,	fare diversification	other	fares
22	1972	Tarif: Produke Wochenend Besucherkarte, Ferienkarte, Familien Tageskarte, Einkaufskarten	fare diversification	other	fares
25	1976	Kängeruhkarte	fare diversification	other	fares
26	1977	Aboverfahren = bargeldlos	other fare innovation	other	fares
27	1977	Wochenendkarte für Wochenpassinhaber der Bundesbahn	other fare innovation	other	fares
30	1978	Promotion ADAC MG wechsel auf ÖPNV innerstädtisch	other fare innovation	other	fares
31	1979	Erfolg Gemeinschaftsaktion ADAC	other fare innovation	other	fares
33	1979	Monatskarte ADAC (Umsteigen anreizen)	other fare innovation	other	fares
36	1981	13 Sondertarife	fare diversification	other	fares
37	1981	neue Tarifprodukte: netz touristenkarte, Städteticket, Hamburgticke, Kulturticket	fare diversification	other	fares
39	1982	Tarif: neue Freizeit und Feierabend Monatskarte	fare diversification	other	fares
40	1982	City Bereichskarte	city ticket	other	fares
43	1988	Tarifvereinfachung	new fare system	other	fares
44	1988	Tarifausbau Angebote	fare diversification	other	fares
45	1990	Test: Firmenticket	job ticket	other	fares
46	1991	hohe Akzeptanz Jobticket	job ticket	other	fares
47	1991	Unfalversicherungsangebot im Abo	other fare innovation	other	fares

50	1993	FahrausweiseSonderangebot	fare diversification	other	fares
52	1994	Semesterticket	student fares	other	fares
53	1994	Karten für Asylbewerber	other fare innovation	other	fares
57	2007	Einführung Kurzsteckenfahrt 1,30 €	short trip ticket	other	fares
58	2007	Test Jandyticket	smartphone ticket	other	fares

PORTO

Table A19: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1959	Update of fares	fare increase	fare change	fares
5	1960	tarifänderung	fare increase	fare change	fares
7	1961	tarifänderung	fare increase	fare change	fares
8	1966	Increase of fares	fare increase	fare change	fares
11	1967	fare increase	fare increase	fare change	fares
12	1970	fare increase	fare increase	fare change	fares
13	1974	Increase of fares (in urban fringes)	fare increase	fare change	fares
15	1975	tariferhöhung	fare increase	fare change	fares
16	1976	fare reduction = social passes	fare increase	fare change	fares
20	1978	fare increase	fare increase	fare change	fares
27	1981	tarif increase 1	fare increase	fare change	fares
28	1982	Modification of Fares;	fare increase	fare change	fares
30	1983	fare increase1	fare increase	fare change	fares
31	1984	farechange	fare increase	fare change	fares
32	1985	fareincrease1	fare increase	fare change	fares
33	1986	fare increase	fare increase	fare change	fares
34	1988	fare increase	fare increase	fare change	fares
35	1989	fare increase 6%	fare increase	fare change	fares
36	1990	fare change	fare increase	fare change	fares
37	1991	fare increase	fare increase	fare change	fares
39	1992	fare increase 1	fare increase	fare change	fares
51	2003	fareincrease	fare increase	fare change	fares
55	2004	fare changes	fare increase	fare change	fares
57	2005	SMS Bus günstiger	fare increase	fare change	fares
60	2006	far increase only bilhetes simples	fare increase	fare change	fares
64	2010	SMSbus price increase	fare increase	fare change	fares
68	2012	social ticket up	fare increase	fare change	fares
2	1959	fare innovation	other fare innovation	other	fares
3	1960	Special fares (trams and trolley-cars)	fare diversification (tram, trolley car)	other	fares
4	1960	multimodal tickets (line 33)	integrated fares	other	fares
6	1960	tarif autocarro	fare diversification (autobus)	other	fares
9	1967	modification of semestrial and student /	student fares	other	fares
10	1967	workers season tickets (trams)	worker fares	other	fares
14	1975	New Fares (for electric and trolley cars)	new fare system (for electric and trolley cars)	other	fares
17	1976	social fare	social fares / subsidization	other	fares
18	1976	reduction of fare options	new fare system (less options)	other	fares
19	1977	New Fare System (without fare modification)	new fare system (less options)	other	fares
21	1978	neue Ticketform "em caderneta"	new ticket ("tear the ticket off a calender")	other	fares
22	1979	; New Fare System	new fare system	other	fares
23	1980	; New Fare System	new fare system	other	fares
24	1980	social pass OPO-VILA GAIA	social fares / subsidization P-VNG	other	fares
25	1980	social pass intermodal trens	social fares / subsidization intermodal	other	fares
26	1980	social pass STCP- privatunternehmen	social fares / subsidization privat companies	other	fares
29	1982	neues Tarifsystem	new fare system	other	fares
38	1992	New Fares	new fare system	other	fares
40	1992	2 neue Tickertypen	fare diversification	other	fares
41	1993	Single Fare in Porto City	new fare system	other	fares
42	1993	New Fares	fare diversification	other	fares
43	1993	3 neue tikettypen	fare diversification	other	fares
44	1994	Fare System Modification (elimination and reformulation)	new fare system	other	fares
45	1994	new fare	fare diversification	other	fares
46	1994	new passes	fare diversification	other	fares
47	1994	new fare2	fare diversification	other	fares
48	1995	Fare System Modification (season tickets for retired people)	new fare system	other	fares
49	1995	fare innovation	other fare innovation	other	fares
50	1996	Fare System Modification (Multi-Trip Tickets)	new fare system	other	fares
52	2003	festival pass, kindertag, europatag, carefree day	fare diversification	other	fares
53	2003	Introduction of Andante Intermodal fare system in 13 lines and for electric cars	new fare system	other	fares
54	2004	ausbau andante	new fare system	other	fares
56	2005	intermodal prices	integrated fares	other	fares
58	2005	doppelter tarif (STCP, andante)	other fare innovation	other	fares
59	2006	neues ticketsystem (tariflich + technisch)	new fare system	other	fares
61	2008	neues ticket: escola	fare diversification	other	fares
62	2009	neues Ticket: sub23	fare diversification	other	fares
63	2009	neue student beginner ticket	fare diversification	other	fares
65	2011	andante social ticket (for lower income)	social fares / subsidization	other	fares
66	2011	new tourist fare pricing scheme	new fare system (tourists)	other	fares
67	2012	change of eligibility of andante youth tickets	other fare innovation	other	fares
69	2013	beeindigung monomodale tarife	new fare system	other	fares
70	2013	new tourist ticket	new fare system (tourists)	other	fares

DRESDEN

Table A20: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
4	1993	Preiserhöhung	fare increase	fare change	fares
6	1995	15% Fahrpreiserhöhung	fare increase	fare change	fares
12	2002	Erhöhung Verbundtarif	fare increase	fare change	fares

1	1957	Tarifvereinfachung (Beseitigung Umsteiger)	new fare system	other	fares
2	1993	kombinierte Monatskarte mit Bahn	integrated fares	other	fares
3	1993	Semesterticket	student fares	other	fares
5	1994	Kombiticket	integrated fares	other	fares
7	1995	Verringerung Altergrenze einzelfahrten	other fare innovation	other	fares
8	1997	Kombifahrer - Straba/Bus (Flexibilität)	integrated fares	other	fares
9	1998	Verbundtarif	integrated fares	other	fares
10	2000	Jobticket Infinion	job ticket	other	fares
11	2001	Jobticket	job ticket	other	fares
13	2002	Jobticket	job ticket	other	fares
14	2003	Jobticket	job ticket	other	fares
15	2004	Jobticket	job ticket	other	fares
16	2005	Firmenticket Drewag	job ticket	other	fares
17	2006	jobticket	job ticket	other	fares
18	2007	Jobticket Uniklinikum	job ticket	other	fares
19	2007	Kombitickets	integrated fares	other	fares
20	2007	17 UN Jobtickets	job ticket	other	fares
21	2007	Kongressticket	fare diversification	other	fares
22	2009	Fusbalticket	fare diversification	other	fares
23	2012	Einführung HandyTicket Deutschland	smartphone ticket	other	fares

Service Decisions

HAMBURG

Table A21: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
2	1951	U-Bahn: selbstätige Türschließvorrichtungen	automatic door system	operations	service
3	1952	Drehkreuze	turnstiles	operations	service
5	1953	Einbau von Abgangssperren	leaving barrier	operations	service
9	1954	U: Verkehrssicherheit	traffic and operations safety	operations	service
6	1954	Klappsperren (Zugang ja, Abgang nein)	leaving barrier	operations	service
7	1954	U: Verbeserung Zugumlauf	circulation	operations	service
11	1955	Fahrsceindrucker	ticket machines	operations	service
14	1957	verbesserung Stromversorgung Ubahn = höhere Zugfolge	circulation	operations	service
17	1959	U: Rolltreppen	passenger dispatching	operations	service
18	1959	U: moderne Fahrgastabfertigungsanlagen	passenger dispatching	operations	service
22	1959	B: FZ auf nachfrageschwachen gebieten	other operations optimization	operations	service
21	1959	Maßnahmen Erhöhung Reisegeschwindikeit,	acceleration	operations	service
24	1960	B: Kleinbusse bei Nachfragemangel	other operations optimization	operations	service
25	1961	SB: L11 besonderer Bahnkörper	acceleration	operations	service
27	1962	Beschleunigung: Abschirmung gegen IV (SB), Vorfahrt, Halteverbote IV, Busverkehr=Vorhfahrtstraße, Busspuren)	acceleration	operations	service
28	1962	Beschleunigung: Abschirmung gegen IV (SB), Vorfahrt, Halteverbote IV, Busverkehr=Vorhfahrtstraße, Busspuren)	acceleration	operations	service
29	1962	Beschleunigung: Abschirmung gegen IV (SB), Vorfahrt, Halteverbote IV, Busverkehr=Vorhfahrtstraße, Busspuren)	acceleration	operations	service
30	1962	Beschleunigung: Abschirmung gegen IV (SB), Vorfahrt, Halteverbote IV, Busverkehr=Vorhfahrtstraße, Busspuren)	acceleration	operations	service
31	1962	Beschleunigung: Abschirmung gegen IV (SB), Vorfahrt, Halteverbote IV, Busverkehr=Vorhfahrtstraße, Busspuren)	acceleration	operations	service
38	1963	Gemeinsame haltestelleninseln	shared bus stops	operations	service
32	1963	U: Aufhebung Zugangssperren für Zeitkarteninhaber = Beschleunigung	acceleration	operations	service
44	1965	Busanlage, passagierabfertigung	passenger dispatching	operations	service
45	1965	B: Kleinbusse bei Nachfragemangel	other operations optimization	operations	service
50	1966	Fahrkartenautomaten	ticket machines	operations	service
51	1966	Münzwechsler	coin changing machine	operations	service
53	1967	Fahrkartenautom.	ticket machine	operations	service
56	1967	Wechselauto	coin changing machine	operations	service
59	1968	Verstärtker einsatz von Fahrkartenautomaten,	ticket machines	operations	service
58	1968	U: Weichenheizung	rail heating	operations	service
66	1970	Verkehrs- und Betriebssicherheit	traffic and operations safety	operations	service
67	1970	Fahrgastzählgeräte	passenger counting	operations	service
69	1970	Zentrale Leitstelle Schnellbus	central dispatch (system)	operations	service
72	1971	U: Weichenheizung	rail heating	operations	service
73	1971	Buspuren	acceleration	operations	service
74	1971	2 SB-Busspur	acceleration	operations	service
82	1973	wachsender Automatiserungsgrad: 206 Fahrtreppen, 11, Aufzüge, 785 Gepäckschließfächer, etc	passenger dispatching	operations	service
83	1973	B: neue Busspur	acceleration	operations	service
86	1974	Ausbau Fahrausweisautomaten	ticket machines	operations	service
88	1974	Weicheheizung beendet Ubahn	rail heating	operations	service
87	1974	Busspuren 3,2 km - Gesamtlänge 9km	acceleration	operations	service
91	1975	30 neue Mehrpreisautomaten	ticket machines	operations	service
90	1975	Busspur 300m	acceleration	operations	service
95	1976	Ausbau Betriebshof	depot upgrade	operations	service
99	1977	Umwandlung SB in Busspuren	acceleration	operations	service
104	1978	Busfahrstreifen +11,63 km (von 19,9)	acceleration	operations	service
112	1980	Fahrkartenautomaten an Haltestellen	ticket machines	operations	service
121	1981	U: herstellung Betriebssicherheit	traffic and operations safety	operations	service
120	1981	neue Maschinelle Anlagen	central dispatching (system)	operations	service
124	1982	Fahrkartenautomaten	ticket machines	operations	service
125	1982	Ausbau maschinelle anlagen, Gesamt: 297 FKA, 203 Fahrtr, 14 Aufzüge, 767 Schließfächer	passenger dispatching	operations	service
122	1982	B: baulich Anpassung Buskehren	bus bay upgrade	operations	service
126	1982	B: Ausrichtung Verkehr auf neue Busvkehren	bus bay upgrade	operations	service
133	1984	neue Betriebsführungs- und Leitzentren,	upgrade central dispatching (system)	operations	service
132	1984	Ausbau Automaten	ticket machines	operations	service
135	1985	B: , Betriebsleitstelle	upgrade central dispatching (system)	operations	service
138	1985	Automaten mit Banknoten	ticket machines	operations	service
136	1985	U. Zentralstellwerk,	central interlocking (system)	operations	service
139	1985	neue Busanlage und kehre = wirtschaftl. Abläufe	bus bay upgrade	operations	service
146	1986	Aufrüstung Zahltische Bus	onboard ticket vending	operations	service
145	1986	Beschleunigung: Busspur vrelängert, Vreschwenkungen	acceleration	operations	service
158	1987	Fahrkartenautomaten mit Scheingeld,	ticket machines	operations	service
166	1988	Ausbau: Automaten)	ticket machines	operations	service
165	1988	Beschleunigungsmaßnahmen (Ampelschaltung)	acceleration	operations	service
163	1988	U: zukünftig "flexible Betriebsweise" durch EDV	flexible operation	operations	service
169	1989	neue Fahrtreppen in Betrieb,	passenger dispatching	operations	service

174	1990	Matrixanzeigen für Fahrtziel an Bus (vorher Rollenband)	matrix displays	operations	service
172	1990	Maßnahmen Qualität: Beschleunigung (Busspuren, signale (LSA) bis 1993)	acceleration	operations	service
178	1991	U: Erhöhung behänguzng	other operations optimization	operations	service
179	1991	Abends tw Großraumtaxen	other operations optimization	operations	service
181	1991	Geldzähl und Quittierautomate für Busfahrer	onboard ticket vending	operations	service
176	1991	Buspuren	acceleration	operations	service
184	1991	LSA Ausbau	acceleration	operations	service
186	1992	Qualität: Busspuren + LSA	acceleration (bus lanes and traffic lights)	operations	service
185	1992	S: Automatenwechsel	ticket machines	operations	service
191	1992	Taxibedienung in Nachfrageschwachen Zeiten	other operations optimization	operations	service
193	1992	B: Geld/Quttingsautomaten erleichter Abrechnug	onboard ticket vending	operations	service
192	1992	B: Matrixanzeigen reduziert Zeit bei Linienwechsel,	matrix displays	operations	service
189	1992	Infra: zukünftig elektronische Weichen	electronic points	operations	service
187	1992	Kosten: Ausbau flexible Betriebsweise	flexible operation	operations	service
197	1993	Qualität: Beschleunigung- Anzeigen gegen Falschparker	acceleration (bus lanes and enforcement)	operations	service
203	1994	Qualität: Busbeschleunigungstrecke und LSA Start	acceleration (bus lanes and traffic lights)	operations	service
208	1994	U: Hochsetzung v_max	other operations optimization (v_max)	operations	service
207	1994	Kleinbusse in Nachfrageschachen Zeiten	other operations optimization	operations	service
217	1995	U: Matrixanzeige mit LED Technik	matrix displays	operations	service
215	1995	B: Problem geschwindigkeit - Lösung LSA (bis 1996) = Steigerung v, Einhaltung Pausen, Senkung Personalbedarf, Senkung Verbrauch	acceleration	operations	service
214	1995	U: flexible Betriebsweise 18% Produktitvätssteiguner seit 1991	flexible operation	operations	service
234	1997	Sicherheitskonzept (Haltestellen, Scheiben zwischen Wagen, Personal)	traffic and operations safety	operations	service
230	1997	U: flexBed	flexible operation	operations	service
243	1998	ausbau elektronische Fahrscheindrucker	ticket machines	operations	service
252	1999	Streckenzentrale mit ESTW	central electronic interlocking (system)	operations	service
261	2001	inbetriebnahme SICAS Stellwerk (1. weltweit)	central electronic interlocking (system)	operations	service
270	2002	B: Beschleunigung: 24 neue LSA: Einsparungen 700.000 € p Jahr	acceleration	operations	service
273	2003	Videoaufzeichnung Ubahb	traffic and operations safety	operations	service
283	2004	Ausbau Stellwerkstechnologie	upgrade interlocking system	operations	service
280	2004	B: zentral Betriebslenkung	upgrade central dispatching (system)	operations	service
285	2005	Rolltreppen mit fahrtrichtung	passenger dispatching	operations	service
288	2005	Anschlusssystem Bus - Sbahn für Fahrer	other operations optimization	operations	service
289	2005	Midi Busse in dicht besiedelten Wohngebieten, Ein - Aus an jeder Stelle	new product / service	operations	service
291	2006	Fahrkartenautomaten mit Touchscreens	ticket machines	operations	service
299	2007	Ausbau Videoüberwachung	traffic and operations safety	operations	service
297	2007	Ausbau: 200 neue Fahrkartenautomaten	ticket machines	operations	service
309	2012	Optimierung Fahrgeschwindigkeit nach Energetischen Punkten	other operations optimization	operations	service
316	2013	Vorfahr für Hamburg via bus Programm	acceleration	operations	service
1	1950	Sonderlinie Peak	capacity	customer	service
4	1952	Verstärkungsfahrten	capacity	customer	service
8	1954	U: Neugestalltung Haltestellen	upgrade stops / stations	customer	service
12	1955	U: 4 statt 2 wagenzüge,	capacity	customer	service
13	1955	U: 6 statt 4,	capacity	customer	service
10	1955	Wetterschutzanlagen	upgrade stops / stations	customer	service
15	1958	Citybus Einführung: Kleinbusse, 13 Sitz, 5 Stehbusse, 5 min takt, 50 Pfg.)	city bus	customer	service
20	1959	neue Schalterhallen	service points	customer	service
23	1959	Citybus eingestellt	city bus	customer	service
16	1959	U: Kapazitäten Haltestelle	capacity underground stations	customer	service
26	1961	Neue Ubahnhöfe	capacity underground stations	customer	service
39	1963	B: Ausdehnung Betriebszeiten	service extension	customer	service
33	1963	U: Fahrgastparken 336 Stellplätze	P+R	customer	service
34	1963	SB: Rauchverbot	no-smoking rule	customer	service
36	1963	U: 8 Wagenzüge (vorher 6),	capacity	customer	service
37	1963	SB: Erhöhung Platzangebot durch Beiwagen	capacity	customer	service
40	1964	U: Rauchen verboten	no-smoking rule	customer	service
41	1964	Leuchtschilder	customer information	customer	service
42	1964	Infotafel	customer information	customer	service
49	1965	Fahrgastinformationen	customer information	customer	service
64	1968	Werklinienverkehr 35 Linien	new product / service	customer	service
60	1968	Informationen für Fahrgast	customer information	customer	service
61	1968	Orientierungspläne	customer information	customer	service
65	1969	Werklnineverkehr Ausbau 51 Lininen	new product / service	customer	service
71	1970	Werklininenverkehr 63 Linien	new product / service	customer	service
68	1970	bargeldloser Zahlungsverkehr (Einzugsermächtigung - 10 Wertmarken)	cashless payment	customer	service
77	1971	Werklinien: 69	new product / service	customer	service
76	1971	bargeldlos	cashless payment	customer	service
79	1972	Werkverkehr: 66 Linien	new product / service	customer	service
78	1972	neues infosystem für fahrgäste: durchsagen des fahrers nach außen und innen und mit zentrale	customer information system upgrade	customer	service
80	1973	Verbesserung Haltestellen	upgrade stops / stations	customer	service
81	1973	Verlängerung Bahnsteige	upgrade stops / stations	customer	service
84	1973	B: Kleinbusse für Sidelungsdichte Gebiete	mini-buses	customer	service
85	1974	Zugtelefonie	train telephone	customer	service
89	1974	Werkverkehr: 60 Linien	new product / service	customer	service
93	1975	Zusammenarbeit mit HH Polizei = Sicherheit	traffic and operations safety	customer	service
92	1975	Eröffnung Parkhaus über U-Bahn 480 plätze	P+R	customer	service
94	1976	Ausbau Fahrgasteinrichtungen	upgrade stops / stations	customer	service
97	1977	47 neue Fahrgastunterstände,	upgrade stops / stations	customer	service
101	1977	Ausbau Kundeberatung	customer service	customer	service
98	1977	U-Bahn mit Zugtelefonie + Lautsprechern für Durchsagen,	customer information system upgrade	customer	service
100	1977	Ausbau Infosystem	customer information system upgrade	customer	service
102	1977	U-Bahn Lautsprechern für Durchsagen,	customer information	customer	service
107	1978	Unterstände	upgrade stops / stations	customer	service
103	1978	Thema: Kundenfreundlichkeit: Sonderangebote,, ,)	customer service	customer	service
106	1978	Ausbau Kundenberatung,	customer service	customer	service
105	1978	Verbessrung info,	customer information	customer	service
110	1979	B: höhere Kapazität wegen SB stilllegung auf best. Linien	capacity	customer	service
111	1980	Verbesserung DL: Modernisierung Haltestellen,,	upgrade stops / stations	customer	service
114	1980	mehr Kapazizäz in peaks	capacity	customer	service
115	1981	U: Modernisierung Haltestellen	upgrade stops / stations	customer	service
118	1981	B: Unterstände	upgrade stops / stations	customer	service
116	1981	U: Radabstellplätze	P+R (bikes)	customer	service
119	1981	Mitnahme von Fahrrädern in Schnellbahnen	free bicycle carriage	customer	service
117	1981	U: Informationswesen	customer information	customer	service
129	1983	Airport Expresslinine (bes. Kennzeichnug, D+Eng, Gepäckmitnahme, Marketing)	new product / service	customer	service
127	1983	Eröffnung Kundenzentrum	customer service	customer	service
134	1984	680 Haltestellen mit Info, Lautsprechern	upgrade stops / stations	customer	service
130	1984	Focus: Service (5 neue Kundenbüros)	customer service	customer	service
137	1985	4 neue Kundenbüros	customer service	customer	service
149	1986	Zugbegleiter für Sicherheitsgefühl	security	customer	service
148	1986	Nachtbus Taxi Service	new product / service	customer	service
151	1986	kostenloser Einkaufsbus	new product / service	customer	service
152	1986	kostenloser MesseBus	new product / service	customer	service

144	1986	4 Kundenbüros	customer service	customer	service
150	1986	Fahrgastbetreuer eingestellt	customer service	customer	service
157	1987	Ausbau Unterstände (JC Decaux und eigene)	upgrade stops / stations	customer	service
156	1987	B: neue Umsteiganlage mitCafe,, Kiosk, Toilette	shopping facilities	customer	service
153	1987	Überwachung P+R Häuser	security	customer	service
154	1987	S: Polizeipräsenz, SicherheitspersonaL;	security	customer	service
159	1987	Behindertengerecht,	handicapped-suited	customer	service
155	1987	B: Haltestellen mit neuem Informationssystem	customer information	customer	service
162	1988	Umgestaltung Haltestelle wegen Einkaufszentrum	shopping facilities	customer	service
164	1988	S: Nachttaxi	new product / service	customer	service
160	1988	Qualität (minimierung Verspätungen), = -15 Reiszeit	service quality	customer	service
161	1988	S: mobiles Personal,	customer service	customer	service
168	1989	Haltestellen Behindertengerecht,	handicapped-suited	customer	service
167	1989	S: neue Wagen,	service quality	customer	service
171	1990	Maßnahme Behindertengerechte Infrastruktur	handicapped-suited	customer	service
173	1990	Qualität: Reinigung Nachts, Fegen der Haltestellen	cleanliness	customer	service
183	1991	Unterstände (JC Decaux)	upgrade stops / stations	customer	service
182	1991	anbindung verkaufsstände	shopping facilities	customer	service
175	1991	S: Maßnahmen behindertenfreundlich,, ,	handicapped-suited	customer	service
177	1991	Qualität: Reinigung	cleanliness	customer	service
188	1992	Qualität: Reiningung, "rotes Telefon" zur kurzfristigen beseitigung Vandalsismus, Rauchverbot	quality and customer orientation	customer	service
199	1993	Infar: Umbau Haltestellen mitt WC, Kioks, etc	upgrade stops / stations	customer	service
195	1993	Verbesserung Sicherheit durch Sicherheitsdienst	security	customer	service
196	1993	Ausbau behindertengerecht	handicapped-suited	customer	service
200	1993	abendl Busverkehr: Bustaxen	new product / service	customer	service
209	1994	Minimierung Umsteigezeiten	service quality	customer	service
201	1994	elektronische Wertmarken Verkaufskassen am Schalter	cashless payment	customer	service
202	1994	bargeldloser Zahlungsverkehr: Ausweitung	cashless payment	customer	service
218	1995	Taxi-Ruf	new product / service	customer	service
219	1995	Halten auf Wunsch	new product / service	customer	service
220	1995	Haustürbedienung	new product / service	customer	service
212	1995	U: Infoscreen zur FG Information	customer information	customer	service
213	1995	U: Countdown bis zu nä U-Bahn	customer information	customer	service
210	1995	Beschwerdemanagement	complaint management	customer	service
211	1995	Programm Saubere Haltestellen	cleanliness	customer	service
216	1995	Vertrieb: PayCard bargeldlos, elektronisches Fahrkartenverkaufssystem (kundengerechte Form)	cashless payment	customer	service
222	1996	B: Halten nach Wunsch	new product / service	customer	service
221	1996	neue Ladenöffnungzeiten: Anpassung durch Zugverlängerung	customer service	customer	service
223	1996	B: Verbesserung Anschlüsse U-Bahn/Bus durch Anzeige	service quality	customer	service
224	1996	Trainscree zur Fahrgastinformation	customer information	customer	service
225	1996	Zeitungsverkauf in Bussen	newspaper onboard	customer	service
226	1996	Einführung Paycard	cashless payment	customer	service
228	1996	U: neues Desing Haltestellem	upgrade stops / stations	customer	service
227	1996	B: nachfrageanpassung (Kleinbus und Verstärkung)	capacity	customer	service
229	1997	S: Fahrradmitnahme,	free bicycle carriage	customer	service
231	1997	Zentrale Kundeninformation (MA Steigerung)	customer service	customer	service
233	1997	Mobilitätszentrale HH	customer service	customer	service
235	1997	ElektronischesFahrkartenverkeufssystem Busse	onboard ticket vending	customer	service
238	1997	Halten auf Wusch,	new product / service	customer	service
241	1998	Leerfahrten für Passagiere	new product / service	customer	service
242	1998	U: Erhöhung Platzangebot,	capacity	customer	service
239	1998	Qualität: Information, Kundenorientierung (freundlichkeit etc), Kundengeespärche, 24h Leitstelle und Kundencenter, Sicherheit, Beschwerdemanagement neu, Hochbahn Infoshops,	quality and customer orientation	customer	service
245	1999	Marketingmaßnahme zur Kundenaquirieunrg	marketing and customer aquisition	customer	service
246	1999	Ausmaub und Anwendung Marketting (Partynachtbus)	marketing and customer aquisition	customer	service
247	1999	Vertärkung Kundenorientierung	customer service	customer	service
249	1999	Medien: intern : expressinfo,	customer information	customer	service
251	1999	Sicherheitskonzept: nach 19:00 nur noch FZ mit Notruf und Durchsicht, Kameras,	security	customer	service
253	1999	U: Zusätzlich Wagen	capacity	customer	service
254	1999	Sicherheit	security	customer	service
255	1999	ausbau Nachtservice = Kundenbindung bei jungen Leuten	new product / service	customer	service
256	1999	B: Service Diskobus	new product / service	customer	service
248	1999	Qualitätsmaßnahmen Schiene: , FG info, Erscheinungsbild.,)	quality and customer orientation	customer	service
257	2000	Eröffnung MediaStation (6 Terminals)	customer information	customer	service
258	2000	neueröffnung Servcestelle	customer service	customer	service
259	2000	Qualität: FG info bei besonderen Betriebslagen + Sicherheit	security	customer	service
259	2000	Qualität: FG info bei besonderen Betriebslagen + Sicherheit	security	customer	service
260	2000	B: Anzeig Haltesztellen innen	customer information	customer	service
263	2001	Kleinbus - Ein-Austige auf Wunsch	new product / service	customer	service
264	2001	Wssertaxis	new product / service	customer	service
265	2001	Einführung neues Produk Metrobus: alte und neue Verbindungen, Direktverbindungen, Querverbindungen außerhalb, Ergänzung zum Schnellbahnnetz	new product / service	customer	service
266	2002	Kampange: HVV statt Auto für Pendler: spart 25000 € pro Jahr	marketing and customer aquisition	customer	service
267	2002	durchführunge eigener Studien., zb zufriedenheitsumfrage	survey	customer	service
268	2002	Fokus Haltestellenausbau	upgrade stops / stations	customer	service
272	2003	Umsteigeanlage modernisiert	upgrade stops / stations	customer	service
277	2004	Internet an Haltestellen	upgrade stops / stations	customer	service
278	2004	Videoausstattung (sämtliche Wagen)	security	customer	service
279	2004	Kundenbefragung	survey	customer	service
282	2004	Ausbau Haltestellen JCDecaux	upgrade stops / stations	customer	service
284	2004	Ausbau Nachverkehrsangebot	new product / service	customer	service
287	2005	Sichrheit: Koop mit Polizei	security	customer	service
286	2005	3 neue U-Store	shopping facilities	customer	service
290	2006	Barrierefreieheit	handicapped-suited	customer	service
292	2006	Marketingaktion mit TV	marketing and customer aquisition	customer	service
294	2006	Mobilfunktversorgung für U-Bahnnetz	upgrade stops / stations	customer	service
296	2006	Fokus Siocherheit	security	customer	service
295	2006	2 neue U Stores	shopping facilities	customer	service
298	2007	Ausbau Fahrgastinfo	customer information	customer	service
300	2007	Umgestaltung Busumsteigeanlage	upgrade stops / stations	customer	service
301	2007	Umgestaltung Ubahnhaltestellen	upgrade stops / stations	customer	service
302	2007	Auffrischung Fahrgastraum alte U-Bahn typen	quality	customer	service
304	2011	Alkoholverbot in Lininen	alcohol ban	customer	service
306	2011	neues Erscheinungsbild Kleidung	quality	customer	service
308	2012	Barrierefrei: Fortsetzung	handicapped-suited	customer	service
310	2012	Ausbau Sicherheit: mehr MA	security	customer	service
311	2013	4 Haltestellen barrierefrei	handicapped-suited	customer	service
312	2013	radabstellplätze	P+R (bikes)	customer	service
313	2013	verbesserung einstieg	handicapped-suited	customer	service
314	2013	anbindung hot spot bezirksamt	upgrade stops / stations	customer	service
315	2013	ausbau kapazitäz	capacity	customer	service
317	2013	ausbau sicherheitskonzept	security	customer	service
318	2013	neues Haltestellendesign	upgrade stops / stations	customer	service
19	1959	EDV einführung: Lochkartenmaschine	punch-card machine	IT	service
35	1963	Betriebsüberwachung durch funk	operation management by radio	IT	service
43	1964	elektronische Fahrpreisberechnung	electronic points	IT	service
46	1965	Fahrgastinformationen und Steuerung Betriebsablauf über leitstelle (funk)	operation management by radio	IT	service
47	1965	Einführung Analogrechner: Ermittlung der wirtschaftlichsten Fahrweise im Abh. Von Energieverbrauch/Strecke	IT (analog computer)	IT	service

48	1965	Betriebsleitsystem Bus (automatische Fahrplanüberwachung, signal alle 2,5 min)	computer aided dispatch and operation (system); automatic vehicle location	IT	service
52	1967	U: Fernsehanlagen,	monitioring via television	IT	service
54	1967	Funkleitstelle	radio control station	IT	service
55	1967	Fernsehkamera zur Verkehrsüberwachung	monitioring via television	IT	service
57	1968	Sprechfunk	radiotelephony	IT	service
62	1968	Fernsehen Zugabfertigung,	monitioring via television	IT	service
63	1968	Bus: vom Computer erstellter Fahrplan	computer aided scheduling	IT	service
70	1970	Echtzeit Datenübermittlung Fahrverlauf	real-time vehicle location	IT	service
75	1971	EDV einführung für Fahrzeugumlaufplanung	computer aided route and circulation planning	IT	service
96	1976	Signal und Nachrichtentechnik	telecommunications	IT	service
108	1979	Streckenprozessrechner	computer aided route and circulation planning	IT	service
109	1979	Nachrichtentechnik an Haltestellen	telecommunications	IT	service
113	1980	Sprechfunksytem für einzelpersonen	radiotelephony	IT	service
123	1982	Betriebsführungssystem U-Ban	computer aided dispatch and operation (system); automatic vehicle location	IT	service
128	1983	U: Sprechfunksystem für Sicherheitspersonal	radiotelephony	IT	service
131	1984	U: BetriebsführungssysteM (Standort, Soll_Ist Fahrplanvergleich)	computer aided dispatch and operation (system); automatic vehicle location	IT	service
140	1985	B: RBL mit 235 Bussen	computer aided dispatch and operation (system); automatic vehicle location	IT	service
141	1985	U: Betriebsführungssystem	computer aided dispatch and operation (system); automatic vehicle location	IT	service
142	1985	Ausbau Informtionssystem Busse	bus tracking system	IT	service
143	1985	Anschlusssicherung EDV	connection protection software	IT	service
147	1986	U: Betriebsführungssystem (6 von 11 Zentralstellwerken)	computer aided dispatch and operation (system); automatic vehicle location	IT	service
180	1991	DV Systeme	data handling software	IT	service
190	1992	DV Systme	data handling software	IT	service
194	1993	neues EDV systemm SAP/Aboriva für tarifumstellung	SAP for fares	IT	service
198	1993	Kosten: Einführung HOT System für Fahrplanumläufe, Dienstpläne, Dienstreihenfolge	HOT system	IT	service
204	1994	DV umstellung abgeschlossen	data handling software	IT	service
205	1994	Update SAP	SAP upgrade	IT	service
206	1994	SAP Abo Riva ausweitung	SAP upgrade	IT	service
232	1997	Einführung Geofox (Fahrplanauskunft)	journey planner (Geofox)	IT	service
236	1997	IT Strategie 2000: Umstellung auf SAP R3 für alle UN Bereiche	SAP R3	IT	service
237	1997	ASS (Anschlusssicherung)	connection protection software (ASS)	IT	service
240	1998	IT: Ausbau: Zugfunk, Train-Info, ASS)	train telephone; journey planner, ASS	IT	service
244	1999	Ausbau SAPR3=Kostensenkung	SAP R3	IT	service
250	1999	Medien extern: Überarbeite Webseite, Kiosk TV	webpage	IT	service
252	1999	ESTW	electronic points	IT	service
262	2001	FIMS SMS Auskunft	journey planner upgrade	IT	service
269	2002	FIMS SMS Auskunft	journey planner upgrade	IT	service
271	2003	Ausbau FIMS abgeschlosssen	journey planner upgrade	IT	service
274	2003	neuer Inetauftritt	webpage (upgrade)	IT	service
275	2003	1. Ausbaustufe in Bündelfunksystem in Betrieb	trunked radio system (digital)	IT	service
276	2004	Ausbau FGInfo	journey planner upgrade	IT	service
281	2004	B: Ausbau Digitalfunk	trunked radio system (digital)	IT	service
293	2006	B: Ausbau FIMS	journey planner upgrade	IT	service
303	2010	digitales funknetz u-bahn	trunked radio system (digital)	IT	service
305	2011	Software zum Stromsparen abegestellter U-Bahnen	energy saving software	IT	service
307	2012	Präsenz auf Social Media Plattformen	social media	IT	service

PORTO

Table A22: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	Tickets printing equipment	ticket machines	operations	service
2	1950	Geschwindigkeit	acceleration	operations	service
3	1950	Geschwindigkeit	acceleration	operations	service
4	1950	gelisdopplung	acceleration	operations	service
8	1951	Speed	acceleration	operations	service
9	1951	Speed	acceleration	operations	service
10	1951	automatische türen	automatic door system	operations	service
13	1952	2 spurig	acceleration	operations	service
18	1953	verdopplung	acceleration	operations	service
21	1955	speed	acceleration	operations	service
23	1955	verdopplung	acceleration	operations	service
24	1956	änderung öffnunfszeiten schulen	acceleration	operations	service
25	1956	verdopplung	acceleration	operations	service
26	1957	dopplung	acceleration	operations	service
33	1961	speed	acceleration	operations	service
35	1962	Turmwagen für Netzwartung	maintenance device	operations	service
36	1962	neue Wartungshalle	maintenance depot	operations	service
40	1964	Parking stations	vehicle parking	operations	service
41	1964	tankstelle	refueling	operations	service
44	1968	new depot (Areosa)	maintenance depot	operations	service
48	1972	Start Ticketmaschinen	ticket machines	operations	service
49	1972	problem troco = senha de troco	coin changing alterative	operations	service
52	1975	New ticket obliteration devices for buses	onboard ticket vending and obliteration devices	operations	service
53	1975	100 ticketentwerter	obliteration devices	operations	service
54	1975	1st bus corredor	acceleration	operations	service
57	1976	7 bus corridore	acceleration	operations	service
66	1978	New ticket obliteration devices	onboard ticket vending and obliteration devices	operations	service
69	1978	ticketdrucker/entwerte in volvo	onboard ticket vending and obliteration devices	operations	service
82	1980	ticketmaschinen	ticket machines	operations	service
84	1981	Reorganization of Parking Stations	vehicle parking	operations	service
85	1982	New Parking Station	vehicle parking	operations	service
86	1982	Parking Stations Specialization according to Vehicle Brand	vehicle parking	operations	service

91	1984	ticketmaschinen 150	ticket machines	operations	service
96	1985	tickermaschinen/entwerter	ticket machines	operations	service
103	1989	magnetticket	magnetic ticketing	operations	service
117	1992	magnetbandtickets	magnetic ticketing	operations	service
116	1992	neue generation ticketmaschinen	ticket machines	operations	service
119	1993	acquisition of new ticket obliteration devices	onboard ticket vending and obliteration devices	operations	service
121	1993	bus corredor	acceleration	operations	service
120	1993	neue ticketmaschininen	ticket machines	operations	service
125	1994	New Parking Station	vehicle parking	operations	service
126	1994	Station Expansion;	vehicle parking	operations	service
131	1995	Closure of Trolley Cars Parking Station	vehicle parking	operations	service
133	1995	neue ticketmaschinen (magnetbandkarte)	onboard ticket vending and obliteration devices	operations	service
139	1996	New ticket obliteration devices	onboard ticket vending n d obliteration devices	operations	service
142	1996	magnetbandkarteneinführung komplett	magnetic ticketing	operations	service
169	2000	New ticket obliteration devices	onboard ticket vending and obliteration devices	operations	service
178	2002	Intermodal Organization	operation upgrade (intermodal organization)	operations	service
179	2002	Parking Stations Relocation	vehicle parking	operations	service
181	2003	Intermodal Organization	operation upgrade (intermodal organization)	operations	service
199	2005	warteschlangenoptimierung an haltestellen	upgrade queuing system	operations	service
227	2010	training of passenger to behave in process	upgrade queuing system	operations	service
5	1951	mehr Wagen	capacity	customer	service
6	1951	Kapazität	capacity	customer	service
7	1951	Kapazität	capacity	customer	service
11	1952	verstärkung	capacity	customer	service
14	1953	recreative tours	new product / service	customer	service
15	1953	kapazität Strandbesuche	capacity	customer	service
16	1953	Kapazität	capacity	customer	service
17	1953	Reiseverkehr (passeio recreativo)	new product / service	customer	service
19	1954	Change of selling points' working hours	customer service	customer	service
20	1954	2 shelter	upgrade stops / stations	customer	service
22	1955	shelter	upgrade stops / stations	customer	service
29	1960	New shelters	upgrade stops / stations	customer	service
31	1961	verstärkerfahrten	capacity	customer	service
32	1961	kapazotät	capacity	customer	service
34	1961	kapazität	capacity	customer	service
38	1963	Kapazität	capacity	customer	service
39	1964	Night service	new product / service	customer	service
42	1965	4 shelter	upgrade stops / stations	customer	service
43	1967	shelter	upgrade stops / stations	customer	service
45	1968	shelter +3 auf 86	upgrade stops / stations	customer	service
46	1971	10 shelter	upgrade stops / stations	customer	service
47	1971	kundenumfrage (OD etc)	survey	customer	service
50	1973	Service Adjustment/Reduction	customer service	customer	service
51	1973	5 shelter	upgrade stops / stations	customer	service
58	1976	shelter	upgrade stops / stations	customer	service
60	1977	shelter	upgrade stops / stations	customer	service
62	1977	40 shelter	upgrade stops / stations	customer	service
63	1977	Kundendienst und Reklamationen	complaint management	customer	service
64	1977	mehr PR	marketing and customer aquisition	customer	service
65	1978	Change of selling points' working hours	customer service	customer	service
67	1978	shelter	upgrade stops / stations	customer	service
70	1978	kapaziät	capacity	customer	service
71	1978	PR und	marketing and customer aquisition	customer	service
72	1979	Single Agent Advertising Campaign	marketing and customer aquisition	customer	service
73	1979	shelter	upgrade stops / stations	customer	service
76	1979	AUFRÜSTUNG UNTERSTÄNDE	upgrade stops / stations	customer	service
77	1979	neues bimestrales Jornal	marketing and customer aquisition	customer	service
79	1980	Publication of a brochure containing the fares and the bus network	customer information	customer	service
80	1980	shelter	upgrade stops / stations	customer	service
83	1980	neuer Service: Transfer	new product / service	customer	service
88	1982	Kundenmanagement	customer service	customer	service
89	1983	bancos moldados	upgrade stops / stations	customer	service
90	1983	guia de transporte	customer information	customer	service
93	1985	nachtservice massiv	new product / service	customer	service
94	1985	Central Booking-Office	customer service	customer	service
95	1985	Expansion of the Network of Shelters	upgrade stops / stations	customer	service
97	1986	78 shelter	upgrade stops / stations	customer	service
98	1987	39 shelter	upgrade stops / stations	customer	service
99	1988	nachtservice	new product / service	customer	service
102	1989	Mobilitätsbefragung	survey	customer	service
104	1990	behinderete fahrgäste	handicapped-suited	customer	service
107	1991	24 h	new product / service	customer	service
108	1991	mobilitätsumfrage	survey	customer	service
110	1991	Transport Menschen mit Behinderung	handicapped-suited	customer	service
111	1992	(Rapid Service)	new product / service	customer	service
113	1992	mobilitätsbefragung	survey	customer	service
114	1992	kundenorientierung/kommunikation	customer service	customer	service
115	1992	6 lines 24h	new product / service	customer	service
118	1992	Behindertentransport	handicapped-suited	customer	service
124	1993	minicarros	mini buses	customer	service
122	1993	Kundeninformation an Haltestellen	customer information	customer	service
123	1993	Kundeninformstion bei Änderungen	customer information	customer	service
128	1994	verbesserte Kundeninformation über Leistung	customer information	customer	service
129	1994	verkaufstände	customer service	customer	service
134	1995	mini carros voller betrieb	mini buses	customer	service
135	1995	kundenorientierung/kommunikation	customer information	customer	service
136	1995	mulitbanco	cashless payment	customer	service
137	1995	neues ticketsystem (physisch) =Komfort für Kunden	magnetic ticketing - upgrade	customer	service
138	1995	SUPER BUS	new product / service	customer	service
140	1996	kundenorientierung/kommunikation real time	customer information	customer	service
141	1996	mobilitätsbefragung	survey	customer	service
143	1996	Kundenbedienzentrum Eröffnung	customer service	customer	service
144	1996	verstärkerfahrten	capacity	customer	service
145	1996	nachtservice	new product / service	customer	service
146	1996	low floor	handicapped-suited	customer	service
147	1997	Pre-purchased tickets	upgrade ticketing	customer	service
148	1997	(increase of the number of resale shops)	customer service	customer	service
149	1997	mobilitätsumfrage	survey	customer	service
150	1998	Pre-purchased tickets	upgrade ticketing	customer	service
151	1998	(increase of the number of resale shops)	customer service	customer	service
154	1998	new sevices1	new product / service	customer	service
155	1998	new sevices1	new product / service	customer	service
156	1998	new sevices1	new product / service	customer	service
157	1998	lowfloor buses	handicapped-suited	customer	service
158	1998	real time customer information	customer information	customer	service
159	1999	Pre-purchased tickets	upgrade ticketing	customer	service
160	1999	(increase of the number of resale shops)	customer service	customer	service
163	1999	neuer service: Aerobus (schnellbus zum FH)	new product / service	customer	service

164	1999	netzkarten	customer information	customer	service
165	1999	vouchers TAP	customer service	customer	service
166	2000	Pre-purchased tickets	upgrade ticketing	customer	service
167	2000	(increase of the number of resale shops)	customer service	customer	service
172	2000	Qualitätsbefragun	survey	customer	service
175	2001	social acitvity: elderly, kids	marketing and customer aquisition	customer	service
176	2001	servic großveranstaltungen	new product / service	customer	service
177	2001	Qualitätsbefragun	survey	customer	service
173	2001	Digital Information Panels	customer information	customer	service
174	2001	real time kundeninofrmation (panels)	customer information	customer	service
180	2002	Qulitätsbefragung	survey	customer	service
182	2003	service for elderly	new product / service	customer	service
183	2003	weihnachtsservice	new product / service	customer	service
184	2003	Coexistence of monomodal and intermodal fare system	customer service	customer	service
185	2004	ombusdsmann	complaint management	customer	service
186	2004	student buses queima	new product / service	customer	service
187	2004	aero service change	new product / service	customer	service
191	2004	vídeo vigilância	security	customer	service
189	2004	20 Painéis de Informação ao Público (PIP)	customer information	customer	service
190	2004	novo videowall no Centro de Controlo da Frota,	customer information	customer	service
193	2005	imrpoved night service	new product / service	customer	service
194	2005	SMS Bus	new product / service	customer	service
196	2005	campagna queues	customer information	customer	service
197	2005	campagna andante	customer information	customer	service
200	2005	informationscampagnen	customer information	customer	service
201	2006	beschwerdebücher	complaint management	customer	service
203	2006	massive kundeninformation	customer information	customer	service
204	2006	massive kundenwerbung	marketing and customer aquisition	customer	service
205	2006	verlängeurng öffnungszeiten kundencenter	customer service	customer	service
206	2006	ausbau social service lines	new product / service	customer	service
207	2006	verdoppeln verkaufpunkte	customer service	customer	service
209	2006	sicherheit FG in FZ durch videoaufz	security	customer	service
210	2006	sicherheitsprozeduren	security	customer	service
211	2006	neue Produkte: porto by night, porto a brilhar	new product / service	customer	service
212	2007	PR massnahmen	marketing and customer aquisition	customer	service
213	2007	Werbemassnahmen PT	marketing and customer aquisition	customer	service
214	2007	gartierte umstiege	marketing and customer aquisition	customer	service
215	2007	ausbau wochenendservice	new product / service	customer	service
216	2007	ausbau nachtservice	new product / service	customer	service
219	2008	Marketing Junge Kunden und ander Kampagnen	marketing and customer aquisition	customer	service
220	2008	ausbau kaufmöglichkeiten tickets	customer service	customer	service
218	2008	Ausbau Information an Haltestellen (physisch): neues System	customer information	customer	service
221	2009	braille info an haltestellen	handicapped-suited	customer	service
222	2009	Porto VIP passport (produkt)	new product / service	customer	service
223	2009	infromation nachtlinien an haltestellen	customer information	customer	service
224	2010	neuer telefonservice für kunden	customer service	customer	service
228	2010	student start kits	new product / service	customer	service
229	2010	customer support on blue line	customer service	customer	service
226	2010	7 information screens + 15 displays real time in action	customer information	customer	service
230	2011	closure selling station	customer service	customer	service
231	2011	new: GATO flexilbe service	new product / service	customer	service
233	2011	closure ombudsmann service	complaint management	customer	service
234	2011	angebotskürzung	customer service	customer	service
235	2011	anapssung kapazität nachtlinien (minibusse weekdays)	capacity	customer	service
236	2011	tourist service (porto tram city tour)	new product / service	customer	service
238	2011	kundenkampagnen	marketing and customer aquisition	customer	service
237	2011	more public information systems	customer information	customer	service
239	2012	civitas bus service	new product / service	customer	service
240	2012	vodafone mexefest	new product / service	customer	service
244	2013	information über zone/zonenwechsel in bussen	customer information	customer	service
12	1952	ausbau kommuniktaion per telefon	radio-telephony	IT	service
27	1959	Traffic statistical data base	data handling (traffic data base)	IT	service
28	1959	traffic analysis	data handling (traffic data base)	IT	service
30	1960	Purchase of controllers	controllers	IT	service
37	1963	Extension of radio-telephonic communiation network	radio-telephony	IT	service
55	1975	bedarfsangepasstes Anggebot = computer	computer-aided demand analyis	IT	service
56	1976	Implementation of an Integrated Information System	monitoring system	IT	service
61	1977	verkehrsmanagement elektronisch	computer aided dispatch and operation (system); automatic vehicle location	IT	service
68	1978	verkehrsmanagement elektronisch	computer aided dispatch and operation (system); automatic vehicle location	IT	service
74	1979	verkehrsmanagement elektronisch	computer aided dispatch and operation (system); automatic vehicle location	IT	service
81	1980	verkehrsmanagement elektronisch	computer aided dispatch and operation (system); automatic vehicle location	IT	service
87	1982	Establishment of Performance Evaluation	computer aided performance montitoring	IT	service
92	1984	einführung Computer	IT (computer)	IT	service
100	1989	New Fleet Control System	computer aided dispatch and operation (system); automatic vehicle location	IT	service
101	1989	IT Investment	IT (computer)	IT	service
105	1990	IT	IT (computer)	IT	service
106	1991	IT Investment (continued)	IT (computer)	IT	service
109	1991	Sistema de Apoio a exploracao	operation support system	IT	service
112	1992	SAP System Implementation (completion)	SAP	IT	service
127	1994	Expansion of SAE System	operation support system	IT	service
130	1994	real time information	customer information	IT	service
132	1995	Expansion of SAE System	operation support system	IT	service
152	1998	new technology for season tickets	upgrade ticketing technology	IT	service
153	1998	Project GIST Implementation (continued)	decision making support system	IT	service
161	1999	SAP System Implementation	SAP	IT	service
162	1999	webauftritt	web page	IT	service
168	2000	Project SIGA	SIGA project	IT	service
170	2000	SAP System Implementation (conclusion)	SAP	IT	service
171	2000	GPS bus tracking/operation planning	GPS bus tracking/operation planning	IT	service
188	2004	ITINERARIUM	journey planner	IT	service
192	2004	MAP NETWORK EASY ACCESS (handicappes)	handicapped-suited	IT	service
195	2005	ITINERARIUM	journey planner	IT	service
198	2005	printing system	printing system	IT	service
202	2006	sms motorista (internes kommunikationssystem)	internal communication system for drivers	IT	service
208	2006	update itinerarium	journey planner (upgrade)	IT	service
217	2007	GESBUS in action (effizienz)	bus management system	IT	service
225	2010	computer platform for complaints and suggestions	complaint management (online)	IT	service
232	2011	STCP facebook/twitter	social media	IT	service
241	2012	ausbau Gobus info sytem	customer information	IT	service
242	2012	ausbau public information system (screens)	customer information	IT	service

243	2012	move-me intermodale info app real time	journey planner	IT	service
245	2013	ausbau GOBUS	customer information	IT	service
246	2013	ausbau social medien	social media	IT	service

DRESDEN

Table A23: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1957	Zeitkartentriebwagen	season ticket-only wagon	operations	service
2	1957	Einschränkung Verkauf in Wagen	other operations optimization	operations	service
7	1958	Zeitkartenwagen fortsetzung	season ticket-only wagon	operations	service
11	1959	Einrichtungswagen (eine Richtung)	one-way train	operations	service
12	1959	Zeitkartensystem Trieb und Beiwagen (ZZ)	season ticket-only wagon	operations	service
13	1959	Kassierschaffner an Bahnhöfen	conductor only at train station	operations	service
18	1960	Ausweitung ZZ Betrieb	season ticket-only wagon	operations	service
21	1960	Stanzzangen/standard Fahrscheine	upgrade ticketing system	operations	service
22	1961	Bus: fahrscheinlose Abkassierung durch Zahlbox auf Linien R, AFILNHPW 97/104 mit Zahlbox KOM	upgrade ticketing system	operations	service
24	1963	Gleis auf Bus wegen Winter = Probleme	acceleration	operations	service
36	1967	Pulkfahren	driving in groups	operations	service
38	1968	Dispatcherfahrzeug	traffic and operations safety	operations	service
43	1969	Doppelhaltestellen	shared bus stops	operations	service
40	1969	Laufende Verkehrsanaylsen um ad hoc einzugreifen	continouse traffic analyis	operations	service
45	1970	Die Gleisschleifen Hellerau und Pillnitz werden im Jahr 1970 in Betrieb genommen	acceleration	operations	service
47	1971	Einführung Großzüge auf hochfrequentierten Achsen	acceleration	operations	service
49	1971	Nord-Südachse wird übergeben	acceleration	operations	service
50	1972	Einführung Haupdispatcher	traffic and operations safety	operations	service
51	1972	Gleisschleife Coschütz	acceleration	operations	service
52	1972	4-Brigade-Systems für Verkehrslenkung	traffic and operations safety	operations	service
56	1973	Verkehrssicherheit erhöht durch Überachung	traffic and operations safety	operations	service
60	1974	Mechanisiering der instandhaltungsprozesse	maintenance	operations	service
61	1974	L9: Fahrzeugupgrade (schneller)	acceleration	operations	service
63	1975	Reduktion Behängungsgrad	other operations optimization	operations	service
69	1977	Umstellung Linie 5 Tatra	acceleration	operations	service
79	1980	Heck-an-Heck Technologie Tatra (nur Einstieg im Voder	acceleration	operations	service
80	1981	neue Betriebswerksttt	maintenance	operations	service
83	1982	neue Dispatcherzentrale	central dispatching	operations	service
88	1983	Wiedereinführung Wechseltechnologie	acceleration	operations	service
89	1983	Reduzieerung SEV: Heck and Heck	acceleration	operations	service
92	1984	Heck-zu-Heck Technologie	acceleration	operations	service
93	1984	Wiedereinführfung Wechseltechnologie im KOM und Strabbetrieb (Kommt als eine Linie an, fährt als andere weiter)	acceleration	operations	service
96	1985	Neuer Betriebsbahnhof senkt Ausfallzeiten und Kraftstoffverbrauch, Leerkilometer, Pausenversorgung, Sanitätsituation	maintenance	operations	service
99	1985	Ablösung SEV Linie durch KOM	tram to bus	operations	service
104	1987	Li 4 auf tatra	acceleration	operations	service
109	1988	L4 Tatra	acceleration	operations	service
115	1993	Verkaufsautomaten (Reduzierung Verkaufspersonal von 80 auff 20)	ticket machines	operations	service
117	1993	Bevorrechtigung: Abmarkierung, onboard, Ausstattung lichtsignalanlagen	acceleration	operations	service
122	1994	Speed	acceleration	operations	service
123	1994	Lösung: Busspuren, Bevorschaltung, Beschilderung)	acceleration	operations	service
124	1995	Beschleunigungsprogramm (infrarot, neubau lichtsignal, behindertengerecht bushs, busspuren, buskaps, verkehrsorga)	acceleration	operations	service
135	1998	Beschleunigungsprogramm	acceleration	operations	service
148	2001	Kombinierte ÖPNV Trasse	acceleration	operations	service
150	2001	1 NGT8=2-3 Tatrawagen	other operations optimization	operations	service
153	2002	einführung mobiler Dispatcher	traffic and operations safety	operations	service
160	2004	Wartungsfreier Bahnsteig = Fußbodenheizung	other operations optimization	operations	service
161	2005	Separierung voranbringen	acceleration	operations	service
168	2007	Separate Spur	acceleration	operations	service
175	2008	separierung	acceleration	operations	service
182	2009	Die Separierung der vorhandenen Infrastruktur für Straßenbahnen und Busse so weit als möglich vom Individualverkehr ist nur eine, letztlich aber die zentrale Möglichkeit, um einen staufreien, schnellen und damit wirtschaftlichen ÖPNV zu realisieren. Ein attraktiver ÖPNV wird ebenso auch durch intelligente Ampelsteuerung, barrierefreie Haltestellen oder Rasengleise geprägt.	acceleration	operations	service
3	1957	Buslinie Kapaziztätserweiterun (D)	capacity	customer	service
4	1957	Buslinie Kapaziztätserweiterung Gelegenheitsverkehr)	capacity	customer	service
5	1957	Behängungsgrad 1,19 auf 1,23	capacity	customer	service
6	1957	Buslinie Kapaziztätserweiterun (K)	capacity	customer	service
9	1958	Bus Flugzeugwerk	new product / service	customer	service
10	1959	Zeitkartenbezugssystem	seasonal ticket system	customer	service
14	1959	Schrank Fundsachen	lost and found	customer	service
15	1959	Bus: Kapazität	capacity	customer	service
16	1959	Bus: Pendelbusse	capacity	customer	service
25	1964	Kapazität +: Li 80	capacity	customer	service
26	1964	Kapazität: - Z, 62, 4	capacity	customer	service
27	1964	nur Berufsverkehr: 3,4,5,17,88	other operations optimization	customer	service
28	1965	Kapazität+: Li. 10, 52, 6	capacity	customer	service
29	1965	Kapazität -: Linie 2	capacity	customer	service
33	1966	Einführung von Bedarfswagen	capacity	customer	service
30	1966	Kapazität +: 3,14,5	capacity	customer	service
31	1966	Kapazität -: 13, 62, 4, 6	capacity	customer	service
32	1966	Sonderlinie Rennbahn	new product / service	customer	service
34	1967	Abendlinien (nach 20 Uhr/20min Takt)	new product / service	customer	service
37	1967	Nur die Linie 11 verkehrt aus sicherheitstechnischen Gründen weiterhin mit Zugbegleitern.	security	customer	service
39	1969	Kapazitätserweiterun auf Linie 10	capacity	customer	service
44	1970	neue Bahnen = mehr Kompfort	quality	customer	service
46	1971	Qualitätsanalysen	quality	customer	service
48	1971	Einführung Großzüge auf hochfrequentierten Achsen	capacity	customer	service
53	1972	service Coschütz	new product / service	customer	service
54	1973	Verbesserung Pünktlichkeit	quality	customer	service
55	1973	Senkung Störzeiten/Sperrzeiten	quality	customer	service
59	1974	Pünktlichkeitsverbesserung	quality	customer	service
62	1975	Erhöhung Pünktlichkeit	quality	customer	service
64	1975	Tracking Qualitätskennziffern	quality	customer	service
65	1975	Beschwerdemanagement - 20%	complaint management	customer	service
66	1976	Erhöhung Verkehrsqualität auf Li/75/94	quality	customer	service
67	1976	Qualitätssicherungssystem Einführung an 8 Punkten mit Fahrerbefragung	quality	customer	service
68	1976	Bäderverkehr wegen Hitze	new product / service	customer	service
70	1978	Verstärkung KOM	capacity	customer	service
71	1978	Verstärking Linie 9	capacity	customer	service

72	1978	Verkehrsqualität	quality	customer	service
73	1978	Qualität und Quantität	quality	customer	service
74	1979	Erhöhung Verkehrsqualität	quality	customer	service
75	1979	Nachtverkehr: 0-4 Li: 2.4.11.12 + Nachtlinien	new product / service	customer	service
76	1979	E Linien als Kapaziätsverstärlkung, fahren gekürzt Linie	capacity	customer	service
78	1980	Stabilisierung Berufsverkehr	quality	customer	service
84	1982	Test Kleinbus	mini-buses	customer	service
85	1982	neue FZ auf Linien 4+5 (schneller)	acceleration	customer	service
91	1984	Kapazizätserhöhung	capacity	customer	service
97	1985	Funkanforderung nach Spiel Dynamo für extra kapazizät	capacity	customer	service
100	1986	L42: 8 Min verkürzung, Erweiterung platzangebot	quality	customer	service
101	1986	Erweiterung platzangebot	quality	customer	service
102	1987	Buslinie 97 = Mütter mit Kleinkindern	new product / service	customer	service
103	1987	Fahrgastinformation	customer information	customer	service
105	1987	Lärm- und Schwingungsminderngen	quality	customer	service
106	1988	Vorbereitung neue Wartehallen	upgrade stops / stations	customer	service
107	1988	Informationssystem	customer information	customer	service
108	1988	Bedarfsorientierte Fahrplananpassung auf Linien 77,78,79,97	capacity	customer	service
110	1989	Anpassung Beförderung an Bedarf:	capacity	customer	service
111	1989	Innengestaltung, piktogramme	customer information	customer	service
113	1993	Fahrradbeförderung	free bicycle carriage	customer	service
118	1993	5% neue Plätze	quality	customer	service
119	1994	Studentenshuttel	new product / service	customer	service
120	1994	Ausbai Vertrieb (5 Verkaufsstellen, 97 Ticketautomaten, 41 onboard, 550 Fremverkauf + Personal)	customer service	customer	service
121	1994	Schnellstraßenbahnlinie 51 "eröffnet". Die Linie, auch alsCitySprinter	new product / service	customer	service
125	1995	Aboclub: Informationen für Abonutzer	upgrade ticketing	customer	service
128	1997	Mobilitätsberatung	customer service	customer	service
129	1997	Nachtverkehr mit garantierten Anschlüssen	new product / service	customer	service
130	1997	Taxiruf	new product / service	customer	service
131	1997	Rabatte für Abonutzer	upgrade ticketing	customer	service
132	1998	Car-Sharing	new product / service	customer	service
133	1998	Mobiler Service (Kundenorientierung)	customer service	customer	service
134	1998	Individuelles Marketing (Anwohner Dresden Nord/Sür, wo netzerweiterung statfand =+30 Nachfragesteigerung)	marketing and customer aquisition	customer	service
136	1998	ALITA (in nachfrageschwachen Zeiten, Gebieten)	new product / service	customer	service
138	1999	Reisezeitverkürzunmg Peripherie um 11 Min	quality	customer	service
141	1999	Ausbau_ Carsharing, Alita, Radmitnahme, Taxiruf, Aboclub, Mobiler Service)	new product / service	customer	service
142	2000	Messung Kundenzufriedenheit	survey	customer	service
143	2000	Angeobtsumstellung	customer service	customer	service
144	2000	neues Mobiöitätszentrum	customer service	customer	service
146	2000	Behindertengerecht (25% Straba, 85% Busse)	handicapped-suited	customer	service
147	2001	verstärktes Marketing (Zusatzleistungen)	marketing and customer aquisition	customer	service
152	2002	Monitore Bus=Fahrgastinofssytem	customer information	customer	service
154	2003	Wochenendnachtverkehr Verbund	new product / service	customer	service
155	2003	Broschüren für Kunden	customer information	customer	service
156	2003	Fahrgastfernsehen	customer information	customer	service
157	2004	Anbindung an Unternehmen ZMD) Route 80	new product / service	customer	service
158	2004	Neue Haltestelle Infineon Nord	new product / service	customer	service
159	2004	Mobiler Service Revival	customer service	customer	service
162	2005	Neuer Servicepunkt Zentral/Postpltz	customer service	customer	service
163	2005	Blindeninformationszenrtum	handicapped-suited	customer	service
165	2005	Infomagazin	customer information	customer	service
166	2007	Verbesserung Samstags/abendverkehr	quality	customer	service
167	2007	Echtzeit abfahrsanzeige für privaten Computer	customer information	customer	service
169	2007	Reiszeitverk. Um 10 min	quality	customer	service
170	2007	14 neue barrierefreie Haltestellen	handicapped-suited	customer	service
171	2007	Hanbdyticket	smartphone ticket	customer	service
172	2007	GelbAss für Schüler	customer information	customer	service
173	2007	Begleitservice für Behinderte	handicapped-suited	customer	service
174	2008	Service: Haltestellen, Fahrzeugreinigung	cleanliness	customer	service
179	2008	Online-Abfahrtszeiten für Gastronomie, Handel und Behörden	customer information	customer	service
180	2008	Neues Kundenzentrum am Postplatz	customer service	customer	service
183	2009	Garantievergabe: Pünktlichkeit, Anschluss, Sauberkeit, Antwort)	quality	customer	service
184	2009	alle StraBa Barrierefrei	handicapped-suited	customer	service
186	2009	21 neue Haltestellen	upgrade stops / stations	customer	service
190	2011	Das Informations- und Werbeprogramm „InFahrt“ täglich	customer information	customer	service
191	2011	Videotechnik in Fahrzeugen	security	customer	service
194	2012	Erfolgreiche Werbekampagnen für das DVB-Abo	marketing and customer aquisition	customer	service
195	2012	Videoausrüstung der Fahrzeuge abgeschlossen	security	customer	service
196	2012	barrierefrei	handicapped-suited	customer	service
197	2013	Echtzeitinfos in Fahrzeugen	customer information	customer	service
198	2013	barrierefrei	handicapped-suited	customer	service
199	2013	Über Integrationsprojekte wie dem „Mobilen Service“ oder „Fahrzeug- und Haltestellenreinigung“ wird mit anderen Trä- gern an der Verbesserung des Services für den Fahrgast gearbeitet.	quality	customer	service
8	1958	Einführung UKW-Funk	VHF radio	IT	service
17	1959	neue UKW Anlage und Peripherie	VHF radio	IT	service
19	1960	Einführung Funkwagen	radio wagon	IT	service
23	1961	Erfolg Funkwagen als Koordinationsmittel(Dispatcher)	radio wagon	IT	service
41	1969	Stadtfunk zur Information	city VHF radio	IT	service
42	1969	Nachrichtentechnik zur Verbeserung Kommunikation Dispatcher, Bahnhof, Verkehrsknotenpunkten	IT for communication and monitoring	IT	service
57	1973	Wageneinsatzoptimierung	IT for optimization of operating vehicles	IT	service
58	1973	Verkürzung der Standzeiten	IT for optimization of standing time	IT	service
77	1979	Verbesserung Verkehrsorganistation	IT for optimization of traffic organisation	IT	service
81	1982	Optimierung der Transportbeziehungen	IT for optimization of traffic organisation	IT	service
82	1982	Energieoptimal Routenplanung	IT for optimization of routing (energy)	IT	service
86	1983	optimierung FZ Bereitstellung	IT for optimization of vehicle allocation	IT	service
87	1983	Optimierung Farzeugstationierung	IT for optmization of vehicle stationing	IT	service
90	1984	Verbesserung Fahrzeugbereitstellung	IT for optimization of vehicle allocation	IT	service
94	1984	Fahrzeugstationierung	IT for optimization of vehicle allocation	IT	service
95	1985	Minimierung Überführungsfahrten durch Optimierte Nutzung von Betriebstandorten	IT for optmization of vehicle stationing	IT	service
98	1985	"+70 Funkgeräte in Straßenbahnen"	radios on trams	IT	service
112	1992	Die ersten Straßenbahnen fahren 1992 testweise mit einem Bordrechner. Damit beginnt die Zeit des rechnergestützten Betriebsleitsystems (RBL) im Dresdner Nahverkehr.	computer aided dispatch (system), automatic vehicle location	IT	service
116	1993	RBL/IBIS/IRIS System	computer aided dispatch (system), automatic vehicle location	IT	service
126	1997	RBL auf Gesamtnetz	computer aided dispatch (system), automatic vehicle location	IT	service
127	1997	Aufbau GIS	GIS system	IT	service

137	1998	3. Stufe RBL	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
139	1999	RBL 3 fertig	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
140	1999	Echtzeitdatenb	real-time data handling	IT	service
145	2000	Handyfahrplan	journey planner	IT	service
149	2001	weppage	web page	IT	service
151	2002	Rechnergestützter Anschlussmanager	connection manager	IT	service
164	2005	ausbauwebseite (Auskunftssystem)	web page	IT	service
178	2008	neue Webseite, neue Funktionen	web page	IT	service
176	2008	Erneuerung RBL	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
177	2008	Verknüpfung mit RBL Regional/Eisenbahnverkehr	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
181	2009	Verbundweiten Kommunikationsund Betriebsleitsystems für den Nahverkehrsraum Oberelbe“ (RBL)	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
185	2009	Das Projekt zur Erneuerung des rechnergestützten Betriebsleitsystems (RBL) läuft seit 2009 und soll 2012 abgeschlossen sein	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
187	2010	Das neue Digitalfunknetz zur operativen Steuerung des Dresdner ÖPNV ist mit sechs von insgesamt acht Funkstationen in Betrieb gegangen: Bordrechner, der Digitalfunkantenne und einer Kombiantenne für das Satellitennavigationssystem GPS und die lokalen Datenfunknetze (WLAN), neuen Fahrscheindrucker	trunked radio system (digital)	IT	service
188	2010	Das Projekt zur Erneuerung des rechnergestützten Betriebsleitsystems (RBL) läuft seit 2009 und soll 2012 abgeschlossen sein	upgrade computer aided dispatch (system), automatic vehicle location	IT	service
189	2011	für Smartphones konzipierte mobile Website	web page	IT	service
192	2011	Fahrwegdiagnosesystem „FADIS“ für die Überwachung von Fahrsignalanlagen, Weichen und Betriebshofsteuerungen	driveway monitoring system	IT	service
193	2012	DVB startet auf Facebook durch	social media	IT	service

Management Decisions

HAMBURG

Table A24: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1950	Fahrzeugbeschaffunf Top Priority: alter Bestand	modernization (resources) [fleet]	optimization	management
2	1950	Rationalisierung: Verzicht auf Zugegleiter	streamlining (service) [single agent policy]	optimization	management
4	1951	Rationalisierung: Verzicht auf Zugegleiter	streamlining (service) [single agent policy]	optimization	management
6	1952	Verwaltungsvereinfachungen	streamlining (administration)	optimization	management
7	1952	Zentralisierung Buswartung	streamlining (administration)	optimization	management
8	1952	Rationalisierung	streamlining (administration)	optimization	management
9	1952	Einmannbedienung Bus	streamlining (service) [single agent policy]	optimization	management
12	1953	Einmannbedienung Bus	streamlining (service) [single agent policy]	optimization	management
13	1954	B: Einmannbetrieb + Großraum	streamlining (service) [single agent policy]	optimization	management
15	1955	B: Einmannbetrieb bis auf 4 Linien	streamlining (service) [single agent policy]	optimization	management
16	1956	B: 2 weitere Linien Einmannbetrieb (noch 3 bleiben)	streamlining (service) [single agent policy]	optimization	management
17	1957	Umstell SB auf Bus	streamlining (service) [supply]	optimization	management
19	1958	B: Einmannbetrieb (41,44)	streamlining (service) [single agent policy]	optimization	management
20	1958	Umstell SB auf Bus	streamlining (service) [supply]	optimization	management
21	1958	SB: Stillegungen	streamlining (service) [supply]	optimization	management
22	1958	Obusende - Wirtschaftlichkeitsgründe	streamlining (service) [supply]	optimization	management
24	1959	Einführung Vorschlagwesen	modernization (administration) [decision making]	optimization	management
28	1959	Rationalisierung in Werkstätten, Optimierung der Abläufe Verwaltung= setzt Personal frei	streamlining (administration)	optimization	management
25	1959	U: Zugabfertigungen nach Bildschirm, bei gekrümmten Bahnhöfen Personaleinsparungen	streamlining (service) [operations]	optimization	management
26	1959	B: Einmannbetrieb (41,44)	streamlining (service) [single agent policy]	optimization	management
27	1959	SB: Stillegungen	streamlining (service) [supply]	optimization	management
30	1960	Outsourcing von Arbeiten = Personalfreisetzung	streamlining (administration) [outsourcing]	optimization	management
32	1960	Personaloptimierung	streamlining (resources) [staff]	optimization	management
31	1960	U: Ultraschallgerät zur Schienenprüfung = Einsparung Streckenläufer	streamlining (service) [operations]	optimization	management
34	1961	300 Vorschläge zum Optmierung des Betriebsablaufs	modernization (administration) [decision making]	optimization	management
35	1964	SB: Einmannbetrieb,	streamlining (service) [single agent policy]	optimization	management
43	1965	Mangel an Personal = private UN	modernization (resources) [staff]	optimization	management
41	1965	S: Einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
44	1966	Einmannbetrieb Straba	streamlining (service) [single agent policy]	optimization	management
46	1966	S: Einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
48	1967	Rationalisierung in allen Bereichen	streamlining (all)	optimization	management
49	1967	Senkung spezifischer Stromverbrauch U,	streamlining (resources) [energy]	optimization	management
47	1967	SB: letze Linien auf Einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
57	1970	weitere Stillegung SB um 30km	streamlining (service) [supply]	optimization	management
61	1971	Erhaltungspolitik: Schwerpunkt Oberbau, elektrische INFRA	modernization (resources) [infrastructure and facilities]	optimization	management
59	1971	Personalmange = jugoslawische Busfahrer	modernization (resources) [staff]	optimization	management
60	1971	Anpassung aller Linine and nachfragschache Abendzeitem	streamlining (service) [supply]	optimization	management
63	1972	Konzessionsvergabe	streamlining (administration) [outsourcing]	optimization	management

66	1973	Erhaltung und Verbesserung bestehender Betriebsanlagen	modernization (resources) [infrastructure and facilities]	optimization	management
67	1973	Erneuerung/Erweiterung elekltrische Anlagen	modernization (resources) [infrastructure and facilities]	optimization	management
70	1974	ausbau erhaltungspolitijk	modernization (resources) [infrastructure and facilities]	optimization	management
69	1974	erhöhung personal, arbeitsmarkt günstig	modernization (resources) [staff]	optimization	management
72	1976	Instandhaltung und Sicherheit	modernization (resources) [infrastructure and facilities]	optimization	management
73	1976	Rüchbau stillgelegter Gleise zu Straße	modernization (resources) [infrastructure and facilities]	optimization	management
80	1977	Schiffe: Einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
81	1977	Anpassung des Angebotes aufgr sorgfältiger beobachtung und Fahrgastbefragun	streamlining (service) [supply]	optimization	management
82	1977	nur noch eine SB linie	streamlining (service) [supply]	optimization	management
83	1977	Umwandlung SB in Busspuren	streamlining (service) [supply]	optimization	management
89	1978	Stilleung SB	streamlining (service) [supply]	optimization	management
96	1979	Präsenz auf IVA	modernization (public image)	optimization	management
94	1979	Senkung Reparaturfälle für maschinelle Anlagen	modernization (resources) [infrastructure and facilities]	optimization	management
97	1979	EDV - software: Fahr, Umlauf, Dienspläne, Dienstreihenfolgen elektronisch erstellt: Kostenminimierung	streamlining (all)	optimization	management
95	1979	Verkürzung/Umgestaltung Bus wegen S-bahn - Wettbewerb	streamlining (service) [supply]	optimization	management
101	1980	U: weiterhin Wahrung und Erhaltung Bausubstanz	modernization (resources) [infrastructure and facilities]	optimization	management
104	1981	U: Umweltentlastung durch Wartungsprogramme	modernization (resources) [infrastructure and facilities]	optimization	management
109	1982	U: Modernisierungarbeiten	modernization (resources) [infrastructure and facilities]	optimization	management
110	1982	Programm: Senkung Stromverbrauch	streamlining (resources) [energy]	optimization	management
111	1982	Betriebsoptimierungen	streamlining (service) [operations]	optimization	management
112	1982	angebotsanpassung,	streamlining (service) [supply]	optimization	management
117	1983	Ende Alsterschifffahrt (nun outgesourcet) Konzession	streamlining (administration) [outsourcing]	optimization	management
127	1984	Öffentlichkeitsarbeit	modernization (public image)	optimization	management
126	1984	Umweltschutz	modernization (public image) [environment]	optimization	management
125	1984	Betriebsbeauftragter für Abfall	modernization (ressources) [environment]	optimization	management
121	1984	B: Antriebsoptimierung, Instandhaltung,	streamlining (resources) [energy]	optimization	management
122	1984	U: stromverbrauch durch geschwindigkeit und Stromabschaltung	streamlining (resources) [energy]	optimization	management
123	1984	Computergesteuerte Heizung von Streckeneinrichtung/Betriebsgebäuden	streamlining (resources) [energy]	optimization	management
124	1984	Wasserrückgewinnungsanlagen	streamlining (resources) [energy]	optimization	management
133	1986	Diesel -30,6%	streamlining (resources) [energy]	optimization	management
136	1987	Fördermittel auch für Busbeschaffung	modernization (resources) [fleet]	optimization	management
142	1988	Vergabe von Konzession 3	streamlining (administration) [outsourcing]	optimization	management
140	1988	Kostenreduzierungmaßnahmen	streamlining (all)	optimization	management
141	1988	Kostenreduzierung: Schließung Betriebshof,	streamlining (all)	optimization	management
144	1988	Stilllegung von Fahrtreppen	streamlining (resources) [infrastructures and facilities]	optimization	management
143	1988	Personaloptimierung	streamlining (resources) [staff]	optimization	management
148	1989	Kostenuntersuchung durch externe	modernization (administration) [decision making]	optimization	management
151	1989	Programm: Behindertenfreundliche U-Bahöfe bis 1995 mit Aufzügen, Bahnsteigerhöhung, Leitstriefen, markierung von Treppenstufen.	modernization (public image)	optimization	management
150	1989	b: Vergabe Konzession 21,4% von Drittunternehmern	streamlining (administration) [outsourcing]	optimization	management
149	1989	Verkauf von Beteiligungen	streamlining (other)	optimization	management
153	1990	umstrukturierung orga: spartenbildung (u.A. U-Bahn, Bus)	modernization (administration) [management structure]	optimization	management
156	1990	Qualität: Beschleunigung (Busspuren, signale (LSA) bis 1993)	modernization (service) [operations]	optimization	management
154	1990	Vergabe von Konzession (25%)	streamlining (administration) [outsourcing]	optimization	management
155	1990	Kostenoptimierung Personal	streamlining (resources) [staff]	optimization	management
166	1991	Kosten: (Konzessionen auf 29,9%)	streamlining (administration) [outsourcing]	optimization	management
164	1991	Ausbau: Peronaleinsatzoptimerung	streamlining (resources) [staff]	optimization	management
165	1991	Optimierung: Reduzierung Zugfahrermehrbedarf durch bessere Planung,	streamlining (resources) [staff]	optimization	management
167	1992	Kosten: Konzessionen 30,1%,	streamlining (administration) [outsourcing]	optimization	management
168	1992	Programme Senkung Krankenstand	streamlining (resources) [staff]	optimization	management
169	1993	Einführung Charterwayverfahren zum chartern von Bussen	modernization (administration) [charter]	optimization	management
170	1993	Programm "Verbesserung des erscheinunbgsbilds" für HS	modernization (public image)	optimization	management
171	1993	Programm Verbesserung Betreib und Instandhaltungsbedingungen	modernization (resources) [infrastructure and facilities]	optimization	management
174	1994	Vorschlagwesen	modernization (administration) [decision making]	optimization	management
173	1994	Ausbau Hausdruckerei (90% inhouse)	modernization (administration) [insourcing]	optimization	management
175	1994	Einführung OPUS und PDS = Bessere Nutzung Personal	streamlining (resources) [staff]	optimization	management
182	1995	Outsourcing Betriebskrankenkasse	modernization (administration) [health insurance]	optimization	management
178	1995	U: leasingverfahren -25 Mio EUR Kostenersparnis	modernization (administration) [leasing]	optimization	management
185	1995	Strategie: bis 2010 +20%, moderne Orga und DV, Besteller-Ersteller Prinz, Sparten, neu: Abteilung Infrastruktur = Optimierung der Abläufe	modernization (administration) [management structure]	optimization	management
184	1995	kompletter BWL ansatz Orga umgesetz	modernization (administration) [management structure]	optimization	management
179	1995	Einführung QM	modernization (administration) [qm]	optimization	management
181	1995	Abfallentsorgung Duales System: 400.000gespart	modernization (ressources) [environment]	optimization	management
183	1995	Haltestellnservice	streamlining (administration) [outsourcing]	optimization	management
180	1995	Personalplanung EDV= 1 mio pro jahr sparen	streamlining (resources) [staff]	optimization	management
186	1996	Neustrutkurierung Betrioebshöfe: BWL	modernization (administration) [management structure]	optimization	management
187	1996	Einsparungen Betriebslenkung: 1,1 Mio/pa	streamlining (service) [operations]	optimization	management
192	1997	gegen Schwarzfahren	modernization (administration) [enforcement]	optimization	management
191	1997	Reorga U	modernization (administration) [management structure]	optimization	management
196	1998	Änderung Systematik Erfassung VErkehrsleistung	modernization (administration) [decision making]	optimization	management
195	1998	Start: restrukturierung Busbereich	modernization (administration) [management structure]	optimization	management
197	1998	Focus: Marketing, Presse- Öffentlichkeitsarbeit auf allen Medien, PR Begleitung Baumaßnahme	modernization (public image)	optimization	management
194	1998	Konzessionsübertrag auf PVG,	streamlining (administration) [outsourcing]	optimization	management

200	1999	Fahrkartenpprüfungh	modernization (administration) [enforcement]	optimization	management
198	1999	Trennung Ressorts Bus und Schienenverkehr	modernization (administration) [management structure]	optimization	management
201	1999	Störfallmanagement	modernization (service) [operations]	optimization	management
202	1999	Auschreibung Busverkehr	streamlining (administration) [outsourcing]	optimization	management
199	1999	Maßnahmen zur Senkung der Fehlzeit	streamlining (resources) [staff]	optimization	management
206	2000	strategische Unternehmensführung + Contolling: Vorbereitung	modernization (administration) [decision making]	optimization	management
207	2000	Risikobewertung	modernization (administration) [decision making]	optimization	management
211	2001	Umsetzung strategische Unternehmenssteuerung	modernization (administration) [decision making]	optimization	management
214	2001	U: restruk	modernization (administration) [management structure]	optimization	management
215	2001	QM bei Tochter	modernization (administration) [qm]	optimization	management
217	2002	Fahrkartenkontrolle Sicht nach 21 bu	modernization (administration) [enforcement]	optimization	management
218	2002	U: restruk	modernization (administration) [management structure]	optimization	management
223	2003	U: restruk	modernization (administration) [management structure]	optimization	management
222	2003	Focus: Brückeninstandhaltung	modernization (resources) [infrastructure and facilities]	optimization	management
228	2004	interne Informatiostechnologie für Controlling, Managemen = Hachbahn Monitor: finanzille und weiche Faktoren, Abweichungskontrolle, Gegensteuerung	modernization (administration) [decision making]	optimization	management
229	2004	Ausbau Conttrllingsystem	modernization (administration) [decision making]	optimization	management
233	2004	U: restruk	modernization (administration) [management structure]	optimization	management
230	2004	U: QM	modernization (administration) [qm]	optimization	management
231	2004	UITP Charta Sustainalbe Development	modernization (public image)	optimization	management
232	2004	Brückenbau fortgesetz	modernization (resources) [infrastructure and facilities]	optimization	management
238	2005	seit 2001 Zusammenführung Betriebsleitstelleb, 2005 erster Abschnitt	modernization (administration) [management structure]	optimization	management
243	2005	U: restruk	modernization (administration) [management structure]	optimization	management
242	2005	Kampagne zur Müllminimierung	modernization (public image) [environment]	optimization	management
241	2005	neues Reinigungskonzept	modernization (service) [operations]	optimization	management
239	2005	Ausbau Zentrale	streamlining (administration)	optimization	management
240	2005	Verlust: SchlswigHolstein Schiene	streamlining (other)	optimization	management
246	2006	Gantägige Fahrkartenkontrolle Schnellbus	modernization (administration) [enforcement]	optimization	management
247	2006	U: restruk	modernization (administration) [management structure]	optimization	management
248	2007	moderen Ideenmanagementsystem	modernization (administration) [decision making]	optimization	management
249	2007	Sale-and-leaseback SchienenfZ	modernization (administration) [sale and leaseback]	optimization	management
250	2007	Reinigungskampagne	modernization (public image) [environment]	optimization	management
256	2008	Verlängerung UITP Charta	modernization (public image)	optimization	management
254	2008	neue Betriebszentrale (Zentralisierte Steuerung)		optimization	management
260	2009	Ecodriving Programm	streamlining (resources) [energy]	optimization	management
269	2012	interne Zukunftskampange: Weiter denken	modernization (administration) [decision making]	optimization	management
266	2012	neue Beleuchtung in Verwaltung	streamlining (resources) [energy]	optimization	management
267	2012	Lichtmanagementsystem	streamlining (resources) [energy]	optimization	management
268	2012	Senung Stormkosten -5%	streamlining (resources) [energy]	optimization	management
271	2013	programm bürgerbeteiligung	modernization (administration) [decision making]	optimization	management
274	2013	Busbeschleunigungsprogramm	modernization (service) [operations]	optimization	management
3	1950	Beteiligung ZOB	vertical expansion (stakeholding scheme) [central bus station]	development	management
5	1951	Ausbau Dienstwohnungsbestand 873	vertical expansion (stakeholding scheme) [housing]	development	management
10	1953	O-BUS netz: neu O4, Sprunghafter Anstieg	horizontal expansion (service) [supply]	development	management
11	1953	Erhöhung Beförderungsangebot	horizontal expansion (service) [supply]	development	management
14	1954	Gemeinschaftsbetrieb mit Bundesbahn bei Störungen: Übernahme der Fahrgäste - kostenlos	horizontal expansion (joint venture) [DB]	development	management
18	1957	Beteiligung Wohnungsbau	vertical expansion (stakeholding scheme) [housing]	development	management
29	1959	Beteiligung an Rund- und Gesellschaftsfahrten Unternehmen	vertical expansion (stakeholding scheme) [touristic activities]	development	management
36	1964	Program Woohnung 29 mio 65-67	vertical expansion (stakeholding scheme) [housing]	development	management
37	1964	Ausbau Beteiligungen	vertical expansion (stakeholding scheme)	development	management
38	1964	Ausbau Angebot	horizontal expansion (service) [supply]	development	management
42	1965	Werklininenverkehr (Zuschüsse UN oder Fahrer aus Werk)	horizontal expansion (stakeholding scheme) [commission-based transport]	development	management
45	1966	Verbund	horizontal expansion (service) [supply]	development	management
50	1967	Ausbau U	horizontal expansion (service) [supply]	development	management
51	1967	Kaufhaus: Verkehrsangebot mit Warenversorgung und DL	vertical expansion (stakeholding scheme) [shopping]	development	management
52	1967	Ausbau Beteiligungen	vertical expansion (stakeholding scheme)	development	management
53	1967	Mineralölsteuer Einnahme	other (additional revenue)	development	management
54	1968	Werklinienverkehr 35 Linien	horizontal expansion (stakeholding scheme) [commission-based transport]	development	management
55	1968	U-Bahn bleibt Investionsschwerpunkt; Ausbau von Schnellbahnen (U)	horizontal expansion (service) [supply]	development	management
56	1968	Stadt gleicht Steuererhöhung aus = keine Tariferhöhung	other (additional revenue)	development	management
58	1970	Auffüllen von Marktlücken	horizontal expansion (service) [supply]	development	management
62	1971	Ausbau Werbung an FZ	vertical expansion [other] (advertisment)	development	management
64	1972	Ausbau Wohnbestand ca. 1500	vertical expansion (stakeholding scheme) [housing]	development	management
65	1972	Verbunderweiterung	horizontal expansion (service) [supply]	development	management

68	1973	Vereinbarung von Auslgeichszahlung für Betriebskosten	other (additional revenue)	development	management
71	1975	Eröffnung Parkhaus über U-Bahn 480 plätze	vertical expansion (stakeholding scheme) [P+R]	development	management
74	1976	Übernahmen Konsession S-Bahn Anbindung	horizontal expansion (service) [supply]	development	management
75	1976	Anbindung einer Gemeinde in Koop mit Duetsche Post = orstverkehrsline	horizontal expansion (service) [supply]	development	management
76	1976	Schiffahrt unrentabel - Vermietung, ausflugsverkehr	vertical expansion (stakeholding scheme) [touristic activities]	development	management
77	1976	Städtetouren mit DB Koop	horizontal expansion (joint venture) [DB]	development	management
78	1976	Ausbau maschineller anlagen (Fahrtreppen, Aufzüge, Automaten, Gepäckschließfächer) und	horizontal expansion (service) [supply]	development	management
84	1977	Übernahme weiterer Konzessionen (Busbahn) = Zubringer	horizontal expansion (service) [supply]	development	management
85	1977	neue Tochtergesellschaft (Touristik Alster = übvernahme unrentalbe Alsterschiffahrt)	vertical expansion (stakeholding scheme) [touristic activities]	development	management
86	1977	gegneleistung Aufträge für Industrie in Subfirmen	horizontal expansion (stakeholding scheme) [commission-based transport]	development	management
90	1978	Start Neubau Ubahnschule	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
98	1979	Netzwerken mit anderen Verkehrsbetrieben	horizontal expansion (joint venture) [other transport companies]	development	management
102	1980	Program zur Betriebsoptimierung verkaufbar, standardisierbar	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
103	1980	Beratungskoop mit Bundesbahn	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
105	1981	höher Zahlungen w/ Schwerbehindertengesetz	other (additional revenue)	development	management
106	1981	erhöhte Abgeltzahlung	other (additional revenue)	development	management
113	1982	Koop JC Decaux: 500 beleuchtete Unterstände mit Werbung	vertical expansion [other] (advertisment)	development	management
114	1982	Gewinnabführungsverträge	other (additional revenue)	development	management
128	1984	Vermarktung von EDV Lösungen ÖPNV	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
129	1985	Vermarktung Planfahrt EDV	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
157	1990	neue Beteiligung	vertical expansion (stakeholding scheme)	development	management
158	1990	Beschluss DV Gesamtkonzept - Durchführung über Tochter	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
172	1993	Übernahme Firma Sicherheitsdienst	vertical expansion (stakeholding scheme) [security]	development	management
188	1996	Konzession zurückführen	horizontal expansion (service) [supply]	development	management
189	1996	Umstrukturierung Verbund	horizontal expansion (service) [supply]	development	management
203	1999	Expansion: Erbringung von SPNV Leistungen außerhalb	vertical expansion (stakeholding scheme) [other cities]	development	management
204	1999	neue Einnahmen-Aufteilungsvertrag = höhere Erklöse	other (additional revenue)	development	management
208	2000	Expansion: Eintritt in reg. Eißenbahnverkehr	vertical expansion (stakeholding scheme) [other cities]	development	management
209	2000	Tochtergesellschaft für Ausdehnung in südliche Richtung	vertical expansion (stakeholding scheme) [other cities]	development	management
210	2000	B: neue Akqusitionen Linien	horizontal expansion (service) [supply]	development	management
212	2001	Start Investitionen Schienenverkehr	horizontal expansion (service) [supply]	development	management
213	2001	Großbauprojekt "2001"	horizontal expansion (service) [supply]	development	management
216	2001	weitere Expansion im nördlichen Niedersachsen	vertical expansion (stakeholding scheme) [other cities]	development	management
219	2002	Weitere expnsionsmaßnahmen	vertical expansion (stakeholding scheme) [other cities]	development	management
220	2002	Ausgründung ODEG (Bahn)	vertical expansion (stakeholding scheme) [other cities]	development	management
221	2002	Beteiligung (Bus)	vertical expansion (stakeholding scheme) [other cities]	development	management
224	2003	Reisebus Kauf	vertical expansion (stakeholding scheme) [touristic activities]	development	management
225	2003	weitere Expansion: Lübeck,	vertical expansion (stakeholding scheme) [other cities]	development	management
226	2003	Shopkonzept U-Store (Kiosk + Fastfood, Getränke) = Steigerung Attraktivität Haltestellen, Verbesserung gesamteindruck, Erhöhung Sicherheut, Kundenbindung, Einnahmequelle	vertical expansion (stakeholding scheme) [shopping]	development	management
227	2003	Kiel metronom	vertical expansion (stakeholding scheme) [other cities]	development	management
234	2004	weiter Expansion: Wiesbaden (B)	vertical expansion (stakeholding scheme) [other cities]	development	management
235	2004	fulda, (B)	vertical expansion (stakeholding scheme) [other cities]	development	management
236	2004	,Nordosthessen (S)	vertical expansion (stakeholding scheme) [other cities]	development	management
244	2005	Ausgründungy hysolutions: wasserstoffbezogene Aktivitäten, Brennstoffzellencluster HH	vertical expansion (stakeholding scheme) [R&D propulsion spin off]	development	management
245	2005	Verbundraumausweitung (Netz)	horizontal expansion (service) [supply]	development	management
251	2007	neue Beteiligung BENEX = Expansionvorhaben = Holdung	vertical expansion (stakeholding scheme) [other cities]	development	management
252	2007	Expansion: Donaubahn ab 2010	vertical expansion (stakeholding scheme) [other cities]	development	management
253	2007	Hydrogen Bus Alliance Gründung F&E	vertical expansion (stakeholding scheme) [R&D propulsion spin off]	development	management
255	2008	Programm Leistungsausweitung bei U + B	horizontal expansion (service) [supply]	development	management
257	2008	Regionalverkehr in Bayern gewonnen	vertical expansion (stakeholding scheme) [other cities]	development	management
261	2009	Neugründung agilis, erwerb Busunternehmen KVL	vertical expansion (stakeholding scheme) [other cities]	development	management
272	2013	Angebotserweiterung	horizontal expansion (service) [supply]	development	management
276	2013	Ausbildung Fachkraft imFahrbetrieb: selbst	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
23	1958	U: Fahrkartenautomaten, Test	ticketing	research	management
33	1960	U: Test Doppelwagen = 20% weniger Gewicht, wenigre Strom, vollelektrische Bremse	high capacity wagon	research	management
39	1964	Test: Triebwagen ohne Schaffner = Zeitkarten, Beiwagen mit Schaffner	single agent	research	management

40	1964	B: Test doppeleinstieg	double doors	research	management
79	1976	Forschungprojekte (F&E)	projects	research	management
87	1977	F&E Aufträge (Erfindungen, Patente)	contract research	research	management
88	1977	F6E: Schwerpunk U Bahnbetrieb: EDV Steuerung der Streckeinrichtungen, Linienzugbeeinflussung, Kabinenbahn (Seilbahn), Geräuschminderung	software	research	management
91	1978	F&E: Ubahn: PUSH Project	driverless trains	research	management
92	1978	U: Erprobung Zugfahrerselbstabfertigung	driverless trains	research	management
93	1978	U: Erprobung Zugfahrerselbstabfertigung	driverless trains	research	management
99	1979	F&E: mehr automatisierung	automatization, driverless trains	research	management
100	1979	F&E Entwicklng Bus zum Verkehrssystem	transport system bus	research	management
107	1981	F&E: schwerpunkt U	transport system underground	research	management
108	1981	F&E: Prototypen Stadtbusse	prototype buses	research	management
115	1982	F&E: Prototypen Behinderte Fahrzeugtyp	prototype for handi-capped	research	management
116	1982	Selbstfahrende Züge, Test	driverless trains	research	management
118	1983	F&E: automatisiertes Fahren	driverless trains	research	management
119	1983	U: Test fahrerlose Züge	driverless trains	research	management
120	1983	F&E: EDV im Busbereich für: Lineneführung, Fahrzeugbedarf = DIANA	software	research	management
130	1985	F&E: Push Komponenten werden Übernhmmen, , , ,	driverless trains	research	management
131	1985	F&E Simulation Busverkehrssystem	simulation	research	management
132	1985	F&E Verbesserung P+R	P+R	research	management
134	1986	Test Anschlusssicherungssystem Bus, Bahn, S-Bahn	connections	research	management
135	1986	Bus: Test Rußfilter = Umweltschutz = Image	environmental protection	research	management
137	1987	F&E: Verbesserung, Weiterentwicklung vorhandene Verkehrssystem Bus	transport system bus	research	management
138	1987	B: Test von Großraumtaxis	taxis	research	management
139	1987	Test Spurgeführte Busse	trolleybuses	research	management
145	1988	F&E: Datentechnologien für ÖPNV, ,	software	research	management
146	1988	FE: bargeldloses Bezahlen (Karten)	payment	research	management
147	1988	FE: Beeinflussung von Lichttsignalanlagen	accelleration	research	management
152	1989	F&E: Kunden: neu Sicherheitsgefühl, Fahrgastzählung, Blindenorientierung, Corporate Design)	customer relation	research	management
159	1990	F&E (neu: elektronisches Stellwerk,)	remote switches	research	management
160	1990	FE: Handbuch: Standardisierung VErkehrssteuerung	standardization	research	management
161	1990	Test Zugselbstabfertigung über Monitor	self-dispatching	research	management
162	1990	test Bio kraftstoffe	bio fuels	research	management
163	1990	Test schwefelarmer Diesel,	fuels	research	management
176	1994	Versuchsweise Radmitnahme auf bestimmte Strecken	cycle transport	research	management
177	1994	Versuch: Halten auf Wunsch	stop on request	research	management
190	1996	Testpotential Busspur: bis 33% ursprüngliche Fahrzeit	accelleration	research	management
193	1997	Test Wasserstoffbusse	hydrogen	research	management
205	1999	Test: Wasserstoffbus	hydrogen	research	management
237	2004	TestXXL Busse Ausbau	XXl buses	research	management
258	2008	Test: Diesel-Hyprid Doppelgelenkbus	hyprids	research	management
259	2008	Test Wasserstoffautos	hydrogen	research	management
262	2009	Test: Emobiliy	emobility	research	management
263	2010	Test E-Mobility	emobility	research	management
264	2010	Test- Hypridbus	hyprids	research	management
265	2011	DT5 im Test	tram upgrade	research	management
270	2012	F&E: E-Mobility, Leifahrzeuge	emobility, carsharing	research	management
278	2013	FE: switchh ausbau	software	research	management
280	2013	FE: Elektrobusse	electro buses	research	management
281	2013	FE: Erdwärme/Abwärme zur Beheizung U-Bahn	geothermal energy	research	management
282	2013	FE: Verbrauchsprognose	consumption forecast	research	management
283	2013	FE: Luftqualität	air quality	research	management

PORTO

Table A25: Network Decisions Porto.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
3	1951	Improvement of results on buses exploration	modernization (service) [operations]	optimization	management
4	1952	reduzierung SB	streamlining (service) [supply]	optimization	management
5	1952	ausbau busdepot	modernization (resources) [infrastructure and facilities]	optimization	management
6	1955	Construction of substations	modernization (resources) [infrastructure and facilities]	optimization	management
7	1956	Partial substitution of electric traction network	modernization (resources) [infrastructure and facilities]	optimization	management
8	1956	change in energy production = now receiver	streamlining (administration)	optimization	management
13	1959	rationalistaiton oficinas	streamlining (administration)	optimization	management
15	1959	replacement of tram lines	streamlining (service) [supply]	optimization	management
16	1959	Management: work divisions	modernization (administration) [management structure]	optimization	management
17	1959	new dvision Commercial and Statistics; organicacao; material e instucao de Pessoal;	modernization (administration) [management structure]	optimization	management
18	1960	verkürzung angebot SB	streamlining (service) [supply]	optimization	management
19	1960	neu: servicio de organicacao cientifica do trabalho	modernization (administration) [management structure]	optimization	management
20	1960	PR section	modernization (public image)	optimization	management
21	1961	neue Struktur: Rede e Telecomunicacoes	modernization (administration) [management structure]	optimization	management
22	1961	neu Büros	streamlining (administration)	optimization	management
23	1962	ausbau interne kommunikation	modernization (administration) [IT, software, communication]	optimization	management
24	1962	Fernwartung NETZ	modernization (administration) [IT, software, communication]	optimization	management
25	1962	neue Wartungshalle	modernization (resources) [infrastructure and facilities]	optimization	management
28	1963	feedback und rückerstattungswesen	modernization (administration) [decision making]	optimization	management
29	1963	ausbau kommuniktionstechnik	modernization (administration) [IT, software, communication]	optimization	management
30	1963	neu: Servico do pessoal (HR)	modernization (administration) [management structure]	optimization	management
31	1963	umfrage firmenintern	modernization (administration) [decision making]	optimization	management
32	1964	arbeitsvorbereitung büro neu	modernization (administration)	optimization	management
33	1964	wettbewerbswesen	modernization (administration) [decision making]	optimization	management
34	1964	Program of simultaneous revision of different spare parts for buses	streamlining (administration)	optimization	management
35	1965	remodelation plan in action (rationalistation)	streamlining (administration)	optimization	management
37	1966	remodeling	streamlining (administration)	optimization	management
38	1967	remodelling	streamlining (administration)	optimization	management
42	1967	SB zu Trolley und Bus	streamlining (administration)	optimization	management
43	1967	strukturänerung personalwesen = sparen	streamlining (resources) [staff]	optimization	management

45	1968	remodelling done	modernization (administration) [decision making]	optimization	management
46	1968	pool = concessions give	streamlining (administration) [outsourcing]	optimization	management
48	1971	Transport Planning	streamlining (service) [single agent policy]	optimization	management
49	1972	Einmannbetrieb start	streamlining (service) [single agent policy]	optimization	management
50	1973	umweltschutz (abgase, lärm)	modernization (ressources) [environment]	optimization	management
51	1973	Einmannbetrieb start	streamlining (service) [single agent policy]	optimization	management
52	1974	Einmannbetrieb start	streamlining (service) [single agent policy]	optimization	management
53	1975	new management	modernization (administration) [management structure]	optimization	management
54	1975	new estatutos	streamlining (administration)	optimization	management
55	1975	replacement of tram by 200 buses	modernization (resources) [fleet]	optimization	management
56	1975	kontrollzentrum netz	modernization (administration) [management structure]	optimization	management
57	1975	neue verwaltungstruktur	modernization (administration) [management structure]	optimization	management
59	1975	PR aktionen	modernization (public image)	optimization	management
61	1976	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
63	1976	management controll system and tracking	modernization (administration) [decision making]	optimization	management
64	1977	analytical accounting	modernization (administration) [decision making]	optimization	management
65	1977	einnahmenerfassung automatisch	modernization (administration) [decision making]	optimization	management
66	1977	neue Monitoringstruktur (Managementdep, Ausrüstung, Operations, Investment, Projekt, Statisitk)	modernization (administration) [management structure]	optimization	management
67	1978	einnahmenerfassung automatisch	modernization (administration) [decision making]	optimization	management
68	1978	kostensparung Homen/viatura	streamlining (service) [operations]	optimization	management
69	1978	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
70	1979	Single Agent (continued implementation)	streamlining (service) [single agent policy]	optimization	management
71	1979	einnahmenerfassung automatisch	modernization (administration) [decision making]	optimization	management
72	1979	Personalsenkung	streamlining (resources) [staff]	optimization	management
73	1979	Management of Investmens	modernization (administration) [decision making]	optimization	management
74	1980	Zentralstation Francos	modernization (resources) [infrastructure and facilities]	optimization	management
75	1980	einnahmenerfassung automatisch	modernization (administration) [decision making]	optimization	management
76	1980	einmanberieb	streamlining (service) [single agent policy]	optimization	management
77	1980	senkung ausfallrate	modernization (service) [operations]	optimization	management
78	1980	verwaltungstechnik	modernization (administration) [IT, software, communication]	optimization	management
80	1981	einmannbetrieb massiv	streamlining (service) [single agent policy]	optimization	management
81	1981	neue Führungspostionen	modernization (administration) [management structure]	optimization	management
83	1982	einmannbetrieb massiv	streamlining (service) [single agent policy]	optimization	management
84	1982	fahrer zur wartung	modernization (resources) [staff]	optimization	management
85	1982	Depot S. Roque	modernization (resources) [infrastructure and facilities]	optimization	management
86	1982	evaluierung personal	modernization (resources) [staff]	optimization	management
89	1983	management von ressourcen optimieren	streamlining (ressources)	optimization	management
90	1983	fensterglas (bessere wartung)	modernization (resources) [fleet]	optimization	management
91	1983	einmannpolitik	streamlining (service) [single agent policy]	optimization	management
92	1983	neues operation/management maintenance	modernization (service) [operations]	optimization	management
93	1983	rationalisierung/optimierung struktur	modernization (administration) [management structure]	optimization	management
94	1983	evaluation MA	modernization (resources) [staff]	optimization	management
95	1983	Dienstplanfahrer Optmierung	streamlining (ressources) staff	optimization	management
97	1984	bau neues depot via norte	modernization (resources) [infrastructure and facilities]	optimization	management
98	1984	ausbau depot francos	modernization (resources) [infrastructure and facilities]	optimization	management
99	1984	ausbau verwaltungsgebäude	modernization (resources) [infrastructure and facilities]	optimization	management
100	1984	strukturänderungwartung (streamlining)	streamlining (all)	optimization	management
101	1984	strafen und kontrollen steigend	modernization (administration) [enforcement]	optimization	management
102	1984	einmannbetrieb mässig	streamlining (service) [single agent policy]	optimization	management
103	1984	optimuerung Prokduktion	streamlining (service)	optimization	management
104	1984	Konzessionsvergabe	streamlining (administration) [outsourcing]	optimization	management
105	1985	verstärkte effizienz	streamlining (service)	optimization	management
106	1985	internet neue strukuren = effizienz	modernization (administration) [management structure]	optimization	management
108	1985	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
109	1985	steigerung kontrolle+strafe	modernization (administration) [enforcement]	optimization	management
107	1985	Konzessionsvergabe	streamlining (administration) [outsourcing]	optimization	management
110	1986	interne struktur	modernization (administration) [management structure]	optimization	management
111	1986	informtionstechnik	modernization (administration) [IT, software, communication]	optimization	management
112	1986	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
113	1987	computertechnick in allen bereichen (massive optimierung)	modernization (administration) [IT, software, communication]	optimization	management
114	1987	verstärkte kontrolle	modernization (administration) [enforcement]	optimization	management
115	1988	optimierung ressourcen	streamlining (ressources)	optimization	management
116	1988	neues depot	modernization (resources) [infrastructure and facilities]	optimization	management
117	1988	computertechnik	modernization (administration) [IT, software, communication]	optimization	management
118	1988	einmannbetrieb (mässig)	streamlining (service) [single agent policy]	optimization	management

119	1988	kontrolle fg	modernization (administration) [enforcement]	optimization	management
120	1989	computerausrstung	modernization (administration) [IT, software, communication]	optimization	management
122	1989	antibetrugsprogramm	modernization (administration) [enforcement]	optimization	management
124	1989	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
125	1989	software: zahlungsverkehr	modernization (administration) [IT, software, communication]	optimization	management
126	1989	umlaufplanug	modernization (administration) [IT, software, communication]	optimization	management
127	1989	verkehrsanalyse	modernization (administration) [IT, software, communication]	optimization	management
128	1989	personalplaungg	modernization (administration) [IT, software, communication]	optimization	management
131	1989	Anti-fraud Policy	modernization (public image)	optimization	management
132	1990	einmannbetrieb	streamlining (service) [single agent policy]	optimization	management
136	1990	interne kommunikation	modernization (administration) [IT, software, communication]	optimization	management
137	1990	ausbau DV	modernization (administration) [IT, software, communication]	optimization	management
138	1990	zentral system	streamlining (administration)	optimization	management
140	1990	Update software	modernization (administration) [IT, software, communication]	optimization	management
135	1990	blutspede	modernization (public image)	optimization	management
149	1991	Marketing	modernization (public image)	optimization	management
150	1991	PR = STCP teil der gesellschaft	modernization (public image)	optimization	management
151	1991	vorschlagswesen	modernization (administration) [decision making]	optimization	management
152	1991	ausbaut IT massiv	modernization (administration) [IT, software, communication]	optimization	management
153	1991	neues depot	modernization (resources) [infrastructure and facilities]	optimization	management
154	1991	SAE = technishce Program	modernization (administration) [IT, software, communication]	optimization	management
157	1992	Survey of Mobility Conditions	modernization (administration) [decision making]	optimization	management
160	1992	effizienzte nutzung	streamlining (all)	optimization	management
161	1992	umweltschutz	modernization (public image)	optimization	management
163	1992	subconcessions	streamlining (administration) [outsourcing]	optimization	management
171	1993	Replacement of trolley cars by motor bus vehicles	streamlining (service) [supply]	optimization	management
172	1993	Full implementation of the Service for Disabled People	modernization (service)	optimization	management
173	1993	Gründung General Management Einheit	modernization (administration) [management structure]	optimization	management
174	1993	outsourcing TÜV	streamlining (administration) [outsourcing]	optimization	management
184	1993	anschaffung computer	modernization (administration) [IT, software, communication]	optimization	management
185	1994	Replacement of trolley cars by motor bus vehicles;	streamlining (service) [supply]	optimization	management
189	1994	qualitätsmonitoring auf 2 linien	modernization (administration) [qm]	optimization	management
191	1994	ausbau IT massiv	modernization (administration) [IT, software, communication]	optimization	management
199	1995	Project GIST Implementation	modernization (administration) [IT, software, communication]	optimization	management
200	1995	trolleycar: ende	streamlining (service) [supply]	optimization	management
201	1995	neues ticketsystem (physisch) =bessr zu knotrollieren, besser zu monitoren	modernization (service) [ticketing]	optimization	management
202	1995	einführung telematic	modernization (service) [operation]	optimization	management
211	1996	gründung Qualitätsmonitoring	modernization (administration) [qm]	optimization	management
218	1996	Gründung Kommunikationsabteilung	modernization (administration) [management structure]	optimization	management
216	1996	konzessionsvergabe	streamlining (administration) [outsourcing]	optimization	management
226	1997	management board introduced	modernization (administration) [management structure]	optimization	management
227	1997	marketingmassnahmen	modernization (public image)	optimization	management
228	1997	internes monitoring system wird genutzt	modernization (administration) [monitoring]	optimization	management
238	1997	restructurieunrg	modernization (administration) [management structure]	optimization	management
240	1997	Increase of Company's Social Capital	modernization (administration) [management structure]	optimization	management
241	1998	neue zentrale maintances building	modernization (resources) [infrastructure and facilities]	optimization	management
242	1998	new image	modernization (public image)	optimization	management
243	1998	new headquarter = bundled = centralization	modernization (resources) [infrastructure and facilities]	optimization	management
244	1998	complete restructuring	modernization (administration) [management structure]	optimization	management
249	1998	new HR performance assessment system	modernization (administration) [monitoring]	optimization	management
250	1998	contract with fuel supplier=less costs	streamlining (ressources) [energy]	optimization	management
255	1999	centralisieurng	streamlining (administration)	optimization	management
256	1999	prozessoptimierung via IT	streamlining (administration)	optimization	management
257	1999	SAP	modernization (administation)	optimization	management
258	1999	restrukturierung	modernization (administration) [management structure]	optimization	management
260	1999	implementation SAP (management system	modernization (administation)	optimization	management
263	2000	Cost Containment Efforts	streamlining (all)	optimization	management
264	2000	personalrotation in maintenance	streamlining (ressources) [staff]	optimization	management
265	2000	work-flow software SAP	modernization (administation)	optimization	management
266	2000	SAP R/3 installation	modernization (administation)	optimization	management
267	2001	bus leasing	modernization (administration) [leasing]	optimization	management
271	2001	strukturänderung personalmanagement	modernization (administration) [management structure]	optimization	management
275	2002	Balanced Scorecard Model	modernization (administration) [monitoring]	optimization	management
276	2002	Staff Surveys	modernization (administration) [monitoring]	optimization	management
278	2002	outsourcing maintenance/nicht kernkompetenzen	streamlining (administration) [outsourcing]	optimization	management
279	2002	restukturierung maintanence	modernization (administration) [management structure]	optimization	management
280	2002	umweltmanagemern (ISO)	modernization (administation) (ISO)	optimization	management
284	2003	restructering, costs	streamlining (all)	optimization	management
285	2003	anpassung depots	streamlining (administration)	optimization	management
286	2003	optimierung resourcen	streamlining (resources)	optimization	management
290	2004	kapazitätsanpassung	streamlining (service) supply	optimization	management
291	2004	rationalisierung netzwekr	streamlining (service) supply	optimization	management

293	2004	restrukturierung intern	streamlining (administration)	optimization	management
294	2004	nur noch 2 depots	streamlining (administration)	optimization	management
295	2004	outsourcing TÜV	streamlining (administration) [outsourcing]	optimization	management
296	2004	produktivitätssteigerungen	streamlining (service)	optimization	management
298	2004	shut down terminal	streamlining (administration)	optimization	management
299	2004	Sistema de Apoio à Exploração e Informação (SAEI),	modernization (administration) [IT, software, communication]	optimization	management
301	2004	external consultant for network after metro	modernization (administration) [monitoring]	optimization	management
302	2004	service cuts	streamlining (service) supply	optimization	management
306	2005	new contracts	streamlining (administration)	optimization	management
307	2005	intranet	modernization (administration) [IT, software, communication]	optimization	management
308	2005	software update	modernization (administration) [IT, software, communication]	optimization	management
309	2005	information system (SAI)	modernization (administration) [IT, software, communication]	optimization	management
310	2005	Leasing	modernization (administration) [leasing]	optimization	management
311	2005	restructering	modernization (administration) [management structure]	optimization	management
312	2005	einführung SAEI system (real time operation management)	modernization (administration) [IT, software, communication]	optimization	management
313	2005	umstrukturierung STAFF departement	modernization (administration) [management structure]	optimization	management
303	2005	line decrease (massive)	streamlinging (service) [supply]	optimization	management
315	2006	neues Strafsystem schwarzfahrer	modernization (administration) [enforcement]	optimization	management
316	2006	sustainable development	modernization (public image)	optimization	management
317	2006	Qualitätszertifizierung	modernization (administation) (ISO)	optimization	management
318	2006	eleektronisches ticket erlauf erfassung kundenströme	modernization (administration) [monitoring]	optimization	management
320	2006	performance monitoring staff	modernization (administration) [monitoring]	optimization	management
321	2006	aquise staff and schulen	modernization (public image)	optimization	management
322	2006	sicherheit im Allg.	modernization (service) operations	optimization	management
323	2006	Support Tourismus und Feste	modernization (public image)	optimization	management
325	2006	verkauf 1 beteiligung	vertical expansion (stakeholding scheme) - disposal	optimization	management
330	2007	Kommunikation mit Stakholdern	modernization (public image)	optimization	management
331	2007	restrukturierung	modernization (administration) [management structure]	optimization	management
332	2007	prozessoptimierung	streamlining (all)	optimization	management
337	2008	Ethical code approved	modernization (public image)	optimization	management
338	2008	Zertifizierung: 3 ISO Normen Management: 9001, 14001 18001	modernization (administation) (ISO)	optimization	management
339	2008	pax kontrolle	modernization (administration) [enforcement]	optimization	management
341	2008	Kundenbefragung	modernization (administration) [monitoring]	optimization	management
342	2008	rationalisieunrg	streamlining (all)	optimization	management
346	2009	eco driving	streamlining (resources) [energy]	optimization	management
347	2009	MA monitoring	modernization (administration) [monitoring]	optimization	management
350	2010	balanced score card implemantiant	modernization (administration) [monitoring]	optimization	management
352	2010	messung kundenzufriedenheit	modernization (administration) [monitoring]	optimization	management
353	2010	implementation spidermaps	modernization (public image)	optimization	management
355	2010	automatische erstellung flyer linienverlauf	modernization (service) operations	optimization	management
356	2010	performance evaluation	modernization (administration) [monitoring]	optimization	management
358	2010	änderung wochenservice bei einigen linine	streamlining (service) supply	optimization	management
359	2010	änderung lebenszeit busse (wann verschrottet, verkauft)	streamlining (resources) [fleet]	optimization	management
362	2011	massive line restructuring	streamlining (service) supply	optimization	management
364	2011	umfrage arbeitbedingungen	modernization (administration) [monitoring]	optimization	management
365	2011	überall restrukturierung	modernization (administration) [management structure]	optimization	management
369	2011	Image: bilbliocarro und cultura sobre rodas	modernization (public image)	optimization	management
370	2011	safety programs	modernization (service) operations	optimization	management
376	2012	update websites	modernization (public image)	optimization	management
377	2012	Reduced frequencies with another operator in February 2012	streamlining (service) supply	optimization	management
378	2012	Readjusted the supply of the majority of the operated lines aiming at ensuring a better adjustment of supply to demand.	streamlining (service) supply	optimization	management
372	2012	closure of concessions with PO: 1 July arising from operating contract termination regarding lines 10, 55, 68, 69, 70, 1ETG and 22ETG with Empresa de Transportes Gondomarense, and line 64 with Pacense	streamlining (administration) [insourcing]	optimization	management
373	2012	somenew contract with PO from July on	streamlining (administration) [outsourcing]	optimization	management
375	2012	somenew contract with PO from July on	streamlining (administration) [outsourcing]	optimization	management
379	2012	New Tram Service Image	modernization (public image)	optimization	management
385	2013	rationalisierung	streamlining (all)	optimization	management
387	2013	monitoring über sociale netswerke	modernization (administration) [monitoring]	optimization	management
389	2013	energy reduction plan	streamlining (resources) [energy]	optimization	management
391	2013	eco driving	streamlining (resources) [energy]	optimization	management
1	1950	beginn ausbau neues busterminal	horizontal expansion (service) [supply]	development	management
9	1956	verstärkter ausbau infra	horizontal expansion (service) [supply]	development	management
11	1958	Approval of trolley-cars system	horizontal expansion (service) [supply]	development	management
36	1965	remodellierung (geld von staat)	other (additional revenue)	development	management
44	1968	investment	horizontal expansion (service) [supply]	development	management
58	1975	abstimmung mit Carris Lisboa	horizontal expansion (joint venture) [Carris]	development	management
87	1982	initiatinvien Bildung, mit Tourismus Führungen =PR	vertical expansion (stakeholding scheme) [touristic activities]	development	management
133	1990	collab museo de transporte	horizontal expansion (joint venture) [Museo]	development	management
134	1990	cola Corunha	horizontal expansion (joint venture) [curunha]	development	management
147	1991	Advertisement in Buses	vertical expansion [other] (advertisment]	development	management
156	1992	Advertisement in Buses	vertical expansion [other] (advertisment]	development	management
158	1992	Museum Inauguration	vertical expansion (stakeholding scheme) [touristic activities]	development	management

187	1994	cooperation events	horizontal expansion (joint venture) [events]	development	management
198	1994	Beteiligunen: 4	vertical expansion (stakeholding scheme)	development	management
213	1996	collaboration mit metro do porto	horizontal expansion (joint venture) [metro]	development	management
219	1996	verkauf von altbussen nach mozambique	other (additional revenue)	development	management
239	1997	Beteiligung: 3 (verkauf)	vertical expansion (stakeholding scheme) - disposal	development	management
245	1998	old buses to Mozambique	other (additional revenue)	development	management
247	1998	25% an Metro do Porto	vertical expansion (stakeholding scheme)	development	management
253	1999	Shareholder of Metro do Porto	vertical expansion (stakeholding scheme)	development	management
254	1999	New Bank Loan	other (additional revenue)	development	management
259	1999	Concession Betrieb Mabuto	vertical expansion (stakeholding scheme) [Mabuto]	development	management
268	2001	copperation europäische kulturhauptstadt	horizontal expansion (joint venture) [events]	development	management
272	2001	konzession von Metro do Porto	horizontal expansion (other) [concession from MP]	development	management
274	2001	Beteiligung: 8	vertical expansion (stakeholding scheme)	development	management
281	2002	Konzessionsnehmer: STCP für CP	horizontal expansion (other) [concession from CP]	development	management
297	2004	neues business: 2 touristenlinien	horizontal expansion [touristic activities]	development	management
300	2004	Verkauf beteiligung	vertical expansion (stakeholding scheme) - disposal	development	management
304	2005	Intermobiliy (massive line change 25)	horizontal expansion (service) [supply]	development	management
305	2005	new historic line	horizontal expansion [touristic activities]	development	management
324	2006	neue Produkte: porto by night, porto a brilhar	horizontal expansion [touristic activities]	development	management
327	2007	vereinbarung mit konkurrenten	horizontal expansion (joint venture) [competitors]	development	management
333	2007	Neu: 3 touristenlinien	horizontal expansion [touristic activities]	development	management
334	2007	consultin Sao Tome	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
336	2008	3. Tourismuslinie	horizontal expansion [touristic activities]	development	management
348	2009	ausbau beteiligung an kulturellen veranstaltungen	horizontal expansion (joint venture) [events]	development	management
349	2010	konzessionsnahme Start	horizontal expansion (other) [concession]	development	management
351	2010	Beteiligungen 5	vertical expansion (stakeholding scheme)	development	management
357	2010	ausbau kulutrelle veranstaltungen massiv	horizontal expansion (joint venture) [events]	development	management
366	2011	mehr geschäft mit touristen	horizontal expansion [touristic activities]	development	management
360	2011	konzessionsvergabe Parking (neues Business)	vertical expansion (stakeholding scheme) [Parking]	development	management
363	2011	NEW: advertisment on buses (new source of income)	vertical expansion [other] (advertisment]	development	management
367	2011	anbindung cuise ship terminal	horizontal expansion (service) [supply]	development	management
368	2011	ausbau akitiväten zu festen, veranstaltungen etc (queima, studenten pack)	horizontal expansion (joint venture) [events]	development	management
371	2011	beteiligungen: 4	vertical expansion (stakeholding scheme) - disposal	development	management
380	2012	stcp servcios (tourist lines) sold to carristur	vertical expansion (stakeholding scheme) - disposal	development	management
381	2012	advertising inside and outside busse	vertical expansion [other] (advertisment]	development	management
382	2012	selling naming of busstops	other (additional revenue)	development	management
383	2012	ausbau akitiväten zu festen, veranstaltungen etc (queima, studenten pack)	horizontal expansion (joint venture) [events]	development	management
388	2013	ausbau akitiväten zu festen, veranstaltungen etc (queima, studenten pack)	horizontal expansion (joint venture) [events]	development	management
390	2013	Beteiligung: 5	vertical expansion (stakeholding scheme)	development	management
2	1951	studie touribus	additional service	research	management
10	1958	plan to remodel industrial divisions	division remodelling	research	management
12	1959	F&E	n.a.	research	management
14	1959	plan to remodel service	service remodelling	research	management
26	1962	Ausbau Arbeitswissenschaften	human factors science	research	management
27	1963	Teilnahme Kongress UITP	congress	research	management
39	1967	teilnahme konferenzen	congress	research	management
40	1967	plan: anbindung regionaltransport	rural transport	research	management
41	1967	plan: vila nova gaia	connection to VNG	research	management
47	1971	study on transport market in porto	market and traffic analysis	research	management
60	1975	Grupo do estudos dp porto (STCP, CMP, Transport Department, Police)	market and traffic analysis	research	management
62	1976	GEPP study on network change	network remodelling	research	management
79	1980	F&E1	n.a.	research	management
82	1981	F&E2	n.a.	research	management
88	1982	F&E 4	n.a.	research	management
96	1983	F&E4	n.a.	research	management
121	1989	netzsimulatiuon	network simulation	research	management
123	1989	F&E Universität	cooperation with university	research	management
129	1989	F&E: fheleranalyse, arbeitsplanung, buchaltung	deficiency analysis, rosters, accounting	research	management
130	1989	F&E: metro ligero, bus corredor integreda, umweltschutz SB zentrum	tram, accelleration, environment	research	management
141	1990	F&E: fahrplanerstellung/scheduling PINGUIN	scheduling	research	management
142	1990	FE: flottenkontrollsystem	fleet monitoring	research	management
143	1990	FE: Kartentechnologie/Tickets	ticketing	research	management
144	1990	FE: arbeitsforschung	human factors science	research	management
145	1990	FE: alternative kraftstoffe	alternative fuels	research	management
146	1990	FE: eneriebilanzintensiver wettbewerb	energy use	research	management
139	1990	F&E: Maintenance / Accounting, Monioring FZ und Fahrer	maintenance + monitoring	research	management
148	1991	Teilnahme an Bildungskonferenz Verkehr	conference	research	management
155	1991	F&E: ticketing + LPG + abgase	ticketing, LPG, exhaust	research	management
159	1992	Project SIGA	software	research	management
164	1992	F&E: real time flottenkontrolle (200 FZ)	fleet monitoring	research	management
165	1992	F&E: automatische betankung	automatic refuelling	research	management
166	1992	F&E: alternative treipstoffe	alternative fuels	research	management
167	1992	F&E_ Hyprid	hyprids	research	management
168	1992	F&E:: interfaces	interfaces	research	management
169	1992	FE: Bedienzentrum	centralized dispatching and monitoring	research	management
170	1992	FE: Echtzeit kundeninformation	real time information	research	management

162	1992	F&E Thermi, Save	energy use	research	management
175	1993	F&E (Mobilitätsanalyse)	market and traffic analysis	research	management
176	1993	FE: live verkehrsmanagement, personenzähler am FZ	real time information	research	management
177	1993	FE: automatische betankung	automatic refuelling	research	management
178	1993	FE: allternative fuels	alternative fuels	research	management
179	1993	FE: hyprid	hyprids	research	management
180	1993	FE: interfaces	interfaces	research	management
181	1993	FE: ticketing	ticketing	research	management
182	1993	FE: Fahrplanerstellung+Dienstplanung	scheduling	research	management
183	1993	FE: real time fahrplan	real time information	research	management
186	1994	F&E transport study	market and traffic analysis	research	management
188	1994	meeting with internationals	conferences	research	management
190	1994	FE: strategisches netz	network planning	research	management
193	1994	FE: automatische betankung	automatic refuelling	research	management
194	1994	FE: allternative fuels	alternative fuels	research	management
195	1994	FE: interfaces	interfaces	research	management
196	1994	FE: ticketing	ticketing	research	management
197	1994	FE: Fahrplanerstellung+Dienstplanung	scheduling	research	management
192	1994	FE: live verkehrsmanagement, personenzähler am FZ	real time information	research	management
203	1995	FE: allternative fuels	alternative fuels	research	management
204	1995	FE: Fahrplanerstellung+Dienstplanung	scheduling	research	management
205	1995	FE: automatische betankung	automatic refuelling	research	management
206	1995	FE: real time fahrplan/operation	scheduling	research	management
207	1995	FE: SEBBU (Savinmg Energy by bus using)	energy use	research	management
209	1995	FE: telematikplan	accelleration	research	management
212	1996	FE: planung integriertes netz	network planning	research	management
214	1996	FE: netzumgestaltung	network planning	research	management
215	1996	FE: switching to PT	mode shift	research	management
217	1996	FE: quattro (qualitiy)	quality	research	management
220	1996	FE: interface eg campanha	interfaces	research	management
221	1996	FE: productions planung	production	research	management
222	1996	FE: real time operations + information 59% ausgestattet	real time information	research	management
223	1996	FE: alternatvie modes	alternative modes	research	management
224	1996	FE: biocompost	alternative fuels	research	management
225	1996	FE: energierückgewining	energy use	research	management
229	1997	FE: biopor	alternative fuels	research	management
230	1997	FE: fuels	alternative fuels	research	management
231	1997	FE: alternative fuels	alternative fuels	research	management
232	1997	FE: real time	real time information	research	management
233	1997	FE: eurobus	eurobus	research	management
234	1997	FE: shot	shot project	research	management
235	1997	FE: ticketing	ticketing	research	management
236	1997	FE: quattro	quality	research	management
237	1997	FE: computer networks	computer networks	research	management
246	1998	FE: Millenium	millienium	research	management
248	1998	Transport system observatory	market and traffic analysis	research	management
251	1998	FE: 6	n.a.	research	management
261	1999	FE: 5	n.a.	research	management
270	2001	congresse	congress	research	management
269	2001	FE: cute, fuel cells	CUTE, fuel cells	research	management
273	2001	FE:6	n.a.	research	management
282	2002	FE: Cute	cute project	research	management
288	2003	FE: Cute	cute project	research	management
287	2003	FE:2	n.a.	research	management
292	2004	FE:1	n.a.	research	management
314	2005	FE:1	n.a.	research	management
319	2006	FE:3	n.a.	research	management
328	2007	teilnahme european mobility week	congress	research	management
329	2007	FE:6	n.a.	research	management
340	2008	FE: 5	n.a.	research	management
345	2009	projekte: maps (spidermaps)	spidermaps project	research	management
344	2009	FE: 11	n.a.	research	management
354	2010	FE: 8	n.a.	research	management
361	2011	FE: 3	n.a.	research	management
374	2012	FE:7	n.a.	research	management
386	2013	FE: 4	n.a.	research	management

DRESDEN

Table A26: Network Decisions Dresden.

#	year	Transcript from text reference indicating a managerial decision	Translation to English	Sub-category	Main-category
1	1957	Personal-300	streamlining (resources) [staff]	optimization	management
2	1957	Einsparung Kraftstoffe	streamlining (resources) [energy]	optimization	management
3	1957	Schaffnerloser Beiwagen auf einigen Linien	streamlining (service) [single agent policy]	optimization	management
4	1957	gebrauchte Busse des Typs 30	streamlinging (resources) [fleet]	optimization	management
5	1958	Enmannwagen partiell	streamlining (service) [single agent policy]	optimization	management
6	1958	Fahrgastkontrollen+Gebühren	modernization (administration) [enforcement]	optimization	management
7	1959	wagengebunde Bridade	modernization (administration) [management structure]	optimization	management
8	1959	Einmanbetrieb Bus	streamlining (service) [single agent policy]	optimization	management
9	1959	Leitbahnhof (ein Bahnhof - mehrere Unterbahnhöfe)	modernization (administration) [management structure]	optimization	management
10	1959	Oberschüler=Schaffner	streamlining (resources) [staff]	optimization	management
11	1959	ZZ-Betrieb eingeführt um weiteres Schaffnerpersonal einsparen zu können.	streamlining (service) [single agent policy]	optimization	management
12	1960	Kontrollschaffner	modernization (resources) [staff]	optimization	management
13	1960	Einmann (30 Bus, 23 Züge)	streamlining (service) [single agent policy]	optimization	management
14	1960	mehr Schaffner	modernization (resources) [staff]	optimization	management
15	1960	Auflösung Dienstzentrale	modernization (administration) [management structure]	optimization	management
16	1960	ZZ-Betrieb eingeführt um weiteres Schaffnerpersonal einsparen zu können.	streamlining (service) [single agent policy]	optimization	management
17	1961	Kürzung um 82 Arbeitskräfte durch neuen Dienstplan	streamlining (resources) [staff]	optimization	management
18	1961	71 Schaffner weniger	streamlining (resources) [staff]	optimization	management
19	1962	Fortsetzung Einmannbetrieb (Linie 20, 16, 7, 8), 22 Wagen	streamlining (service) [single agent policy]	optimization	management
20	1962	Fahrgastkontrollen	modernization (administration) [enforcement]	optimization	management

21	1963	Einmann: Linie 20	streamlining (service) [single agent policy]	optimization	management
22	1963	Wettbewerbe Abteilung zur Senkung der Produktionsmittel	modernization (administration) [decision making]	optimization	management
23	1963	Vorschlagswesen	modernization (administration) [decision making]	optimization	management
24	1964	neuer Strukturplan mit verbesserter Verkehrslenkung	modernization (administration) [management structure]	optimization	management
25	1964	Verbesserung Berufsverkehr: Herausnahme von Decklinien	modernization (service) [operations]	optimization	management
26	1964	OS Betrieb (ohne Schaffner) auf 11 Linien	streamlining (service) [single agent policy]	optimization	management
27	1964	B: 1964 wurden die Linienbezeichnungen von Buchstaben auf Zahlen umgestellt.	modernization (service) [operations]	optimization	management
28	1965	OS: Betrieb	streamlining (service) [single agent policy]	optimization	management
29	1966	OS: 8, 50,51	streamlining (service) [single agent policy]	optimization	management
30	1966	Wettbewerbe: Kosteneinhaltung, Senkung Verkehrsunfälle	modernization (administration) [decision making]	optimization	management
31	1966	Wettbewerbe: Senkung Verkehrsunfälle	modernization (administration) [decision making]	optimization	management
32	1967	OS Betrieb	streamlining (service) [single agent policy]	optimization	management
33	1967	Wettbewerb: Kostensenkung	streamlining (service) [single agent policy]	optimization	management
34	1968	OS: Li 85	streamlining (service) [single agent policy]	optimization	management
35	1969	Anmietung Busse aus anderen Städten	streamlining (administration) [outsourcing]	optimization	management
36	1969	Maßnahmen EDV einführung	modernization (administration) [IT, software, communication]	optimization	management
37	1969	Neue Leitungsstruktur	modernization (administration) [management structure]	optimization	management
38	1969	Einführung Einheitl Rechnungsführung	modernization (administration) [controlling]	optimization	management
39	1969	neues Liniennetz: Zentrumsoirnetierung, Direktanschlüsse an Stadtmitte, Anbindung Peripherie, (Linie 11)	streamlining (service) [supply]	optimization	management
40	1970	Ausweitung Furhpark StrabA auf T4D B4D + 84	modernization (resources) [fleet]	optimization	management
41	1970	Ausweitung Bus auf Ikarus 180 und 556	modernization (resources) [fleet]	optimization	management
42	1970	R-300 Lohn-Gehaltsprojekt Prüfung Übernahme aus Leipzig	modernization (administration) [IT, software, communication]	optimization	management
43	1971	Wettbewerbe: Fokus Qualitätsverbesserungen	modernization (administration) [decision making]	optimization	management
44	1971	Engergieeinsparungen	streamlinging (resources) [energy]	optimization	management
45	1971	schrittweise Einführung der EDV in Verkehrsplaung, Abrechnung, Fahrplnerstellung, Rechnungswesen	modernization (administration) [IT, software, communication]	optimization	management
46	1971	Einführung Prognositk: Planung langfristiger städtebaul. Maßnahmen	modernization (administration) [IT, software, communication]	optimization	management
47	1971	schrittweise Einführung der EDV in Verkehrsplaung, Abrechnung, Fahrplnerstellung, Rechnungswesen	modernization (administration) [IT, software, communication]	optimization	management
48	1971	schrittweise Einführung der EDV in Verkehrsplaung, Abrechnung, Fahrplnerstellung, Rechnungswesen	modernization (administration) [IT, software, communication]	optimization	management
49	1971	schrittweise Einführung der EDV in Verkehrsplaung, Abrechnung, Fahrplnerstellung, Rechnungswesen	modernization (administration) [IT, software, communication]	optimization	management
50	1972	Meisterbereich Verkehr	modernization (administration) [management structure]	optimization	management
51	1972	EDV Fahrplan: Übernahme Karl-M-Stadt	modernization (administration) [IT, software, communication]	optimization	management
52	1972	EDV Materialrechnung	modernization (administration) [IT, software, communication]	optimization	management
53	1972	EDV: Finanz, Arbeitskräfte, Leistungsrechnung,	modernization (administration) [IT, software, communication]	optimization	management
54	1972	Standortoptimiernug Werkstäten	modernization (administration)	optimization	management
55	1973	Zusammenführung Bahnhöfe unf Werkstääten	modernization (administration) [management structure]	optimization	management
56	1973	Verkehrsmeister auf allen Verkehrsbereichen	modernization (administration) [management structure]	optimization	management
57	1973	Einsparungen: Reparatur, Energie, Treibstoff)	streamlinging (resources) [energy]	optimization	management
58	1973	Entwertersystem: Senkung Arbeitsaufwand 30%	streamlining (service) [operations]	optimization	management
59	1973	Flottenerweiterung (52+26+13+17)	modernization (resources) [fleet]	optimization	management
60	1973	Optimierung des Liniennetzes	modernization (resources) [network]	optimization	management
61	1974	Schadenminimierung	streamlining (service) [operations]	optimization	management
62	1974	Flotte (68+33+21)	modernization (resources) [fleet]	optimization	management
63	1975	kein O-Bus	streamlining (service) [supply]	optimization	management
64	1975	Schadensenkungsprogramm	streamlining (service) [operations]	optimization	management
65	1975	Sparprogramme	streamlining (all)	optimization	management
66	1975	EDV im Dienst: Verkehrsplanung, Abrechungleistung, Fahrplandruck, Zeichnung Gleise, Kraftstoffabrechnung, Garantieleistung	modernization (administration) [IT, software, communication]	optimization	management
67	1975	Angebot=Bedarf	streamlining (service) [supply]	optimization	management
68	1975	Stabilisierung im Liniennetz	streamlining (service) [operations]	optimization	management
69	1975	Erhöhung Verkehrsleitsung	modernization [service] supply	optimization	management
70	1976	Verbesserung Rechnungswesen	modernization (administration) [IT, software, communication]	optimization	management
71	1976	durch 10 KOM und 48 T4D	modernization (resources) [fleet]	optimization	management
72	1976	Umsetzung Personenbeförderungsordnung	streamlining (service) [operations]	optimization	management
73	1977	Geschwindigkeitskontrolle an Langsamfahrstellen	modernization (administration) [enforcement]	optimization	management
74	1977	Bestand: +20 T4D + 16KOM	modernization (resources) [fleet]	optimization	management
75	1977	Anstelle der Straßenbahnen verkehrt jetzt eine Buslinie	streamlining (service) [supply]	optimization	management
76	1978	Optimierung: Neubau und Stadtmitte	streamlining (service) [operations]	optimization	management
77	1978	Gleiszustand verbessert	modernization (resources) [network]	optimization	management
78	1979	wöchentl. Meetings (Rapporte)	modernization (administration) [decision making]	optimization	management
79	1979	EDV+	modernization (administration) [IT, software, communication]	optimization	management
80	1980	Kostenprogram	streamlining (all)	optimization	management
81	1980	Senkung Kraftstoffverbrauch	streamlinging (resources) [energy]	optimization	management
82	1980	Energiestab	modernization (administration) [management structure]	optimization	management
83	1981	Selbstkostensenkung	streamlining (all)	optimization	management
84	1982	Verbrauchsreduzierungen	streamlinging (resources) [energy]	optimization	management
85	1983	Energiedispatcheranlage (Stabilisierung der Stromversorgung)	streamlinging (resources) [energy]	optimization	management
86	1983	Reduzierung Ersatzverkehtr mit KOM	streamlining (service) [operations]	optimization	management
87	1983	Invest in Zug - und Kippvorrichtungen	modernization (service) [operations]	optimization	management
88	1984	Contollingforcierung	modernization (administration) [controlling]	optimization	management
89	1984	EDV in Verwaltung -Erweiterung	modernization (administration) [IT, software, communication]	optimization	management
90	1984	Rationaliserung der Fahrleistung	streamlining (service) [supply]	optimization	management
91	1984	Minimierung Ausfall	streamlining (service) [operations]	optimization	management
92	1984	"Erweitertes Qualitätsicherungssystem"	modernization (administration) [qm]	optimization	management

93	1984	"--> alles extra DDR Prorgamm"	streamlining (all)	optimization	management
94	1984	Technik: querschellengleikörper (vorher Großverbundplatte)	modernization (resources) [network]	optimization	management
95	1984	(Rapporte)	modernization (administration) [decision making]	optimization	management
96	1985	Dienstellenverlegung	modernization (administration) [management structure]	optimization	management
97	1985	"fahren und bauen"	streamlining (resources) [staff]	optimization	management
98	1985	Neuer Betriebsbahnhof senkt Ausfallzeiten und Kraftstoffverbrauch, Leerkilometer, Pausenversorgung, Sanitätsituation	streamlining (administration)	optimization	management
99	1986	Forcierung Querschwellenbauweise	modernization (resources) [network]	optimization	management
100	1986	Bauen und Fahren	streamlining (resources) [staff]	optimization	management
101	1986	Vereinfachung Planung	streamlining (administration)	optimization	management
102	1986	Zentralisierung der Arbeits- und Lohnplanung	streamlining (administration)	optimization	management
103	1986	Einheitslichtsignalanlage (für alle Straßenbahnbetriebe gleich)	streamlining (service) [operations]	optimization	management
104	1986	EDV: Arbeitszeit und Lohnanalyse	streamlining (administration)	optimization	management
105	1987	Arbeitsplatzcomputer A 7100 = dezentrale Rechentechnik (Ziel = Freisetzung von Arbeitskräften für andere Aufgaben)	modernization (administration) [IT, software, communication]	optimization	management
106	1987	Fahr- und Dienstplanoptimuerung	modernization (administration)	optimization	management
107	1987	Gleisbautechnologien	modernization (resources) [network]	optimization	management
108	1987	Bahnstromversorgung	modernization (resources) [network]	optimization	management
109	1987	Freisetzung Personal durch dezentrale Rechentechnik	streamlining (resources) [staff]	optimization	management
110	1988	Breite Anwendung Kleincomputer = Umsetzun von Arbeitskräften	modernization (administration) [IT, software, communication]	optimization	management
111	1988	neues Farbdesing	modernization (public image)	optimization	management
112	1988	Überstunden	streamlining (resources) [staff]	optimization	management
113	1988	Arbeitnehmer im zweiten Arbeitsverhältnis und Betriebsangehörigen im Fahrdienst eingesetzt werden	modernization (resources) [staff]	optimization	management
114	1989	Ausbau: alles schwarz gelb	modernization (public image)	optimization	management
115	1993	Umfimrierung AG	modernization (administration) [management structure]	optimization	management
116	1993	minus 30% Personal	streamlining (resources) [staff]	optimization	management
117	1993	Gründung Marketing und Vertrieb	modernization (public image)	optimization	management
118	1993	EDV: SAP einführung	modernization (administration) [IT, software, communication]	optimization	management
119	1993	Umweltschutz	modernization (ressources) [environment]	optimization	management
120	1993	vorbereitung outsourcing	streamlining (administration) [outsourcing]	optimization	management
121	1993	Flotte: 53 neue Busse	modernization (resources) [fleet]	optimization	management
122	1993	moderniz: 11% neue Straba	modernization (resources) [fleet]	optimization	management
123	1994	Senkung Personalaufwand	streamlining (resources) [staff]	optimization	management
124	1994	Verkehrszählung	modernization (administration) [monitoring]	optimization	management
125	1994	Flotte: +99 Strababeiw, +13 NFL B	modernization (resources) [fleet]	optimization	management
126	1995	Liniennmetzumstellung (=Kosteneinsparung - Abschöpfung Fahrgastpotential, Fahrzeugeinsatz anhand Topgraphie)	streamlining (service) [supply]	optimization	management
127	1995	umfangreiche Fahrgastzählung: Informationsgewinn)	modernization (administration) [monitoring]	optimization	management
128	1996	Betriebshof Gorbitz	streamlining (administration)	optimization	management
129	1996	Umstrukturierung Personal (Schulungen für Service, Kontakt zu Kunden, innerbetr. Kommunikation)	streamlining (resources) [staff]	optimization	management
130	1996	ISO 9000 Zertifizierung (QM)	modernization (administation) (ISO)	optimization	management
131	1997	Lease out in lease out geshäft straba (vermietung und zurückmietung)	modernization (administration) [leasing]	optimization	management
132	1997	Betriebsleitstelle in Trachenberge	streamlining (administration)	optimization	management
133	1997	QM Bus	streamlining (administration) [qm]	optimization	management
134	1997	aus 2012: „Feste Fahrbahn“ soll 60 Jahre halten: Seit 15 Jahren bauen wir straßenbündige Gleistrassen für die Straßenbahn vorzugsweise in einer neuen Bauweise, die als „Feste Fahrbahn“ bezeichnet wird. Dabei liegen die Schwellen nicht mehr im Schotterbett, sondern werden einbetoniert. Die Konstruktion ist wesentlich belastbarer und kann bis zu 60 Jahre genutzt werden. Lediglich die Schienen müssen	modernization (resources) [network]	optimization	management
135	1997	Ausbau Flotte (weniger Verbrauch/Unterhalt)	modernization (resources) [fleet]	optimization	management
136	1998	Lease out/in	modernization (administration) [leasing]	optimization	management
137	1998	Schienenschleifzug (Insourcing)	streamlining (resources) [insourcing]	optimization	management
138	1998	SAP r3 Management	modernization (administration) [IT, software, communication]	optimization	management
139	1998	R3 + für Wrkstat/Instandhaltung	modernization (administration) [IT, software, communication]	optimization	management
140	1999	Energieversorgung: Windenergie, DrehmaSSENSPEICHER	streamlinging (resources) [energy]	optimization	management
141	1999	Erte Umsetzun Liniennetz 2000 (neuer Takt, Neuerschließung)	streamlining (service) [supply]	optimization	management
142	2000	Mittelpunkt Kostensenkung	streamlining (all)	optimization	management
143	2000	Restrukturierungsvertrag	streamlining (all)	optimization	management
144	2000	Liniennetz 2000	streamlining (service) [supply]	optimization	management
145	2000	Ende city sprinter	streamlining (service) [supply]	optimization	management
146	2001	Einführung Balanced Scorecards	modernization (administration) [monitoring]	optimization	management
147	2001	Busdepot gruna (z.B. temperierte Busse beim ausrücken)	streamlining (administration)	optimization	management
148	2001	Linie 3: Einsparung 5 min Umlauf = 200.000 Eur p.a.)	streamlining (service) [supply]	optimization	management
149	2001	Centerorganisation/Unternehmenseinheiten	modernization (administration) [management structure]	optimization	management
150	2001	Outsourcing	streamlining (administration) [outsourcing]	optimization	management
151	2002	Ausbau Betriebsbahnhöfe	streamlining (administration)	optimization	management
152	2002	Optimierung: Konzentration der Werkstattkapazitätäten:	streamlining (administration)	optimization	management
153	2002	neues Betriebshofkonzept	streamlining (administration)	optimization	management
154	2002	moderne Wirtschaftsfahrzeuge Neuanschaffung: Renaul Kangoo	modernization (resources) [fleet]	optimization	management
155	2002	Senkung Betriebskosten	streamlining (all)	optimization	management
156	2003	Leasinggeschäft	modernization (administration) [leasing]	optimization	management
157	2003	Konsolidierungsprogram	streamlining (all)	optimization	management
158	2003	Mobiler Service: Einstellung aus Kostengründen	streamlining (service) [supply]	optimization	management
159	2003	Modernisierung Flotte	modernization (resources) [fleet]	optimization	management
160	2004	Wartungsfreier Bahnsteig = Fußbodenheizung	streamlining (service) [operations]	optimization	management
161	2004	Schwerpunktwerkstatt (Personalreduktion, Senkung Kosten Strabainstandhaltung)	streamlining (administration)	optimization	management
162	2007	Betriebshof Reick = 45 Strabab	streamlining (administration)	optimization	management
163	2007	optimaler Standort	streamlining (administration)	optimization	management
164	2007	Toleranzkampange, Imagefilm	modernization (public image)	optimization	management
165	2008	Zukunft: weiter separierung + Flotte	streamlining (service) [operations]	optimization	management
166	2009	Neue Netzleitstelle für die Bahnstromversorgung	streamlining (administration)	optimization	management
167	2009	DVB stellt Arbeitssuchende als Busfahrer ein	modernization (resources) [staff]	optimization	management
168	2009	neues Busnetz (21 neue Haltestellen, Lininennummersystem, +1,7 Mio FG, Neuerschließungen, Time-lag 2 Jahre)	streamlining (service) [supply]	optimization	management

169	2010	Kundenservice der DVB durch 23 Bildungseinrichtungen getourt - Jugendliche und Bahn	modernization (resources) [staff]	optimization	management
170	2010	Aktuelle Software für alle PCs	streamlining (administration)	optimization	management
171	2010	Neue Telefonanlage für das Verwaltungsgebäude	streamlining (administration)	optimization	management
172	2010	Elektronisches Bekleidungsbuch eingeführt (onlinebestellung)	streamlining (administration)	optimization	management
173	2010	Ideenmanagement: 161.000 Euro.	modernization (administration) [decision making]	optimization	management
174	2010	Leistungsfähigkeit des Knotenpunktes aus ÖPNV-Sicht am Pirnaischen Platz	modernization (resources) [network]	optimization	management
175	2011	Bahnstromnetz weiter verbessert	modernization (resources) [network]	optimization	management
176	2011	Straßenbahnwerkstatt Trachenberge modernisiert	streamlining (administration)	optimization	management
177	2011	Bahnstromnetz der DVB von 600 auf 750 Volt Gleichstrom statt. Damit sinken die durch den elektrischen Widerstand entstehenden Übertragungsverluste. Der Bahnstromverbrauch soll sich mit der mittelfristig geplanten Erhöhung der Netzspannung um zirka acht Prozent reduzieren.	modernization (resources) [network]	optimization	management
178	2011	neues Intranet	streamlining (administration)	optimization	management
179	2011	Ideenmanagement: 94000	modernization (administration) [decision making]	optimization	management
180	2011	Modernisierng Flotte senkt Kosten	modernization (resources) [fleet]	optimization	management
181	2012	Printmedien mit neuem Design	modernization (public image)	optimization	management
182	2012	Neuorganisation des Centers Fahrbetrieb	modernization (administration) [management structure]	optimization	management
183	2012	Betriebliches Ideenmanagement: 200000	modernization (administration) [decision making]	optimization	management
184	2013	weltweiten Kampagne des internationalen Verbandes des öffentlichen Verkehrswesens UITP (International Association of Public Transport) beteiligt	modernization (public image)	optimization	management
185	2013	bedarfsorientierter Signalsteuerungen auf Nord-Süd Achse (Kosten)	modernization (resources) [network]	optimization	management
195	1957	Aschetransport Westkraftwerk	horizontal expansion (stakeholding scheme) [commission-based transport]	development	management
196	1958	Stadtrundfahrten	horizontal expansion [touristic activities]	development	management
197	1962	Ausbau Stadtrundfahrten	horizontal expansion [touristic activities]	development	management
198	1967	Zubringerverkehr zum Netz (Linie 61)	horizontal expansion [feeder service]	development	management
199	1970	Kooperationsbeziehungen	horizontal expansion (joint venture) [other transport companies]	development	management
200	1970	Ersatzteilproduktion	vertical expansion (resources) [production of spare parts)	development	management
201	1973	EDV kooperation mit bahn	horizontal expansion (joint venture) [DB]	development	management
202	1976	Bäderverkehr wegen Hitze	horizontal expansion (service) [supply]	development	management
186	1982	Finanzierungsreform	other (additional revenue)	development	management
203	1982	Stadtrundfahrt mit Straßenbahn	horizontal expansion [touristic activities]	development	management
204	1982	Die Verkehrsbetriebe führen am 28. Oktober 1982 wieder den Güterverkehr mit Straßenbahnen ein. Dafür werden extra Tatrabahnen umgebaut: T4D-G.	vertical expansion (stakeholding scheme) [goods]	development	management
205	1982	Wagenumbau eigenleistung	vertical expansion (resources) [production of spare parts)	development	management
187	1988	Start Liniennetzplanung bis 1995	horizontal expansion (service) [supply]	development	management
206	1988	Anbringung von Werbung	vertical expansion [other] (advertisment]	development	management
207	1989	Werbeflächen	vertical expansion [other] (advertisment]	development	management
208	1993	vorbereitung tochtergesellsch	vertical expansion (stakeholding scheme)	development	management
209	1995	Beteiligungen 2	vertical expansion (stakeholding scheme)	development	management
210	1996	Erhalt von Konzessionen (24 Omnibnus)	horizontal expansion (other) [concession from MP]	development	management
211	1996	Beteiligungen 3	vertical expansion (stakeholding scheme)	development	management
188	1998	Infrasturktur	horizontal expansion (service) [supply]	development	management
189	1998	ÖV Konzept Plauen	horizontal expansion (service) [supply]	development	management
212	1998	Beteiligungen (zuverdienst)	vertical expansion (stakeholding scheme)	development	management
213	1998	Ausgründungen - Konzessionen	horizontal expansion (other) [concession from MP]	development	management
214	1998	Konzessionen	horizontal expansion (other) [concession from MP]	development	management
215	1999	CarGotram (VW)	vertical expansion (stakeholding scheme) [goods]	development	management
216	2000	CarGo tram in work	vertical expansion (stakeholding scheme) [goods]	development	management
217	2000	Beteiligungen 5	vertical expansion (stakeholding scheme)	development	management
218	2001	Beteiligungen 6 (+DDIT	vertical expansion (stakeholding scheme)	development	management
219	2002	Beteiligungen 7	vertical expansion (stakeholding scheme)	development	management
190	2003	quasi verkauf Beteiligung -1 = 5	vertical expansion (stakeholding scheme) - disposal	development	management
220	2003	Übernahme 75% Meißen (beteiligung +)	vertical expansion (stakeholding scheme) [other cities]	development	management
221	2003	Busnetz Süd-Ost	horizontal expansion (service) [supply]	development	management
222	2003	Elbepark Koop	horizontal expansion (joint venture) [shopping]	development	management
191	2004	Verkauf Beteiliging Carsharing	vertical expansion (stakeholding scheme) - disposal	development	management
223	2004	kauf dd netz	vertical expansion (stakeholding scheme)	development	management
224	2004	beteiligung: 6	vertical expansion (stakeholding scheme) - disposal	development	management
225	2004	P+R Einkaufslinie 9 Promotion	horizontal expansion (joint venture) [shopping]	development	management
192	2005	tw verkauf VCBD	vertical expansion (stakeholding scheme) - disposal	development	management
193	2007	Straba: Ausbau Dresden West	horizontal expansion (service) [supply]	development	management
226	2007	Koop mit RVD = Doppellinie 81 = Anbindung an Industriestandorte im DD-NORD	horizontal expansion (joint venture) [other transport companies]	development	management
227	2008	Verknüpfung mit RBL Regional/Eisenbahnverkehr	horizontal expansion (joint venture) [other transport companies]	development	management

228	2008	Online-Abfahrtszeiten für Gastronomie, Handel und Behörden	horizontal expansion (joint venture) [shopping]	development	management
229	2008	P+R	vertical expansion (stakeholding scheme) [P+R]	development	management
230	2008	beteiligung: riesa + 1	vertical expansion (stakeholding scheme)	development	management
231	2009	TU Dresden Koop	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
232	2010	Messe Dresden Koop	horizontal expansion (joint venture) [fare]	development	management
233	2011	Ausbildungsverkehr 20.000 Studenten 39500	horizontal expansion (joint venture) [students]	development	management
194	2013	„Stadtbahn Dresden 2020"	horizontal expansion (service) [supply]	development	management
234	2013	Innovative Software zur Qualitätssicherung von Lichtsignalanlagen entwickelt (auch Verkauf)	vertical expansion (stakeholding scheme) [education, training, consulting]	development	management
235	1965	Typ T3 Test	prototype tram	research	management
236	1967	Td4 test	prototype tram	research	management
237	1972	kostenrechnungforschung: Platzangebot, Abfertigungstechnologie, Dispatchsystem, Verkehrsmitteleinsatz	controlling capacity	research	management
238	1972	kostenrechnungforschung: Platzangebot, Abfertigungstechnologie, Dispatchsystem, Verkehrsmitteleinsatz	controlling dispatching technology	research	management
239	1972	kostenrechnungforschung: Platzangebot, Abfertigungstechnologie, Dispatchsystem, Verkehrsmitteleinsatz	controlling dispatching systems	research	management
240	1972	kostenrechnungforschung: Platzangebot, Abfertigungstechnologie, Dispatchsystem, Verkehrsmitteleinsatz	controlling vehicle use	research	management
264	1973	Forschung: Abfertigung, Umsteigevorgänge, Nachtlinienverkehr, Lärm	dispatching, interchanges, night lines, external effects	research	management
241	1974	Forschung (alles nachfolgend): O-Busse sinnvoll?	usability studies	research	management
242	1974	Spezialisierung verschieden Verkehrsbetriebe auf instandsetzung von KOMs	vehicle maintenance	research	management
243	1974	Standortplanung Energieversorgungsanlagen	location planning	research	management
244	1974	Effekticität Tarifverbund	transport association efficiency	research	management
245	1975	EDV Test: Lohn, Umlaufplanung, Materialwirtschaft,	software	research	management
262	1975	Foschung: Verkehrssicherheit, Umleitungsoptimierung, Standortoptimierung Stromversorgung,	traffic safety, detouring, electric supply	research	management
246	1979	nachfolgend forschung: Nachtliniennetz	night network	research	management
247	1979	Verkehrsbeobachtung via TV	traffic monitoring	research	management
248	1979	Fahrplanoptimierung	scheduling	research	management
249	1979	Fernsteuerung Energieversorungung	remote controöl	research	management
265	1983	Forschung: Fahr- und Dienstpläne, Energieträgerumstellung, Verlagerung Staße-Schiene, Funkanlagen für Staßenbahnen, EDV Durchfahrtskontrolle, Energiedispatcherzentrale	rostering, energy transition, mode shift, radio communication, energy dispatching, vehicle monitoring	research	management
250	1984	Forschung: Mikroelektronik	microelectronics	research	management
263	1987	Wissenschaft unfd Technik: Ferienfahrpläne, Fahrplanoptimierung L 85, Rationalisierung Rechnungswesen/Buchaltung)	scheduling, streamlining controlling	research	management
251	1994	Test: Thyristorsteuerung	thyristor controller	research	management
252	1999	Projekt EU Benchmarking	benchmarking	research	management
253	1999	Ikarus 417.14 A zum Testen bereitgestellt.	prototype tbus	research	management
254	2007	Hypridtest: -13,7% Verbrauch	hyprids	research	management
255	2007	intelligente Ampelsteuerung, test	accelleration	research	management
256	2012	F&1: 3	n.a.	research	management
257	2012	F&1: 3	n.a.	research	management
258	2012	F&1: 3	n.a.	research	management
259	2013	F6E Emob: 3 projekte - 2 , 1 Schnelladung	electromobility	research	management
260	2013	F6E Emob: 3 projekte - 2 , 1 Schnelladung	electromobility	research	management
261	2013	F6E Emob: 3 projekte - 2 , 1 Schnelladung	electromobility	research	management

Contextual Events and Effects

HAMBURG

Table A27: Network Decisions Hamburg.

#	year	Transcript from text reference indicating a contextual event	Translation to English	Sub-category	Main-category
23	1967	Mehrwertsteuer auf Fahrgelder: 5%	vat on tickets	legal	context
30	1973	Füller	n.a.	legal	context
32	1974	Wegfall Zuschüße ausbildungsverkehr	subsidy reduction	legal	context
53	1981	Kürzung Erstattung Mineralsteuersatz	subsidy reduction	legal	context
60	1982	Steigerung Freifahrten Schwerbehindertengesetz	Severely Disabled Persons' Act	legal	context
66	1984	sinkender Anteil Verbund	reduced share transport association	legal	context
73	1987	Verminderung Fördermittel	subsidy reduction	legal	context
74	1988	Rahmen: politische Rahmenbed, sinkende Schülerz, abwanerung, PKW wegen niedrige Preis Sprit	lack of politcal support	legal	context
87	1995	Neuordnung ÖPNV in Region: EU Verordnung 1892/91, Rücckzug Bund, Änderung HVV rechtsform, Ausschreibung Bus ab 1999, generell ab 2005 = Wettbewerb!! = = Vorbereitungen = Innoovationspusher	EU regulation	legal	context
92	2001	Kürzung Aussgleichzahlungen	subsidy reduction	legal	context
94	2004	Kürzung Ausgleichszahlungen Ausbildungsverkehr	subsidy reduction	legal	context
97	2005	EWG- VO 1191/69 -Ausdehnung Ausschreibung	EU regulation	legal	context
100	2006	EWG VO 1191/69	EU regulation	legal	context
105	2008	EU 1370/2007	EU regulation	legal	context
111	2009	neue Einnahmenaufteilung Verbund	transport association changes	legal	context
4	1952	Koreakonflikt = Kostentreiber	increased energy prices (Korean War)	energy	context
7	1955	steigende Energiepreise (+35% Dieselpreis)	increased energy prices	energy	context
9	1958	Rückläufige Entwicklung Dieselpreis	reduced energy prices	energy	context
24	1967	Steigerung Diesel durch Steuer und Nahost	increased energy prices (Middle East + Taxes)	energy	context
31	1973	starkgestiegene Kraftstoffpreise	increased energy prices	energy	context
46	1979	Dieselpreis+77%	increased energy prices	energy	context
50	1980	Diesel +35%	increased energy prices	energy	context
56	1981	Diesel + 36%	increased energy prices	energy	context
61	1982	Diesel + 20%	increased energy prices	energy	context
64	1983	Diesel: +5,6%	increased energy prices	energy	context
67	1984	Diesel: +6,5%, Strom +5,6%	increased energy prices	energy	context
70	1986	Strom: +14,4%	increased energy prices	energy	context
99	2005	Engergiekosten: steigende Strompreise, kaum reKTIONSMÖGLICHKEITEN;	increased energy prices	energy	context
103	2006	steigende Energiepreise	increased energy prices	energy	context
107	2008	hohes Energiepreisniveau bis Mitte 2008	increased energy prices	energy	context
115	2012	Steigerung doeselkosten +7%	increased energy prices	energy	context

3	1951	Rückgang Verkehrsleistung wegen: Wegfall Versorgungsfahrten, Mode-shift (Rad, KfZ), Währungsreform)	increased indivdual transport (less demand)	demand	context
8	1956	zuwachs KfZ: +21000	increased indivdual transport (less demand)	demand	context
10	1958	Arbeitswoche Änderung Verkehrsstil, weniger Nachfrage Samstag	workdays change (less demand)	demand	context
11	1960	wachsender IV	increased indivdual transport (less demand)	demand	context
14	1961	Motorisierungszunahme	increased indivdual transport (less demand)	demand	context
16	1962	steigender IV, ,	increased indivdual transport (less demand)	demand	context
20	1963	Fahrgastabwanderungen w Tarif und Preisdifferenz S-Bahn	competition (S-Bahn)	demand	context
21	1965	Auifwärtsbeweg. IV (64 5,5 EW =1 FZ 65 6 EW = 1 FZ)	increased indivdual transport (less demand)	demand	context
25	1968	Wanderung in Randzonen	suburbanization	demand	context
26	1970	FÜLLER	n.a.	demand	context
28	1972	Anstieg PKW rate +3,3% auf 26%	increased indivdual transport (less demand)	demand	context
34	1975	gesamtwirtschaftli Lage wirkt auf ÖPNV: weniger Konsumverhalten, weniger Gelegenheitsverkehr,	economy (less demand)	demand	context
35	1976	externe Faktoren: Bevölkerungsrückgang	schrinking population	demand	context
43	1977	externe Faktoren: -20000, PKW zum Enkuafen,	increased indivdual transport (less demand)	demand	context
44	1978	PKW+3,5 %	increased indivdual transport (less demand)	demand	context
47	1979	PKW+4,5%	increased indivdual transport (less demand)	demand	context
58	1981	Sinkende Bevölkerung	schrinking population	demand	context
63	1982	externe Faktoren: -Zunahme Freifahrten schwerbehinderte, Verkürzung der Reiselängen	other (less demand)	demand	context
68	1984	neue S-Bahnlinie	competition (S-Bahn)	demand	context
75	1988	Rahmen: politische Rahmenbed, sinkende Schülerz, abwanerung, PKW wegen niedrige Preis Sprit	lack of politcal support	demand	context
85	1992	LG erhöhung	n.a.	demand	context
88	1995	Rahmen: Arbeitsloigkeit, sinkende Bevölkerungswachstum, gesunkenes Realeinkommen, PKW	economy (less demand)	demand	context
89	1996	Anstieg Arbeitslose	unemployment	demand	context
93	2003	Rahmen: Rückgang BIP	economy (less demand)	demand	context
112	2009	schrumpfende Wirtschaft, Ende Erholung	economic (less demand)	demand	context
1	1950	33% Ausfallrate Strab	increased failure rate	other	context
13	1960	Behinderung Oberflächentransport (Vordenken Trennung)	reduced traffic flow	other	context
19	1962	Sturmflut	weather	other	context
42	1976	Reparatur (mutwillige Zerstörung)	vandalism	other	context
45	1978	200 Reparaturfälle Mmaschinelle Anlage/Jahr	increased failure rate	other	context
49	1979	heftige schneefälle=zuwachs an Kunden	weather	other	context
52	1980	Schäden durch Zerstörung: 2,4 Mio	vandalism	other	context
71	1986	Behinderungen durch VERkehrsberuhigungen	reduced traffic flow	other	context
76	1989	Steigende Verkehrsverstöße (Parken n Busbucht etc)	reduced traffic flow	other	context
80	1990	Modellversuch Innenstadtberuhigung (Senkung Geschwindigkeit)	traffic calming	other	context
86	1994	Problem der Abfallentsorgun von Fahrgästen = Kosten	garbage	other	context
90	1996	24 Mio Verlust durch Schwarzfahrer	fare evasion	other	context
108	2008	Beginn der Finanzkrise	fincancial crisis	other	context
119	2013	Kapazitätsgrenzen erreicht	maximum capacity	other	context

PORTO

Table A28: Network Decisions Porto.

#	year	Transcript from text reference indicating a contextual event	Translation to English	Sub-category	Main-category
3	1952	ausbau SB begrenzt, da zu teuer	lack of funding	legal	context
20	1959	Law gives priority to IT	Law gives priority to IT	legal	context
32	1963	change of law (less payment for STCP)	subsidy reduction	legal	context
36	1964	regulation of payment to camera municpal	regulation of payment to camera municpal	legal	context
43	1967	increase insurance	increase insurance	legal	context
52	1969	exploration cost increasing	exploration cost increasing	legal	context
59	1970	financial problems	financial problems	legal	context
62	1971	änderung regulation gesetz	regulation	legal	context
66	1972	2 new laws	regulation	legal	context
76	1973	finanzlast:zinsen	increased interests	legal	context
93	1978	Establishment of Service Intensity Criteria in Rush Hours	Establishment of Service Intensity Criteria in Rush Hours	legal	context
110	1982	Plano de Transport de Regioa do Porto wirkungslos, da keine mitte vorgegeben	lack of planning	legal	context
114	1983	Implementation of Municipal Transport Tax	taxation	legal	context
117	1984	neues Gesetzt 439/83	regulation	legal	context
135	1993	Road Network Changes	change of road network	legal	context
139	1994	umfirmierung eigenständig (kapitalgesellschaft 100% in händen der stadt)	public company	legal	context
141	1995	Increase of Company's Social Capital	Increase of Company's Social Capital	legal	context
156	2002	Gründung TIP/ACE intermobilität	transport authority	legal	context
160	2004	Gründung public transport authority	transport authority	legal	context
185	2007	EU 1370/2007: regelwerk PT subsidies	regulation	legal	context
11	1954	electricity	increased energy prices	energy	context
24	1961	Increase of gasoline price	increased energy prices	energy	context
41	1966	enery prices increase	increased energy prices	energy	context
44	1967	increas energy	increased energy prices	energy	context
69	1973	Energy Crises of the 70s	increased energy prices	energy	context
92	1978	Oil and Vehicle Price Increase	increased energy prices	energy	context
113	1982	steigend Benzinkosten wegen mäßigen verkehrsfluss	increased energy prices	energy	context
144	1999	Oil Price Increase	increased energy prices	energy	context
165	2004	increase energy costs	increased energy prices	energy	context
4	1952	wachsender IV - Parken etc	increased indivdual transport (less demand)	demand	context
7	1954	wachsender IV	increased indivdual transport (less demand)	demand	context
17	1958	steigender IV	increased indivdual transport (less demand)	demand	context
21	1960	passenger loss due to competition	competition	demand	context
31	1962	lebenskosten (1960=103 1962=108)	increased costs of living	demand	context
64	1971	prei höher aber qualität schlechter - Kunden gehen	price increas but quality decrease (less demand	demand	context
128	1990	Decline of Passenger Numbers	less demand	demand	context
137	1993	Gründung Empresa Metro do Porto	competition	demand	context
152	2001	Decline of Passenger Numbers	less demand	demand	context

155	2002	Metro Porto	competition	demand	context
162	2004	Eröffnung METRO PORTO	competition	demand	context
175	2005	"-30% SMSBUS"	less demand ("-30% SMSBUS")	demand	context
1	1950	Last year of transition regime of exploration	transition peridod	other	context
5	1952	Problem Energieversorgung SB	energy supply problems	other	context
8	1954	Passenger crossing	reduced traffic flow	other	context
16	1957	costs but no benefits of measures	lack of efficiency	other	context
19	1959	heavy traffic in center	reduced traffic flow	other	context
28	1962	Repair works in the city	reduced traffic flow	other	context
33	1963	vernachlässigung Infrastruktur	deteriorating infrastructure	other	context
47	1967	semana inglese = Friday Saturday traffic	reduced traffic flow (englisch week)	other	context
50	1968	less space for PT	reduced traffic flow	other	context
57	1969	politic für autos	car-oriented policy	other	context
60	1970	2 und 3 reihe parken	reduced traffic flow	other	context
65	1971	problem: verkehrsfluss	reduced traffic flow	other	context
70	1973	Material Price Increase	material price increase	other	context
77	1974	Revolution of 25 April	revolution	other	context
83	1976	CBD traffic flow problem	reduced traffic flow (CBD)	other	context
88	1977	außerhalb busspuren verschlechterung verkehrsfluss	reduced traffic flow (except of bus lanes)	other	context
101	1980	problem traffic flow	reduced traffic flow	other	context
106	1981	10 Tage Streik	strikes	other	context
109	1982	Fahrplan wird durch Verkehr gestört	reduced traffic flow	other	context
121	1986	2 montae streik	strikes	other	context
124	1989	Bad Travel Conditions	reduced traffic flow	other	context
133	1992	streik	strikes	other	context
148	2000	Social strikes	strikes	other	context
151	2001	Establishment of single currency	currency change	other	context
159	2003	starke verkehrsbehinderung	reduced traffic flow	other	context
167	2004	road work	reduced traffic flow	other	context
179	2005	45/97 linien = andante	intermodality process	other	context
181	2006	verbesserung verkehrsfluss durch einbahnstaßen	road changes	other	context
190	2009	massiver Streik	strikes	other	context
194	2011	crise	economic crisis	other	context
199	2012	Organisational redesign plan of Casa da Música transport hub	reduced traffic flow (casa da musica)	other	context

DRESDEN

Table A29: Network Decisions Dresden.

#	year	Transcript from text reference indicating a contextual event	Translation to English	Sub-category	Main-category
35	1976	Peronbeförderungsordnung	regulation	legal	context
41	1978	neue STVO	regulation	legal	context
66	1999	drohender Wettbewerb	competition	legal	context
69	2000	Verordnung: Marköffnung ÖPNV	regulation	legal	context
71	2001	Euroumstellung: 1,75 Mio EUR	currency change	legal	context
74	2002	Zuschußkürzung	reduced funding	legal	context
76	2004	Verkürzte ausgleichszahlungen für Studenten	reduced funding	legal	context
79	2007	Klima/Umweltdebatte	public pressure (environment)	legal	context
33	1975	Großzüge konnten wegen Energiemangel tw nicht einsetzbar	lack of energy supply	energy	context
88	2008	steigende Dieselkosten	increased diesel costs	energy	context
60	1994	zunehmende Motorisierung	increased indivdual transport (less demand)	demand	context
27	1969	Zunahme Individualverkehr	increased indivdual transport (less demand)	demand	context
14	1963	geringe Nachfrage wegen Winter	weather (less demand)	demand	context
2	1957	chronischer Personalmangel	staff shortage	other	context
3	1958	Hochwasserkatastrophe	weather	other	context
6	1959	Fahrermangel	staff shortage	other	context
8	1960	Fahrermangel	staff shortage	other	context
9	1961	Stillegung/Kürzung wegen Fahrermangel	staff shortage	other	context
10	1962	schlechter Gleiszustand	deteriorating infrastructure	other	context
13	1963	Fahrzeugschäden durch Schneefälle	weather	other	context
17	1964	Linienausfall	increased failure rate	other	context
20	1965	Winter	weather	other	context
23	1966	starker Personalmangel	staff shortage	other	context
24	1967	Personalmangelk	staff shortage	other	context
25	1968	Personalmangel	staff shortage	other	context
28	1970	Rückläufiger Fachkräfte	staff shortage	other	context
30	1971	sozialitische Rationalisierung	socialist streamlining programs	other	context
34	1975	keine Fahrplantreue	increased failure rate	other	context
38	1976	extreme Witterung	weather	other	context
39	1978	Kapazizätsgrenzen	capacity limits	other	context
42	1980	Personalausfälle	staff shortage	other	context
43	1983	Problem: Material- und Ersatzteile	spare parts shortage	other	context
46	1985	Vollsperrung Elbbrücken	reduced traffic flow (construction)	other	context
50	1987	Personalmangel	staff shortage	other	context
54	1988	160 Baumaßahmen	reduced traffic flow (construction)	other	context
56	1989	Personalmangel Faher	staff shortage	other	context
58	1993	verringerung Reisgeschwindigkeiten	reduced traffic flow (IV)	other	context
62	1994	Stau durch IV	reduced traffic flow (IV)	other	context
72	2002	Elbflut	weather	other	context
78	2005	Ausbau A17 (context)	reduced traffic flow (construction)	other	context
92	2009	Finanzmarkt- und Wirtschaftskrise	economic crisis	other	context
98	2010	straffer winter	weather	other	context
111	2013	s umfangreichen Baugeschehens	reduced traffic flow (construction)	other	context

5 Database 2 - Decision Counts

Hamburg

Table A30: Decision and context counts Hamburg Hochbahn (Hamburg).

main-category	network decisions					fleet decisions			personnel decisions				schedule decisions			fare decisions			service decisions				management decisions				context				
sub-category	management	accessibility	(re)organization	other	SUM	fleet upgrade	technology	SUM	incentives	training	other	SUM	frequency	other	SUM	fare change	other	SUM	operations	customer	IT	SUM	optimization	development	research	SUM	legal	energy	demand	other	SUM
1950	12	1	0	0	13	1	0	1	0	0	1	1	1	0	1	1	1	2	0	1	0	1	2	1	0	3	0	0	0	1	1
1951	6	1	0	0	7	2	1	3	0	0	1	1	1	0	1	0	0	0	1	0	0	1	1	1	0	2	0	0	1	0	1
1952	5	1	0	0	6	1	0	1	0	0	1	1	0	2	2	1	1	2	1	1	0	2	4	0	0	4	0	1	0	0	1
1953	8	1	1	3	13	2	1	3	0	0	2	2	2	1	3	0	2	2	1	0	0	1	1	2	0	3	0	0	0	0	0
1954	14	2	0	0	16	1	0	1	1	0	1	2	0	0	0	0	0	0	3	1	0	4	1	1	0	2	0	0	0	0	0
1955	16	3	0	2	21	0	1	1	0	0	1	1	1	1	2	0	1	1	1	3	0	4	1	0	0	1	0	1	0	0	1
1956	10	0	0	2	12	0	0	0	1	0	2	3	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	1
1957	9	0	0	4	13	0	0	0	2	0	0	2	2	0	2	1	1	2	1	0	0	1	1	1	0	2	0	0	0	0	0
1958	10	0	0	2	12	0	1	1	0	0	1	1	1	0	1	0	1	1	0	1	0	1	4	0	1	5	0	1	1	0	2
1959	21	0	0	1	22	0	0	0	1	0	3	4	1	0	1	0	0	0	4	3	1	8	6	1	0	7	0	0	0	0	0
1960	15	3	1	0	19	0	1	1	0	0	3	3	1	0	1	1	0	1	1	0	0	1	3	0	1	4	0	0	1	1	2
1961	24	0	0	1	25	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	2	1	0	0	1	0	0	1	0	1
1962	12	1	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	0	0	0	0	0	0	1	1	2
1963	18	1	0	0	19	0	0	0	0	0	0	0	3	0	3	0	2	2	2	5	1	8	0	0	0	0	0	0	1	0	1
1964	14	0	0	1	15	0	0	0	0	0	1	1	3	0	3	0	0	0	0	3	1	4	1	3	2	6	0	0	0	0	0
1965	26	0	0	0	26	1	0	1	1	0	1	2	1	0	1	0	0	0	2	1	3	6	2	1	0	3	0	0	1	0	1
1966	9	0	1	0	10	0	1	1	1	0	1	2	0	0	0	0	1	1	2	0	0	2	2	1	0	3	0	0	0	0	0
1967	31	0	0	0	31	0	0	0	0	0	1	1	1	0	1	0	0	0	2	0	3	5	3	4	0	7	1	1	0	0	2
1968	20	0	0	0	20	2	0	2	0	0	0	0	0	0	0	0	2	2	2	3	3	8	0	3	0	3	0	0	1	0	1
1969	12	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0
1970	32	0	0	1	33	0	0	0	0	0	0	0	0	1	1	0	1	1	3	2	1	6	1	1	0	2	0	0	1	0	1
1971	11	0	0	0	11	1	0	1	0	0	0	0	0	0	0	1	1	2	3	2	1	6	3	1	0	4	0	0	0	0	0
1972	4	1	0	1	6	1	0	1	0	0	0	0	1	1	2	0	1	1	0	2	0	2	1	2	0	3	0	0	1	0	1
1973	9	3	0	0	12	0	1	1	4	0	0	4	1	0	1	1	0	1	2	3	0	5	2	1	0	3	1	1	0	0	2
1974	7	1	0	0	8	0	1	1	1	0	0	1	1	1	2	0	0	0	3	2	0	5	2	0	0	2	1	0	0	0	1
1975	11	2	0	0	13	0	1	1	3	0	0	3	0	1	1	0	0	0	2	2	0	4	0	1	0	1	0	0	1	0	1
1976	9	0	0	0	9	1	0	1	0	0	0	0	0	0	0	1	1	2	1	1	1	3	2	5	1	8	0	0	1	1	2
1977	4	1	0	0	5	2	0	2	0	0	1	1	0	0	0	1	2	3	1	5	0	6	4	3	5	12	0	0	1	0	1
1978	5	0	0	0	5	0	2	2	1	0	0	1	0	0	0	1	1	2	1	4	0	5	1	1	3	5	0	0	1	1	2
1979	5	0	0	0	5	2	1	3	0	0	0	0	2	0	2	1	2	3	0	1	2	3	7	1	2	10	0	1	1	1	3
1980	4	0	0	0	4	1	0	1	1	1	1	3	1	0	1	1	0	1	1	2	1	4	1	2	0	3	0	1	0	1	2
1981	5	0	0	0	5	0	0	0	1	0	0	1	0	0	0	1	2	3	2	5	0	7	1	2	2	5	1	1	1	0	3
1982	9	0	0	0	9	1	1	2	0	0	0	0	2	1	3	1	2	3	4	0	1	5	4	2	2	8	1	1	1	0	3
1983	12	2	1	0	15	0	1	1	1	0	0	1	0	0	0	1	0	1	0	2	1	3	1	0	4	5	0	1	0	0	1
1984	8	1	0	0	9	1	1	2	1	2	0	3	0	1	1	1	0	1	2	2	1	5	7	1	0	8	1	1	1	0	3
1985	8	2	0	0	10	0	0	0	1	1	0	2	0	1	1	0	0	0	4	1	4	9	0	1	3	4	0	0	0	0	0
1986	4	1	0	0	5	0	1	1	2	1	2	5	0	0	0	0	0	0	2	6	1	9	1	0	2	3	0	1	0	1	2
1987	2	1	1	0	4	2	1	3	0	0	0	0	1	1	2	0	0	0	1	6	0	7	1	0	3	4	1	0	0	0	1
1988	6	0	0	0	6	1	0	1	0	0	2	2	2	0	2	0	2	2	3	4	0	7	5	0	3	8	1	0	1	0	2
1989	5	1	0	0	6	0	0	0	0	1	0	1	0	0	0	0	0	0	1	2	0	3	4	0	4	8	0	0	0	1	1
1990	4	1	1	1	7	0	1	1	0	0	3	3	1	0	1	0	1	1	2	2	0	4	5	2	5	12	0	0	0	1	1
1991	10	1	0	0	11	1	1	2	0	0	3	3	2	0	2	0	2	2	5	4	1	10	3	0	0	3	0	0	0	0	0
1992	7	0	0	0	7	0	0	0	0	1	3	4	2	1	3	1	0	1	8	3	1	12	2	0	0	2	0	0	1	0	1
1993	1	0	0	0	1	0	2	2	0	1	0	1	3	0	3	1	1	2	2	4	4	10	3	1	0	4	0	0	0	0	0
1994	3	0	0	0	3	0	1	1	0	0	2	2	0	0	0	1	2	3	4	3	3	10	3	0	2	5	0	0	0	1	1
1995	5	0	0	0	5	0	2	2	0	0	1	1	1	0	1	1	0	1	3	9	0	12	11	0	0	11	1	0	1	0	2
1996	3	1	0	0	4	0	1	1	2	0	4	6	0	0	0	1	0	1	0	9	0	9	2	2	1	5	0	0	1	1	2
1997	4	0	0	0	4	1	0	1	1	0	0	1	0	0	0	1	0	1	2	5	3	10	2	0	1	3	0	0	0	0	0
1998	11	1	0	0	12	0	0	0	2	1	0	3	0	0	0	0	0	0	1	9	3	13	4	0	0	4	0	0	0	0	0

1999	4	0	1	0	5	0	0	0	1	1	2	4	0	0	0	0	0	0	1	11	3	15	5	2	1	8	0	0	0	0	0
2000	1	0	0	0	1	0	0	0	0	0	2	2	0	0	0	0	0	0	0	5	0	5	2	3	0	5	0	0	0	0	0
2001	2	0	1	1	4	1	0	1	1	1	0	2	0	0	0	0	0	0	1	3	1	5	3	3	0	6	1	0	0	0	1
2002	3	0	0	0	3	2	0	2	0	1	1	2	1	0	1	0	0	0	1	3	1	5	2	3	0	5	0	0	0	0	0
2003	1	1	0	0	2	2	0	2	2	1	0	3	0	0	0	0	0	0	1	1	3	5	2	4	0	6	0	0	1	0	1
2004	0	0	0	0	0	2	0	2	1	0	2	3	0	0	0	0	0	0	2	5	2	9	6	3	1	10	1	0	0	0	1
2005	1	0	0	1	2	3	0	3	0	0	1	1	0	1	1	0	0	0	3	4	0	7	6	2	0	8	1	1	0	0	2
2006	7	1	0	0	8	0	1	1	3	0	2	5	1	0	1	0	0	0	1	6	1	8	2	0	0	2	1	1	0	0	2
2007	8	0	0	0	8	1	2	3	2	0	0	2	1	2	3	1	2	3	2	4	0	6	3	3	0	6	0	0	0	0	0
2008	4	0	0	0	4	1	1	2	1	0	0	1	2	1	3	0	0	0	0	0	0	0	2	2	2	6	1	1	0	1	3
2009	5	1	1	0	7	0	0	0	0	1	2	3	0	0	0	0	0	0	0	0	0	0	1	1	1	3	1	0	1	0	2
2010	3	0	0	0	3	1	0	1	2	0	1	3	0	0	0	0	0	0	0	0	1	1	0	0	2	2	0	0	0	0	0
2011	1	0	0	0	1	2	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	3	0	0	1	1	0	0	0	0	0
2012	2	2	0	0	4	1	0	1	0	0	0	0	0	0	0	1	0	1	1	2	1	4	4	0	2	6	0	1	0	0	1
2013	0	0	0	0	0	1	0	1	2	2	0	4	1	0	1	0	0	0	1	7	0	8	2	2	5	9	0	0	0	1	1
sum	542	39	9	21	611	42	29	71	43	16	55	114	44	17	61	23	37	60	106	179	55	340	157	76	62	295	15	16	25	14	70

Porto

Table A31: Decision and context counts STCP (Porto).

main-category	network decisions					fleet decisions			personnel decisions				schedule decisions			fare decisions			service decisions				management decisions				context				
sub-category	management	accessibility	(re)organization	other	SUM	fleet upgrade	technology	SUM	incentives	training	other	SUM	frequency	other	SUM	fare change	other	SUM	operations	customer	IT	SUM	optimization	development	research	SUM	legal	energy	demand	other	SUM
1950	13	0	1	0	14	0	0	0	0	0	0	0	4	0	4	0	0	0	4	0	0	4	0	1	0	1	0	0	0	1	1
1951	8	0	0	0	8	0	0	0	1	1	0	2	3	1	4	0	0	0	3	3	0	6	1	0	1	2	0	0	0	0	0
1952	7	1	0	0	8	0	0	0	0	0	1	1	1	1	2	0	0	0	1	1	1	3	2	0	0	2	1	0	1	1	3
1953	4	0	1	0	5	0	0	0	0	1	2	3	0	1	1	0	0	0	1	4	0	5	0	0	0	0	0	0	0	0	0
1954	2	0	0	0	2	0	0	0	0	0	1	1	0	1	1	0	0	0	0	2	0	2	0	0	0	0	0	1	1	1	3
1955	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	3	1	0	0	1	0	0	0	0	0
1956	1	0	1	0	2	1	0	1	0	0	0	0	0	1	1	0	0	0	2	0	0	2	2	1	0	3	0	0	0	0	0
1957	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1
1958	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	0	1	0	1
1959	6	0	0	0	6	2	0	2	1	0	0	1	0	0	0	1	1	2	0	0	2	2	4	0	2	6	1	0	0	1	2
1960	20	0	2	0	22	0	1	1	1	0	1	2	0	1	1	1	3	4	0	1	1	2	3	0	0	3	0	0	1	0	1
1961	11	1	1	0	13	0	0	0	2	0	3	5	1	0	1	1	0	1	1	3	0	4	2	0	0	2	0	1	0	0	1
1962	0	0	0	0	0	2	0	2	5	0	1	6	1	0	1	0	0	0	2	0	0	2	3	0	1	4	0	0	1	1	2
1963	12	1	0	0	13	0	0	0	0	0	0	0	1	1	2	0	0	0	0	1	1	2	4	0	1	5	1	0	0	1	2
1964	7	0	0	1	8	0	0	0	1	0	0	1	0	1	1	0	0	0	2	1	0	3	3	0	0	3	1	0	0	0	1
1965	4	2	0	2	8	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	1	1	1	0	2	0	0	0	0	0
1966	4	0	0	1	5	0	0	0	1	0	0	1	0	1	1	1	0	1	0	0	0	0	1	0	0	1	0	1	0	0	1
1967	25	0	0	0	25	1	0	1	1	0	1	2	0	0	0	1	2	3	0	1	0	1	3	0	3	6	1	1	0	1	3
1968	15	0	1	0	16	0	0	0	1	0	1	2	0	0	0	0	0	0	1	1	0	2	2	1	0	3	0	0	0	1	1
1969	25	0	1	1	27	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
1970	6	0	1	0	7	0	0	0	0	0	2	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	2
1971	7	0	0	0	7	0	0	0	1	0	0	1	0	0	0	0	0	0	0	2	0	2	1	0	1	2	1	0	1	1	3
1972	44	1	1	0	46	0	0	0	1	0	1	2	0	0	0	0	0	0	2	0	0	2	1	0	0	1	1	0	0	0	1
1973	21	0	0	0	21	0	0	0	0	0	1	1	0	0	0	0	0	0	0	2	0	2	2	0	0	2	1	1	0	1	3
1974	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	1	1
1975	36	0	0	0	36	0	0	0	2	0	2	4	0	0	0	1	1	2	3	0	1	4	6	1	1	8	0	0	0	0	0
1976	20	0	0	0	20	0	0	0	0	1	1	2	0	0	0	1	2	3	1	1	1	3	2	0	1	3	0	0	0	1	1
1977	20	0	1	1	22	0	0	0	1	0	1	2	0	0	0	0	1	1	0	4	1	5	3	0	0	3	0	0	0	1	1
1978	23	1	0	0	24	0	0	0	0	2	2	4	0	0	0	1	1	2	2	4	1	7	3	0	0	3	1	1	0	0	2
1979	10	1	0	0	11	0	0	0	1	2	1	4	0	0	0	0	1	1	0	4	1	5	4	0	0	4	0	0	0	0	0
1980	5	2	0	2	9	0	0	0	0	1	4	5	0	0	0	0	4	4	1	3	1	5	5	0	1	6	0	0	0	1	1
1981	0	1	0	0	1	0	0	0	0	1	1	2	0	0	0	1	0	1	1	0	0	1	2	0	2	4	0	0	0	1	1
1982	6	0	0	0	6	0	0	0	0	0	3	3	0	0	0	1	1	2	2	1	1	4	4	1	4	9	1	1	0	1	3
1983	2	0	0	1	3	2	0	2	1	0	4	5	0	0	0	1	0	1	0	2	0	2	7	0	4	11	1	0	0	0	1
1984	12	0	0	0	12	1	0	1	1	0	1	2	0	0	0	1	0	1	1	0	1	2	8	0	0	8	1	0	0	0	1

1985	21	0	0	1	22	0	0	0	0	0	4	4	1	1	2	1	0	1	1	3	0	4	5	0	0	5	0	0	0	0	0
1986	4	0	0	0	4	0	0	0	0	0	3	3	0	1	1	1	0	1	0	1	0	1	3	0	0	3	0	0	0	1	1
1987	8	0	0	0	8	1	0	1	0	0	1	1	0	0	0	0	0	0	0	1	0	1	2	0	0	2	0	0	0	0	0
1988	14	1	0	1	16	0	0	0	0	0	2	2	0	0	0	1	0	1	0	1	0	1	5	0	0	5	0	0	0	0	0
1989	3	0	0	0	3	1	0	1	0	0	1	1	0	0	0	1	0	1	1	1	2	4	8	0	8	16	0	0	0	1	1
1990	2	1	0	0	3	1	0	1	0	0	5	5	0	0	0	1	0	1	0	1	1	2	6	2	8	16	0	0	1	0	1
1991	5	1	0	0	6	0	1	1	1	1	0	2	0	0	0	1	0	1	0	3	2	5	6	1	4	11	0	0	0	0	0
1992	4	0	0	1	5	2	1	3	0	0	3	3	0	0	0	1	2	3	2	5	1	8	4	2	10	16	0	0	0	1	1
1993	10	0	0	0	10	1	1	2	0	0	1	1	0	0	0	0	3	3	3	3	0	6	5	0	9	14	1	0	1	0	2
1994	4	0	0	0	4	0	0	0	2	0	1	3	0	0	0	0	4	4	2	2	2	6	3	2	10	15	1	0	0	0	1
1995	0	0	0	0	0	2	0	2	2	0	0	2	0	0	0	0	2	2	2	5	1	8	4	0	6	10	1	0	0	0	1
1996	4	3	0	2	9	0	0	0	2	1	1	4	0	0	0	0	1	1	2	6	0	8	3	2	10	15	0	0	0	0	0
1997	3	0	0	1	4	0	0	0	1	0	0	1	1	1	2	0	0	0	0	3	0	3	5	1	9	15	0	0	0	0	0
1998	23	0	2	1	26	0	0	0	3	2	2	7	1	1	2	0	0	0	0	7	2	9	6	2	8	16	0	0	0	0	0
1999	6	1	0	0	7	2	1	3	6	0	1	7	0	0	0	0	0	0	0	5	2	7	5	3	5	13	0	1	0	0	1
2000	0	1	0	0	1	1	1	2	0	1	1	2	0	0	0	0	0	0	1	3	3	7	4	0	0	4	0	0	0	1	1
2001	7	1	0	1	9	2	1	3	0	0	1	1	0	0	0	0	0	0	0	5	0	5	2	3	10	15	0	0	1	1	2
2002	1	0	1	0	2	0	0	0	0	0	1	1	0	0	0	0	0	0	2	1	0	3	5	1	1	7	1	0	1	0	2
2003	0	0	1	2	3	0	0	0	0	0	0	0	1	0	1	1	2	3	1	3	0	4	3	0	3	6	0	0	0	1	1
2004	4	0	1	0	5	1	0	1	0	1	0	1	2	0	2	1	1	2	0	6	2	8	10	2	1	13	1	1	1	1	4
2005	40	1	1	1	43	0	0	0	0	1	1	2	1	0	1	1	2	3	1	5	2	8	9	2	1	12	0	0	1	1	2
2006	7	0	1	1	9	2	1	3	2	1	1	4	0	0	0	1	1	2	0	9	2	11	9	1	3	13	0	0	0	1	1
2007	17	0	1	0	18	0	0	0	2	2	3	7	1	1	2	0	0	0	0	5	1	6	3	3	7	13	1	0	0	0	1
2008	7	0	0	0	7	0	0	0	3	1	2	6	1	0	1	0	1	1	0	3	0	3	5	1	5	11	0	0	0	0	0
2009	6	0	0	0	6	0	0	0	3	0	3	6	0	0	0	0	2	2	0	3	0	3	2	1	12	15	0	0	0	1	1
2010	7	3	0	0	10	0	0	0	2	2	2	6	1	1	2	1	0	1	1	4	1	6	7	3	8	18	0	0	0	0	0
2011	12	2	0	1	15	0	0	0	1	2	1	4	1	3	4	0	2	2	0	8	1	9	5	6	3	14	0	0	0	1	1
2012	12	0	0	0	12	0	0	0	1	1	2	4	2	2	4	1	1	2	0	2	3	5	7	4	7	18	0	0	0	1	1
2013	1	0	0	0	1	0	0	0	3	0	2	5	1	1	2	0	2	2	0	1	2	3	4	2	4	10	0	0	0	0	0
sum	614	26	19	22	681	25	8	33	60	25	82	167	25	21	46	27	43	70	52	148	43	243	226	51	175	452	20	9	12	31	72

Dresden

Table A32: Decision and context counts DVB (Dresden).

main-category	network decisions					fleet decisions			personnel decisions				schedule decisions			fare decisions			service decisions				management decisions				context				
sub-category	management	accessibility	(re)organization	other	SUM	fleet upgrade	technology	SUM	incentives	training	other	SUM	frequency	other	SUM	fare change	other	SUM	operations	customer	IT	SUM	optimization	development	research	SUM	legal	energy	demand	other	SUM
1950																															
1951																															
1952																															
1953																															
1954																															
1955																															
1956																															
1957	0	0	0	0	0	2	0	2	1	0	1	2	1	0	1	0	1	1	2	4	0	6	4	1	0	5	0	0	0	1	1
1958	10	0	0	0	10	0	1	1	1	1	3	5	0	0	0	0	0	0	1	1	1	3	2	1	0	3	0	0	0	1	1
1959	10	0	0	0	10	1	0	1	1	1	3	5	2	0	2	0	0	0	3	4	1	8	5	0	0	5	0	0	0	1	1
1960	10	0	0	0	10	0	0	0	2	0	1	3	0	0	0	0	0	0	2	0	1	3	5	0	0	5	0	0	0	1	1
1961	41	1	0	0	42	1	0	1	0	1	2	3	1	0	1	0	0	0	1	0	1	2	2	0	0	2	0	0	0	1	1
1962	83	1	0	0	84	2	0	2	1	0	1	2	1	0	1	0	0	0	0	0	0	0	2	1	0	3	0	0	0	1	1
1963	20	0	0	0	20	1	0	1	0	0	2	2	0	0	0	0	0	0	1	0	0	1	3	0	0	3	0	0	1	1	2
1964	15	0	0	0	15	1	0	1	0	0	1	1	0	0	0	0	0	0	0	3	0	3	4	0	0	4	0	0	0	1	1
1965	30	1	0	0	31	0	0	0	0	0	2	2	0	0	0	0	0	0	0	2	0	2	1	0	1	2	0	0	0	1	1
1966	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	4	0	4	3	0	0	3	0	0	0	1	1
1967	10	0	0	0	10	1	0	1	2	0	2	4	0	0	0	0	0	0	1	2	0	3	2	1	1	4	0	0	0	1	1
1968	2	0	0	0	2	2	0	2	0	0	1	1	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	1	1
1969	79	1	1	0	81	1	0	1	0	1	0	1	0	0	0	0	0	0	2	1	2	5	5	0	0	5	0	0	1	0	1
1970	18	0	0	0	18	1	0	1	1	1	0	2	0	0	0	0	0	0	1	1	0	2	3	2	0	5	0	0	0	1	1

1971	8	0	0	0	8	1	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0	4	7	0	0	7	0	0	0	1	1
1972	41	1	0	0	42	1	1	2	1	0	0	1	0	0	0	0	0	0	3	1	0	4	5	0	4	9	0	0	0	0	0
1973	4	0	0	0	4	1	0	1	0	0	1	1	0	1	1	0	0	0	1	2	2	5	6	1	4	11	0	0	0	0	0
1974	1	0	0	0	1	0	0	0	0	0	0	0	2	0	2	0	0	0	2	1	0	3	2	0	4	6	0	0	0	0	0
1975	39	0	0	0	39	1	0	1	0	0	1	1	2	0	2	0	0	0	1	3	0	4	7	0	4	11	0	1	0	1	2
1976	2	1	0	0	3	0	0	0	1	0	0	1	0	0	0	0	0	0	0	3	0	3	3	1	0	4	1	0	0	1	2
1977	33	1	0	0	34	0	0	0	1	1	0	2	0	0	0	0	0	0	1	0	0	1	3	0	0	3	0	0	0	0	0
1978	10	0	1	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	4	2	0	0	2	1	0	0	1	2
1979	2	0	0	0	2	0	0	0	0	1	0	1	0	0	0	0	0	0	0	3	1	4	2	0	4	6	0	0	0	0	0
1980	23	1	0	0	24	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	3	0	0	3	0	0	0	1	1
1981	9	0	0	0	9	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0
1982	13	1	0	0	14	0	0	0	0	0	0	0	0	1	1	0	0	0	1	2	2	5	1	4	0	5	0	0	0	0	0
1983	5	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	4	3	0	6	9	0	0	0	1	1
1984	9	1	0	0	10	0	2	2	0	0	0	0	0	0	0	0	0	0	2	1	2	5	8	0	1	9	0	0	0	0	0
1985	4	0	0	0	4	0	1	1	0	0	0	0	0	0	0	0	0	0	2	1	2	5	3	0	0	3	0	0	0	1	1
1986	4	1	0	0	5	1	1	2	2	0	0	2	1	0	1	0	0	0	0	2	0	2	7	0	0	7	0	0	0	0	0
1987	0	1	0	0	1	0	0	0	2	0	0	2	0	0	0	0	0	0	1	3	0	4	5	0	3	8	0	0	0	1	1
1988	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	4	4	2	0	6	0	0	0	1	1
1989	9	0	1	0	10	1	0	1	1	0	1	2	1	1	2	0	0	0	0	2	0	2	1	1	0	2	0	0	0	1	1
1990	37	0	0	1	38	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1991	37	0	0	1	38	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	37	0	0	1	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
1993	37	0	0	1	38	3	0	3	0	0	0	0	1	1	2	1	2	3	2	2	1	5	8	1	0	9	0	0	0	1	1
1994	0	0	0	0	0	1	1	2	0	0	0	0	0	3	3	0	1	1	2	3	0	5	3	0	1	4	0	0	1	1	2
1995	0	0	1	0	1	2	0	2	0	0	0	0	0	0	0	1	1	2	1	1	0	2	2	1	0	3	0	0	0	0	0
1996	0	0	0	0	0	1	1	2	0	1	2	3	0	0	0	0	0	0	0	0	0	0	3	2	0	5	0	0	0	0	0
1997	0	0	0	0	0	0	1	1	1	0	1	2	0	0	0	0	1	1	0	4	2	6	5	0	0	5	0	0	0	0	0
1998	0	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	4	1	6	4	5	0	9	0	0	0	0	0
1999	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	2	4	2	1	2	5	1	0	0	0	1
2000	0	1	1	0	2	0	0	0	0	0	2	2	0	3	3	0	1	1	0	4	1	5	4	2	0	6	1	0	0	0	1
2001	0	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	1	1	2	1	1	4	5	1	0	6	1	0	0	0	1
2002	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	1	3	5	1	0	6	1	0	0	1	2
2003	0	2	0	0	2	2	0	2	0	0	0	0	1	1	2	0	1	1	0	3	0	3	4	4	0	8	0	0	0	0	0
2004	3	0	0	0	3	0	0	0	0	0	0	0	1	0	1	0	1	1	1	3	0	4	2	4	0	6	1	0	0	0	1
2005	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	1	1	1	3	1	5	0	1	0	1	0	0	0	1	1
2006	3	0	0	0	3	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2007	4	0	0	0	4	0	1	1	1	1	0	2	0	2	2	0	4	4	1	7	0	8	3	2	2	7	1	0	0	0	1
2008	7	1	0	0	8	0	0	0	2	1	0	3	1	1	2	0	0	0	1	3	3	7	1	4	0	5	0	1	0	0	1
2009	11	1	0	0	12	1	0	1	0	1	1	2	0	0	0	0	1	1	1	3	2	6	3	1	0	4	0	0	0	1	1
2010	1	1	0	0	2	1	0	1	0	2	3	5	0	0	0	0	0	0	0	0	2	2	6	1	0	7	0	0	0	1	1
2011	3	1	0	0	4	1	1	2	1	3	3	7	0	0	0	0	0	0	0	2	2	4	6	1	0	7	0	0	0	0	0
2012	2	0	0	0	2	0	1	1	0	1	5	6	0	0	0	0	1	1	0	3	1	4	3	0	3	6	0	0	0	0	0
2013	3	0	1	0	4	0	0	0	2	1	4	7	0	0	0	0	0	0	0	3	0	3	2	2	3	7	0	0	0	1	1
sum	731	22	7	4	764	35	12	47	25	18	46	89	16	14	30	3	20	23	50	108	38	196	186	49	43	278	8	2	3	30	43

6 Learning Curves

Notations

C_{mn}	original count
n	decision category
m	year 0 to t
t	maximum year
k	growth parameter
$L_x(t)$	maximum convex learning curve
$L_v(t)$	maximum concave learning curve
$AC_x(0)$	maximum convex adjustment curve
$AC_v(0)$	maximum concave adjustment curve
$sL_x(m)$	$= L_x(m)/L_x(t)$ scaled convex learning curve: min $sL_x(0)$; max 1 at $m = t$
$sL_v(m)$	$= L_v(m)/L_v(t)$ scaled concave learning curve: min $sL_v(0)$; max 1 at $m = t$
$sAC_x(m)$	$= AC_x(m)/L_x(t)$ scaled convex adjustment curve:
$sAC_v(m)$	$= AC_v(m)/L_v(t)$ scaled concave adjustment curve
$sL_x(0)$	minimum scaled convex learning curve
$sL_v(0)$	minimum scaled concave learning curve
$sAC_x(t)$	minimum scaled convex adjustment curve
$sAC_v(t)$	minimum scaled concave adjustment curve
$F_{xr}(m)$	$= sAC_v(m)$ adjustment factor for year m to convex learning curve, recent (data deflation)
$F_{vr}(m)$	$= sAC_x(m)$ adjustment factor for year m to concave learning curve, recent (data deflation)
$F_{xp}(m)$	$= (1 + sAC_v(m) - sAC_v(t))$ adjustment factor for year m to convex learning curve, past (data inflation)
$F_{vp}(m)$	$= (1 + sAC_x(m) - sAC_x(t))$ adjustment factor for year m to concave learning curve, past (data inflation)

Formulas

convex learning curve *regular order of m*

$$L_x(m) = exp^{km};\ (\mathrm{m} = 0, 1, 2, \dots \mathrm{t}) \quad (45)$$

convex adjustment curve *inverted order of m*

$$AC_x(m) = exp^{km}; (\mathrm{m} = \mathrm{t}, \mathrm{t}-1, \mathrm{t}-2, \dots, 0) \quad (46)$$

concave learning curve *regular order of m*

$$L_v(m) = 1 - exp^{k(t-m)} + L_v(t)\ ; (\mathrm{m} = 1, 2, 3, \dots \mathrm{t}) \quad (47)$$

concave adjustment curve *inverted order of m*

$$AC_v(m) = 1 - exp^{k(t-m)} + AC_v(0);\ (\mathrm{m} = \mathrm{t}, \mathrm{t}-1, \mathrm{t}-2, \dots, 0) \quad (48)$$

count adjustment to convex learning curve *recent*

$$c_{mn} = C_{mn} \times F_{xr}(m) \quad (49)$$

count adjustment to concave learning curve *recent*

$$c_{mn} = C_{mn} \times F_{vr}(m) \quad (50)$$

count adjustment to convex learning curve *past*

$$c_{mn} = C_{mn} \times F_{xp}(m) \quad (51)$$

count adjustment to concave learning *past*

$$c_{mn} = C_{mn} \times F_{vp}(m) \quad (52)$$

Learning curves and adjustment curves - Hamburg

year	m↑	m↓	LCx convex	LCv concave	LCl linear	sLCx	sLCv	sLCl	ACx	ACv	ACl	sACx	sACv	sACl
1950	0	63	1.00	1.00	1.00	0.15	0.15	0.15	6.68	6.68	6.68	1.00	1.00	1.00
1951	1	62	1.03	1.20	1.09	0.15	0.18	0.16	6.48	6.65	6.59	0.97	1.00	0.99
1952	2	61	1.06	1.39	1.18	0.16	0.21	0.18	6.29	6.62	6.50	0.94	0.99	0.97
1953	3	60	1.09	1.58	1.27	0.16	0.24	0.19	6.10	6.59	6.41	0.91	0.99	0.96
1954	4	59	1.13	1.76	1.36	0.17	0.26	0.20	5.92	6.55	6.32	0.89	0.98	0.95
1955	5	58	1.16	1.94	1.45	0.17	0.29	0.22	5.75	6.52	6.23	0.86	0.98	0.93
1956	6	57	1.20	2.11	1.54	0.18	0.32	0.23	5.58	6.48	6.14	0.83	0.97	0.92
1957	7	56	1.23	2.27	1.63	0.18	0.34	0.24	5.41	6.45	6.05	0.81	0.96	0.91
1958	8	55	1.27	2.43	1.72	0.19	0.36	0.26	5.25	6.41	5.96	0.79	0.96	0.89
1959	9	54	1.31	2.59	1.81	0.20	0.39	0.27	5.09	6.37	5.87	0.76	0.95	0.88
1960	10	53	1.35	2.74	1.90	0.20	0.41	0.28	4.94	6.33	5.78	0.74	0.95	0.87
1961	11	52	1.39	2.89	1.99	0.21	0.43	0.30	4.80	6.29	5.69	0.72	0.94	0.85
1962	12	51	1.44	3.03	2.08	0.21	0.45	0.31	4.65	6.25	5.60	0.70	0.93	0.84
1963	13	50	1.48	3.17	2.17	0.22	0.47	0.33	4.52	6.20	5.51	0.68	0.93	0.82
1964	14	49	1.53	3.30	2.26	0.23	0.49	0.34	4.38	6.16	5.42	0.66	0.92	0.81
1965	15	48	1.57	3.43	2.35	0.24	0.51	0.35	4.25	6.11	5.33	0.64	0.91	0.80
1966	16	47	1.62	3.56	2.44	0.24	0.53	0.37	4.12	6.06	5.24	0.62	0.91	0.78
1967	17	46	1.67	3.68	2.53	0.25	0.55	0.38	4.00	6.01	5.15	0.60	0.90	0.77
1968	18	45	1.72	3.80	2.62	0.26	0.57	0.39	3.88	5.96	5.06	0.58	0.89	0.76
1969	19	44	1.77	3.91	2.71	0.27	0.59	0.41	3.77	5.91	4.97	0.56	0.88	0.74
1970	20	43	1.83	4.03	2.80	0.27	0.60	0.42	3.66	5.85	4.88	0.55	0.88	0.73
1971	21	42	1.88	4.13	2.89	0.28	0.62	0.43	3.55	5.80	4.79	0.53	0.87	0.72
1972	22	41	1.94	4.24	2.98	0.29	0.63	0.45	3.44	5.74	4.70	0.52	0.86	0.70
1973	23	40	2.00	4.34	3.07	0.30	0.65	0.46	3.34	5.68	4.61	0.50	0.85	0.69
1974	24	39	2.06	4.44	3.16	0.31	0.66	0.47	3.24	5.62	4.52	0.49	0.84	0.68
1975	25	38	2.12	4.54	3.25	0.32	0.68	0.49	3.14	5.56	4.43	0.47	0.83	0.66
1976	26	37	2.19	4.63	3.35	0.33	0.69	0.50	3.05	5.49	4.34	0.46	0.82	0.65
1977	27	36	2.26	4.72	3.44	0.34	0.71	0.51	2.96	5.43	4.25	0.44	0.81	0.64
1978	28	35	2.33	4.81	3.53	0.35	0.72	0.53	2.87	5.36	4.16	0.43	0.80	0.62
1979	29	34	2.40	4.89	3.62	0.36	0.73	0.54	2.79	5.28	4.07	0.42	0.79	0.61
1980	30	33	2.47	4.98	3.71	0.37	0.74	0.55	2.70	5.21	3.98	0.40	0.78	0.60
1981	31	32	2.55	5.06	3.80	0.38	0.76	0.57	2.62	5.14	3.89	0.39	0.77	0.58
1982	32	31	2.62	5.14	3.89	0.39	0.77	0.58	2.55	5.06	3.80	0.38	0.76	0.57
1983	33	30	2.70	5.21	3.98	0.40	0.78	0.60	2.47	4.98	3.71	0.37	0.74	0.55
1984	34	29	2.79	5.28	4.07	0.42	0.79	0.61	2.40	4.89	3.62	0.36	0.73	0.54
1985	35	28	2.87	5.36	4.16	0.43	0.80	0.62	2.33	4.81	3.53	0.35	0.72	0.53
1986	36	27	2.96	5.43	4.25	0.44	0.81	0.64	2.26	4.72	3.44	0.34	0.71	0.51
1987	37	26	3.05	5.49	4.34	0.46	0.82	0.65	2.19	4.63	3.35	0.33	0.69	0.50
1988	38	25	3.14	5.56	4.43	0.47	0.83	0.66	2.12	4.54	3.25	0.32	0.68	0.49
1989	39	24	3.24	5.62	4.52	0.49	0.84	0.68	2.06	4.44	3.16	0.31	0.66	0.47

1990	40	23	3.34	5.68	4.61	0.50	0.85	0.69	2.00	4.34	3.07	0.30	0.65	0.46
1991	41	22	3.44	5.74	4.70	0.52	0.86	0.70	1.94	4.24	2.98	0.29	0.63	0.45
1992	42	21	3.55	5.80	4.79	0.53	0.87	0.72	1.88	4.13	2.89	0.28	0.62	0.43
1993	43	20	3.66	5.85	4.88	0.55	0.88	0.73	1.83	4.03	2.80	0.27	0.60	0.42
1994	44	19	3.77	5.91	4.97	0.56	0.88	0.74	1.77	3.91	2.71	0.27	0.59	0.41
1995	45	18	3.88	5.96	5.06	0.58	0.89	0.76	1.72	3.80	2.62	0.26	0.57	0.39
1996	46	17	4.00	6.01	5.15	0.60	0.90	0.77	1.67	3.68	2.53	0.25	0.55	0.38
1997	47	16	4.12	6.06	5.24	0.62	0.91	0.78	1.62	3.56	2.44	0.24	0.53	0.37
1998	48	15	4.25	6.11	5.33	0.64	0.91	0.80	1.57	3.43	2.35	0.24	0.51	0.35
1999	49	14	4.38	6.16	5.42	0.66	0.92	0.81	1.53	3.30	2.26	0.23	0.49	0.34
2000	50	13	4.52	6.20	5.51	0.68	0.93	0.82	1.48	3.17	2.17	0.22	0.47	0.33
2001	51	12	4.65	6.25	5.60	0.70	0.93	0.84	1.44	3.03	2.08	0.21	0.45	0.31
2002	52	11	4.80	6.29	5.69	0.72	0.94	0.85	1.39	2.89	1.99	0.21	0.43	0.30
2003	53	10	4.94	6.33	5.78	0.74	0.95	0.87	1.35	2.74	1.90	0.20	0.41	0.28
2004	54	9	5.09	6.37	5.87	0.76	0.95	0.88	1.31	2.59	1.81	0.20	0.39	0.27
2005	55	8	5.25	6.41	5.96	0.79	0.96	0.89	1.27	2.43	1.72	0.19	0.36	0.26
2006	56	7	5.41	6.45	6.05	0.81	0.96	0.91	1.23	2.27	1.63	0.18	0.34	0.24
2007	57	6	5.58	6.48	6.14	0.83	0.97	0.92	1.20	2.11	1.54	0.18	0.32	0.23
2008	58	5	5.75	6.52	6.23	0.86	0.98	0.93	1.16	1.94	1.45	0.17	0.29	0.22
2009	59	4	5.92	6.55	6.32	0.89	0.98	0.95	1.13	1.76	1.36	0.17	0.26	0.20
2010	60	3	6.10	6.59	6.41	0.91	0.99	0.96	1.09	1.58	1.27	0.16	0.24	0.19
2011	61	2	6.29	6.62	6.50	0.94	0.99	0.97	1.06	1.39	1.18	0.16	0.21	0.18
2012	62	1	6.48	6.65	6.59	0.97	1.00	0.99	1.03	1.20	1.09	0.15	0.18	0.16
2013	63	0	6.68	6.68	6.68	1.00	1.00	1.00	1.00	1.00	1.00	0.15	0.15	0.15
	max		6.68	6.68	6.68	1.00	1.00	1.00	6.68	6.68	6.68	1.00	1.00	1.00
	min		1.00	1.00	1.00	0.15	0.15	0.15	1.00	1.00	1.00	0.15	0.15	0.15

Learning curves and adjustment curves - Porto

year	m↑	m↓	LCx convex	LCv concave	LCl linear	sLCx	sLCv	sLCl	ACx	ACv	ACl	sACx	sACv	sACl
1950	0	63	1.00	1.00	1.00	0.18	0.18	0.18	5.71	5.71	5.71	1.00	1.00	1.00
1951	1	62	1.03	1.16	1.07	0.18	0.20	0.19	5.55	5.68	5.63	0.97	1.00	0.99
1952	2	61	1.06	1.31	1.15	0.19	0.23	0.20	5.40	5.65	5.56	0.95	0.99	0.97
1953	3	60	1.09	1.45	1.22	0.19	0.25	0.21	5.25	5.62	5.48	0.92	0.98	0.96
1954	4	59	1.12	1.60	1.30	0.20	0.28	0.23	5.11	5.59	5.41	0.90	0.98	0.95
1955	5	58	1.15	1.74	1.37	0.20	0.30	0.24	4.97	5.56	5.33	0.87	0.97	0.93
1956	6	57	1.18	1.87	1.45	0.21	0.33	0.25	4.84	5.53	5.26	0.85	0.97	0.92
1957	7	56	1.21	2.00	1.52	0.21	0.35	0.27	4.70	5.49	5.19	0.82	0.96	0.91
1958	8	55	1.25	2.13	1.60	0.22	0.37	0.28	4.58	5.46	5.11	0.80	0.96	0.90
1959	9	54	1.28	2.26	1.67	0.22	0.40	0.29	4.45	5.43	5.04	0.78	0.95	0.88
1960	10	53	1.32	2.38	1.75	0.23	0.42	0.31	4.33	5.39	4.96	0.76	0.94	0.87
1961	11	52	1.36	2.50	1.82	0.24	0.44	0.32	4.21	5.35	4.89	0.74	0.94	0.86
1962	12	51	1.39	2.61	1.90	0.24	0.46	0.33	4.10	5.31	4.81	0.72	0.93	0.84
1963	13	50	1.43	2.72	1.97	0.25	0.48	0.35	3.98	5.28	4.74	0.70	0.92	0.83
1964	14	49	1.47	2.83	2.05	0.26	0.50	0.36	3.88	5.24	4.66	0.68	0.92	0.82
1965	15	48	1.51	2.94	2.12	0.27	0.51	0.37	3.77	5.19	4.59	0.66	0.91	0.80

1966	16	47	1.56	3.04	2.20	0.27	0.53	0.38	3.67	5.15	4.51	0.64	0.90	0.79
1967	17	46	1.60	3.14	2.27	0.28	0.55	0.40	3.57	5.11	4.44	0.62	0.89	0.78
1968	18	45	1.64	3.24	2.35	0.29	0.57	0.41	3.47	5.06	4.36	0.61	0.89	0.76
1969	19	44	1.69	3.33	2.42	0.30	0.58	0.42	3.38	5.02	4.29	0.59	0.88	0.75
1970	20	43	1.74	3.42	2.49	0.30	0.60	0.44	3.28	4.97	4.21	0.58	0.87	0.74
1971	21	42	1.79	3.51	2.57	0.31	0.62	0.45	3.19	4.92	4.14	0.56	0.86	0.73
1972	22	41	1.84	3.60	2.64	0.32	0.63	0.46	3.11	4.87	4.06	0.54	0.85	0.71
1973	23	40	1.89	3.69	2.72	0.33	0.65	0.48	3.02	4.82	3.99	0.53	0.84	0.70
1974	24	39	1.94	3.77	2.79	0.34	0.66	0.49	2.94	4.77	3.91	0.51	0.84	0.69
1975	25	38	2.00	3.85	2.87	0.35	0.67	0.50	2.86	4.71	3.84	0.50	0.83	0.67
1976	26	37	2.05	3.93	2.94	0.36	0.69	0.52	2.78	4.66	3.77	0.49	0.82	0.66
1977	27	36	2.11	4.00	3.02	0.37	0.70	0.53	2.71	4.60	3.69	0.47	0.81	0.65
1978	28	35	2.17	4.08	3.09	0.38	0.71	0.54	2.63	4.54	3.62	0.46	0.80	0.63
1979	29	34	2.23	4.15	3.17	0.39	0.73	0.55	2.56	4.48	3.54	0.45	0.78	0.62
1980	30	33	2.29	4.22	3.24	0.40	0.74	0.57	2.49	4.42	3.47	0.44	0.77	0.61
1981	31	32	2.36	4.29	3.32	0.41	0.75	0.58	2.42	4.35	3.39	0.42	0.76	0.59
1982	32	31	2.42	4.35	3.39	0.42	0.76	0.59	2.36	4.29	3.32	0.41	0.75	0.58
1983	33	30	2.49	4.42	3.47	0.44	0.77	0.61	2.29	4.22	3.24	0.40	0.74	0.57
1984	34	29	2.56	4.48	3.54	0.45	0.78	0.62	2.23	4.15	3.17	0.39	0.73	0.55
1985	35	28	2.63	4.54	3.62	0.46	0.80	0.63	2.17	4.08	3.09	0.38	0.71	0.54
1986	36	27	2.71	4.60	3.69	0.47	0.81	0.65	2.11	4.00	3.02	0.37	0.70	0.53
1987	37	26	2.78	4.66	3.77	0.49	0.82	0.66	2.05	3.93	2.94	0.36	0.69	0.52
1988	38	25	2.86	4.71	3.84	0.50	0.83	0.67	2.00	3.85	2.87	0.35	0.67	0.50
1989	39	24	2.94	4.77	3.91	0.51	0.84	0.69	1.94	3.77	2.79	0.34	0.66	0.49
1990	40	23	3.02	4.82	3.99	0.53	0.84	0.70	1.89	3.69	2.72	0.33	0.65	0.48
1991	41	22	3.11	4.87	4.06	0.54	0.85	0.71	1.84	3.60	2.64	0.32	0.63	0.46
1992	42	21	3.19	4.92	4.14	0.56	0.86	0.73	1.79	3.51	2.57	0.31	0.62	0.45
1993	43	20	3.28	4.97	4.21	0.58	0.87	0.74	1.74	3.42	2.49	0.30	0.60	0.44
1994	44	19	3.38	5.02	4.29	0.59	0.88	0.75	1.69	3.33	2.42	0.30	0.58	0.42
1995	45	18	3.47	5.06	4.36	0.61	0.89	0.76	1.64	3.24	2.35	0.29	0.57	0.41
1996	46	17	3.57	5.11	4.44	0.62	0.89	0.78	1.60	3.14	2.27	0.28	0.55	0.40
1997	47	16	3.67	5.15	4.51	0.64	0.90	0.79	1.56	3.04	2.20	0.27	0.53	0.38
1998	48	15	3.77	5.19	4.59	0.66	0.91	0.80	1.51	2.94	2.12	0.27	0.51	0.37
1999	49	14	3.88	5.24	4.66	0.68	0.92	0.82	1.47	2.83	2.05	0.26	0.50	0.36
2000	50	13	3.98	5.28	4.74	0.70	0.92	0.83	1.43	2.72	1.97	0.25	0.48	0.35
2001	51	12	4.10	5.31	4.81	0.72	0.93	0.84	1.39	2.61	1.90	0.24	0.46	0.33
2002	52	11	4.21	5.35	4.89	0.74	0.94	0.86	1.36	2.50	1.82	0.24	0.44	0.32
2003	53	10	4.33	5.39	4.96	0.76	0.94	0.87	1.32	2.38	1.75	0.23	0.42	0.31
2004	54	9	4.45	5.43	5.04	0.78	0.95	0.88	1.28	2.26	1.67	0.22	0.40	0.29
2005	55	8	4.58	5.46	5.11	0.80	0.96	0.90	1.25	2.13	1.60	0.22	0.37	0.28
2006	56	7	4.70	5.49	5.19	0.82	0.96	0.91	1.21	2.00	1.52	0.21	0.35	0.27
2007	57	6	4.84	5.53	5.26	0.85	0.97	0.92	1.18	1.87	1.45	0.21	0.33	0.25
2008	58	5	4.97	5.56	5.33	0.87	0.97	0.93	1.15	1.74	1.37	0.20	0.30	0.24
2009	59	4	5.11	5.59	5.41	0.90	0.98	0.95	1.12	1.60	1.30	0.20	0.28	0.23
2010	60	3	5.25	5.62	5.48	0.92	0.98	0.96	1.09	1.45	1.22	0.19	0.25	0.21
2011	61	2	5.40	5.65	5.56	0.95	0.99	0.97	1.06	1.31	1.15	0.19	0.23	0.20

2012	62	1	5.55	5.68	5.63	0.97	1.00	0.99	1.03	1.16	1.07	0.18	0.20	0.19
2013	63	0	5.71	5.71	5.71	1.00	1.00	1.00	1.00	1.00	1.00	0.18	0.18	0.18
	max		5.71	5.71	5.71	1.00	1.00	1.00	5.71	5.71	5.71	1.00	1.00	1.00
	min		1.00	1.00	1.00	0.18	0.18	0.18	1.00	1.00	1.00	0.18	0.18	0.18

Learning curves and adjustment curves - Dresden

year	m↑	m↓	LCx convex	LCv concave	LCl linear	sLCx	sLCv	sLCl	ACx	ACv	ACl	sACx	sACv	sACl
1957	0	56	1.00	1.00	1.00	0.00	0.00	0.00	249.34	249.34	249.34	1.00	1.00	1.00
1958	1	55	1.10	24.40	5.43	0.00	0.10	0.02	225.94	249.23	244.90	0.91	1.00	0.98
1959	2	54	1.22	45.60	9.87	0.00	0.18	0.04	204.73	249.12	240.47	0.82	1.00	0.96
1960	3	53	1.34	64.82	14.30	0.01	0.26	0.06	185.52	248.99	236.03	0.74	1.00	0.95
1961	4	52	1.48	82.23	18.74	0.01	0.33	0.08	168.11	248.85	231.60	0.67	1.00	0.93
1962	5	51	1.64	98.01	23.17	0.01	0.39	0.09	152.33	248.70	227.16	0.61	1.00	0.91
1963	6	50	1.81	112.30	27.61	0.01	0.45	0.11	138.03	248.53	222.73	0.55	1.00	0.89
1964	7	49	1.99	125.26	32.04	0.01	0.50	0.13	125.08	248.34	218.29	0.50	1.00	0.88
1965	8	48	2.20	136.99	36.48	0.01	0.55	0.15	113.34	248.14	213.86	0.45	1.00	0.86
1966	9	47	2.43	147.63	40.91	0.01	0.59	0.16	102.70	247.91	209.42	0.41	0.99	0.84
1967	10	46	2.68	157.27	45.35	0.01	0.63	0.18	93.07	247.66	204.99	0.37	0.99	0.82
1968	11	45	2.96	166.00	49.78	0.01	0.67	0.20	84.33	247.38	200.56	0.34	0.99	0.80
1969	12	44	3.26	173.92	54.21	0.01	0.70	0.22	76.42	247.07	196.12	0.31	0.99	0.79
1970	13	43	3.60	181.09	58.65	0.01	0.73	0.24	69.24	246.73	191.69	0.28	0.99	0.77
1971	14	42	3.97	187.59	63.08	0.02	0.75	0.25	62.75	246.36	187.25	0.25	0.99	0.75
1972	15	41	4.39	193.48	67.52	0.02	0.78	0.27	56.86	245.95	182.82	0.23	0.99	0.73
1973	16	40	4.84	198.81	71.95	0.02	0.80	0.29	51.52	245.50	178.38	0.21	0.98	0.72
1974	17	39	5.34	203.65	76.39	0.02	0.82	0.31	46.69	244.99	173.95	0.19	0.98	0.70
1975	18	38	5.89	208.03	80.82	0.02	0.83	0.32	42.30	244.44	169.51	0.17	0.98	0.68
1976	19	37	6.50	212.00	85.26	0.03	0.85	0.34	38.33	243.83	165.08	0.15	0.98	0.66
1977	20	36	7.18	215.60	89.69	0.03	0.86	0.36	34.74	243.16	160.64	0.14	0.98	0.64
1978	21	35	7.92	218.86	94.13	0.03	0.88	0.38	31.48	242.41	156.21	0.13	0.97	0.63
1979	22	34	8.74	221.81	98.56	0.04	0.89	0.40	28.52	241.59	151.78	0.11	0.97	0.61
1980	23	33	9.65	224.49	103.00	0.04	0.90	0.41	25.85	240.69	147.34	0.10	0.97	0.59
1981	24	32	10.65	226.92	107.43	0.04	0.91	0.43	23.42	239.69	142.91	0.09	0.96	0.57
1982	25	31	11.75	229.11	111.86	0.05	0.92	0.45	21.22	238.59	138.47	0.09	0.96	0.56
1983	26	30	12.97	231.11	116.30	0.05	0.93	0.47	19.23	237.37	134.04	0.08	0.95	0.54
1984	27	29	14.31	232.91	120.73	0.06	0.93	0.48	17.43	236.03	129.60	0.07	0.95	0.52
1985	28	28	15.79	234.55	125.17	0.06	0.94	0.50	15.79	234.55	125.17	0.06	0.94	0.50
1986	29	27	17.43	236.03	129.60	0.07	0.95	0.52	14.31	232.91	120.73	0.06	0.93	0.48
1987	30	26	19.23	237.37	134.04	0.08	0.95	0.54	12.97	231.11	116.30	0.05	0.93	0.47
1988	31	25	21.22	238.59	138.47	0.09	0.96	0.56	11.75	229.11	111.86	0.05	0.92	0.45
1989	32	24	23.42	239.69	142.91	0.09	0.96	0.57	10.65	226.92	107.43	0.04	0.91	0.43
1990	33	23	25.85	240.69	147.34	0.10	0.97	0.59	9.65	224.49	103.00	0.04	0.90	0.41
1991	34	22	28.52	241.59	151.78	0.11	0.97	0.61	8.74	221.81	98.56	0.04	0.89	0.40
1992	35	21	31.48	242.41	156.21	0.13	0.97	0.63	7.92	218.86	94.13	0.03	0.88	0.38
1993	36	20	34.74	243.16	160.64	0.14	0.98	0.64	7.18	215.60	89.69	0.03	0.86	0.36
1994	37	19	38.33	243.83	165.08	0.15	0.98	0.66	6.50	212.00	85.26	0.03	0.85	0.34

1995	38	18	42.30	244.44	169.51	0.17	0.98	0.68	5.89	208.03	80.82	0.02	0.83	0.32
1996	39	17	46.69	244.99	173.95	0.19	0.98	0.70	5.34	203.65	76.39	0.02	0.82	0.31
1997	40	16	51.52	245.50	178.38	0.21	0.98	0.72	4.84	198.81	71.95	0.02	0.80	0.29
1998	41	15	56.86	245.95	182.82	0.23	0.99	0.73	4.39	193.48	67.52	0.02	0.78	0.27
1999	42	14	62.75	246.36	187.25	0.25	0.99	0.75	3.97	187.59	63.08	0.02	0.75	0.25
2000	43	13	69.24	246.73	191.69	0.28	0.99	0.77	3.60	181.09	58.65	0.01	0.73	0.24
2001	44	12	76.42	247.07	196.12	0.31	0.99	0.79	3.26	173.92	54.21	0.01	0.70	0.22
2002	45	11	84.33	247.38	200.56	0.34	0.99	0.80	2.96	166.00	49.78	0.01	0.67	0.20
2003	46	10	93.07	247.66	204.99	0.37	0.99	0.82	2.68	157.27	45.35	0.01	0.63	0.18
2004	47	9	102.70	247.91	209.42	0.41	0.99	0.84	2.43	147.63	40.91	0.01	0.59	0.16
2005	48	8	113.34	248.14	213.86	0.45	1.00	0.86	2.20	136.99	36.48	0.01	0.55	0.15
2006	49	7	125.08	248.34	218.29	0.50	1.00	0.88	1.99	125.26	32.04	0.01	0.50	0.13
2007	50	6	138.03	248.53	222.73	0.55	1.00	0.89	1.81	112.30	27.61	0.01	0.45	0.11
2008	51	5	152.33	248.70	227.16	0.61	1.00	0.91	1.64	98.01	23.17	0.01	0.39	0.09
2009	52	4	168.11	248.85	231.60	0.67	1.00	0.93	1.48	82.23	18.74	0.01	0.33	0.08
2010	53	3	185.52	248.99	236.03	0.74	1.00	0.95	1.34	64.82	14.30	0.01	0.26	0.06
2011	54	2	204.73	249.12	240.47	0.82	1.00	0.96	1.22	45.60	9.87	0.00	0.18	0.04
2012	55	1	225.94	249.23	244.90	0.91	1.00	0.98	1.10	24.40	5.43	0.00	0.10	0.02
2013	56	0	249.34	249.34	249.34	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
	max		249.34	249.34	249.34	1.00	1.00	1.00	249.34	249.34	249.34	1.00	1.00	1.00
	min		1.00	1.00	1.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00

Selection of growth parameter k for Hamburg: 0.03015 for 1980=70%

Table A33: Annual and cumulated learning Hamburg.

year	delta/year (CHANGE PER YEAR) convex (learn late)	**concave (learn early)**	linear (learn steady)	cumulated learning success convex (learn late)	**concave (learn early)**	linear (learn steady)
1950	0.00%	**0.00%**	0.00%	0.00%	**0.00%**	0.00%
1960	0.60%	**2.26%**	1.35%	6.19%	**30.61%**	15.87%
1970	0.81%	**1.67%**	1.35%	14.56%	**53.25%**	31.75%
1980	1.10%	**1.24%**	1.35%	25.88%	**70.00%**	47.62%
1990	1.48%	**0.92%**	1.35%	41.18%	**82.39%**	63.49%
2000	2.01%	**0.68%**	1.35%	61.87%	**91.55%**	79.37%
2010	2.71%	**0.50%**	1.35%	89.83%	**98.33%**	95.24%
2013	2.97%	**0.46%**	1.35%	100.00%	**100.00%**	100.00%

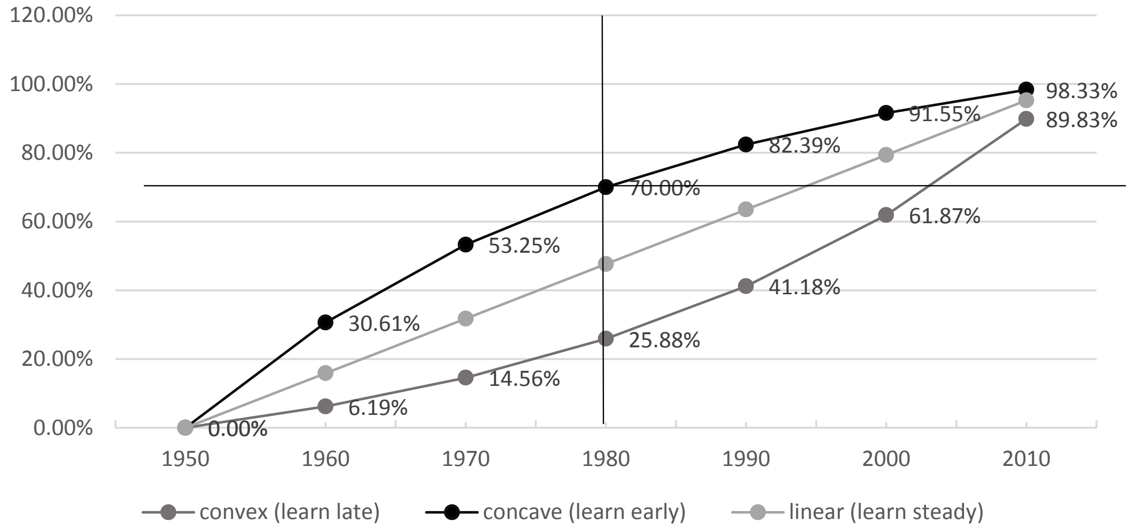


Figure A2: Annual and cumulated learning Hamburg.

Selection of growth parameter k for Porto: 0.02765 for 1974=20%

Table A34: Annual and cumulated learning Porto.

year	delta/year (CHANGE PER YEAR) convex (learn late)	concave (learn early)	linear (learn steady)	cumulated learning success convex (learn late)	concave (learn early)	linear (learn steady)
1950	**0.00%**	0.00%	0.00%	**0.00%**	0.00%	0.00%
1960	**0.63%**	2.13%	1.31%	**6.76%**	29.29%	15.87%
1970	**0.83%**	1.61%	1.31%	**15.68%**	51.50%	31.75%
1980	**1.10%**	1.22%	1.31%	**27.44%**	68.35%	47.62%
1990	**1.44%**	0.93%	1.31%	**42.95%**	81.12%	63.49%
2000	**1.90%**	0.70%	1.31%	**63.39%**	90.81%	79.37%
2010	**2.51%**	0.53%	1.31%	**90.35%**	98.16%	95.24%
2013	**2.73%**	0.49%	1.31%	**100.00%**	100.00%	100.00%

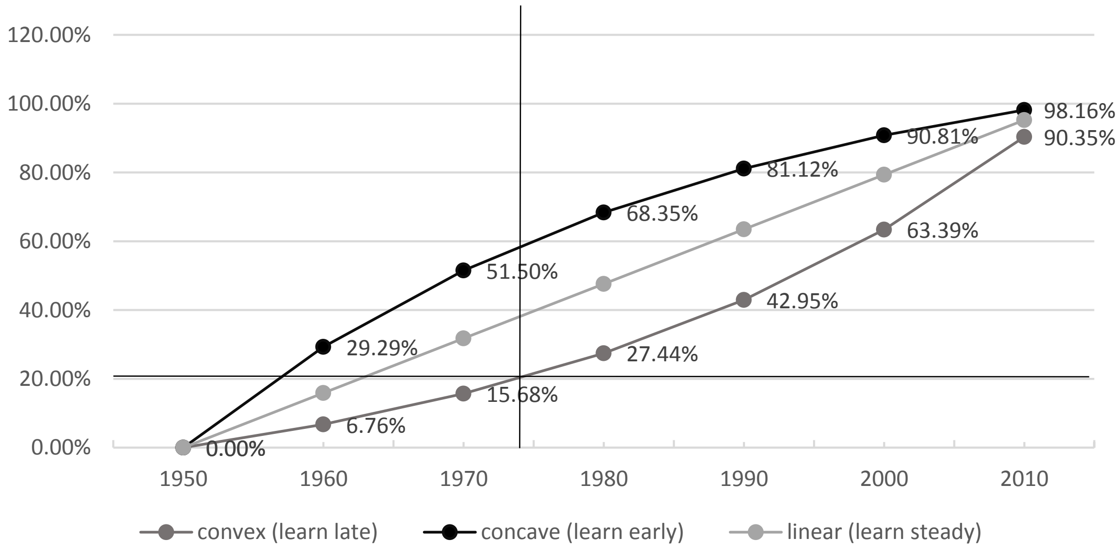


Figure A3: Annual and cumulated learning Porto.

Selection of growth parameter k for Dresden: 0.09855 for 1990=10%

Table A35: Annual and cumulated learning Dresden.

	delta/year (CHANGE PER YEAR)			cumulated learning success		
year	**convex (learn late)**	concave (learn early)	linear (learn steady)	**convex (learn late)**	concave (learn early)	linear (learn steady)
1950						
1960	**0.05%**	7.71%	1.78%	**0.14%**	25.70%	5.36%
1970	**0.14%**	2.88%	1.78%	**1.05%**	72.52%	23.21%
1980	**0.36%**	1.07%	1.78%	**3.48%**	90.00%	41.07%
1990	**0.97%**	0.40%	1.78%	**10.00%**	96.52%	58.93%
2000	**2.61%**	0.15%	1.78%	**27.48%**	98.95%	76.79%
2010	**6.98%**	0.06%	1.78%	**74.30%**	99.86%	94.64%
2013	**9.38%**	0.04%	1.78%	**100.00%**	100.00%	100.00%

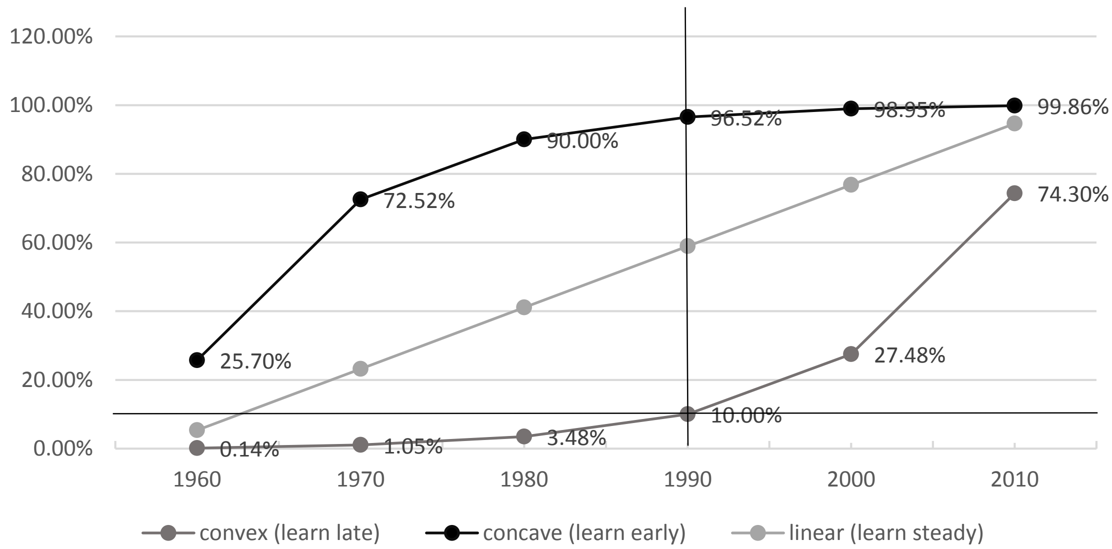


Figure A4: Annual and cumulated learning Dresden.

7 Managerial Style - Coding Rules

measure	management style	coding scheme (0,1,2)			assessment
		0	1	2	
mean	active	low (below average)	average (around average)	high (above average)	empirical
CoV	positioned	high (above average)	average (around average)	low (below average)	empirical
FD	balanced	high (above average)	average (around average)	low (below average)	empirical
overall trend	strategic	no	weak	strong	empirical
recent trend	tactical	no	weak	strong	visual
level-shift	resilient	multiple (>2)	few (up to 2)	no	visual
necklines or plateaus	cautious	no	few short	few long or multiple short (>3)	visual
peaks or head-shoulders	flexible	no	few (up to 4)	multiple (>4)	count
cycles	systematic	no	one short	one or few long or few short	count

average=average per category and operator

	Hamburg									Porto									Dresden								
category/style	strategic	tactical	resilient	cautious	flexible	systematic	active	positioned	balanced	strategic	tactical	resilient	prudent	flexible	systematic	active	steady	balanced	strategic	tactical	resilient	prudent	flexible	systematic	active	steady	balanced
network	2	2	1	2	2	2	0	1	1	1	2	0	2	2	2	1	2	0	1	2	1	2	1	2	0	1	1
fleet	0	0	1	2	2	1	0	1	0	1	2	0	0	2	1	0	0	0	1	2	0	1	2	0	2	2	2
personnel	1	1	1	2	2	2	2	2	1	2	1	2	1	1	0	2	2	2	1	2	1	1	1	2	1	1	2
schedule	2	1	2	1	2	1	0	0	0	1	2	0	0	2	0	0	0	1	1	2	0	0	1	0	0	0	0
fares	1	1	0	1	1	0	1	0	1	2	1	1	1	2	2	2	1	1	1	2	1	1	1	1	0	0	0
service	2	2	1	2	2	1	2	2	2	2	2	0	2	1	1	2	2	2	1	2	1	2	2	1	2	2	2
management	1	1	1	2	1	0	2	2	2	2	1	1	2	1	0	2	2	2	1	0	1	2	1	0	2	2	2
sum	9	8	7	12	12	7	7	8	7	11	11	4	8	11	6	9	9	8	7	12	6	9	9	6	7	8	9

8 Database 2 - Key Data: Performance, Financial and Socio-economic Data

HAMBURG

Table A36: Key data Hamburg 1950-2013. In prices of 2013. Rounded. From

variable	net length	vehicles	staff	energy	vehicle-km	seat-km	pax	pax-km	invest_sum	invest_vehicles	invest_infra	revenue	GDP	population	unemployment	motorization rate
year/unit	#	#	#	EUR	x10^3	x10^6	#	x10^6	EUR	EUR	EUR	EUR	x10^9 EUR	#	#	#
1950	337	1,550	8,999	14,003,773	72,645	3,779	427,361,308	2,501	26,298,822	13,083,051	13,215,771	169,852,537	248	1,620,000	111,600	22
1951	349	1,642	8,746	14,432,472	75,258	3,993	402,538,522	2,505	52,734,835	35,421,989	17,312,846	171,435,319	283	1,658,000	127,000	28
1952	354	1,668	8,666	16,677,136	73,322	4,276	416,466,663	2,509	33,333,055	23,274,137	10,058,918	175,152,745	318	1,687,000	130,000	35
1953	358	1,705	8,353	18,980,394	75,065	4,519	429,893,009	2,514	42,880,557	25,444,982	17,435,576	195,040,166	347	1,723,000	92,000	43
1954	378	1,638	8,380	19,859,218	73,629	4,643	422,522,295	2,509	37,331,294	9,745,637	27,585,657	192,602,152	372	1,752,000	80,000	49
1955	423	1,603	8,473	22,553,625	80,945	6,681	425,319,095	2,520	39,751,197	18,156,978	21,594,219	209,378,650	418	1,782,000	56,000	56
1956	442	1,636	8,400	24,563,063	83,790	6,950	440,570,840	2,514	40,134,190	7,770,390	32,363,800	216,934,751	450	1,800,000	42,000	65
1957	480	1,690	8,785	26,546,057	85,055	7,116	424,447,107	2,508	42,237,155	27,277,804	14,959,351	234,994,380	481	1,787,000	33,000	77
1958	553	1,795	8,653	27,837,177	86,359	7,177	418,776,817	2,502	30,410,752	20,302,778	10,107,974	245,387,074	505	1,808,000	17,000	83
1959	594	1,686	8,148	29,984,412	89,227	7,445	415,817,169	2,477	42,110,126	28,384,475	13,725,651	246,495,881	550	1,826,000	8,700	94
1960	603	1,695	7,470	31,498,103	91,431	7,684	409,067,545	2,444	37,124,237	16,398,547	20,725,689	247,656,020	642	1,836,000	6,100	110
1961	636	1,640	6,974	31,093,868	91,115	7,572	416,877,568	2,494	43,896,155	11,989,717	31,906,438	248,344,921	687	1,848,000	4,200	126
1962	651	1,720	6,899	30,273,049	90,275	7,489	409,880,833	2,455	70,691,660	33,806,465	36,885,195	240,370,697	729	1,849,000	4,623	144
1963	664	1,752	6,814	31,225,428	96,488	8,073	388,516,649	2,247	58,883,041	34,123,606	24,759,434	260,814,730	748	1,855,000	4,638	161
1964	684	1,792	6,361	28,880,246	97,742	8,159	376,359,941	2,136	62,324,257	31,222,725	31,101,533	259,147,080	803	1,858,000	4,645	178
1965	689	1,864	6,182	26,813,396	97,897	8,127	369,652,923	2,070	98,143,271	54,717,869	43,425,401	247,443,854	849	1,854,000	4,635	190
1966	706	1,846	5,639	24,977,169	94,860	7,765	361,216,129	2,036	88,345,521	44,355,011	43,990,510	240,877,669	871	1,847,000	9,235	205
1967	739	1,867	5,392	25,828,735	99,192	8,157	361,796,508	1,908	60,169,845	14,558,680	45,611,165	275,481,860	870	1,835,000	9,175	221
1968	790	1,851	5,266	27,154,021	96,867	7,935	360,720,015	1,902	44,899,684	15,529,097	29,370,587	274,434,231	928	1,822,000	9,110	237
1969	787	1,899	5,197	30,319,139	101,718	8,258	368,994,908	1,950	107,007,357	71,397,059	35,610,298	279,572,245	1,012	1,817,000	13,628	252
1970	821	1,882	5,078	32,225,745	106,451	8,581	382,774,404	2,025	92,080,810	62,582,955	29,497,855	280,739,996	1,165	1,812,000	13,590	267
1971	830	1,888	5,096	32,207,485	108,066	8,815	382,781,978	1,999	43,534,439	6,842,608	36,691,831	290,556,624	1,228	1,782,000	13,365	281
1972	830	1,885	5,096	29,779,156	106,792	8,772	384,043,094	1,995	49,438,539	22,014,681	27,423,857	304,656,542	1,274	1,766,000	17,660	295
1973	843	1,837	5,063	31,656,955	105,800	8,761	389,996,473	1,963	25,093,368	6,080,293	19,013,075	299,186,290	1,328	1,752,000	21,900	308
1974	843	1,864	5,371	32,719,953	107,533	8,946	393,474,958	1,975	62,114,491	36,744,721	25,369,771	244,215,730	1,346	1,734,000	21,675	319
1975	859	1,767	5,326	29,622,826	107,575	9,088	383,894,449	1,926	37,311,994	24,683,842	12,628,151	252,692,754	1,328	1,717,000	25,755	330
1976	859	1,769	5,271	29,893,270	106,313	8,403	378,687,137	1,902	80,169,867	18,666,496	61,503,370	257,831,585	1,403	1,699,000	25,485	340

Appendix

1977	871	1,812	5,373	30,222,827	103,829	8,210	377,578,453	1,888	21,795,475	2,083,474	19,712,001	254,923,464	1,415	1,680,000	25,200	349
1978	863	1,748	5,392	28,920,973	103,555	8,175	385,066,568	1,927	18,049,050	819,333	17,229,717	280,159,068	1,476	1,664,000	29,120	356
1979	839	1,781	5,533	31,703,413	104,215	8,277	391,594,645	1,970	47,110,763	23,325,456	23,785,306	289,574,397	1,539	1,653,000	28,928	362
1980	837	1,776	5,642	31,645,681	105,054	8,374	389,197,387	1,958	51,993,841	22,544,186	29,449,655	292,181,715	1,567	1,600,000	28,000	366
1981	841	1,754	5,777	32,907,071	106,315	8,488	400,155,467	2,017	54,564,186	19,805,781	34,758,405	305,191,237	1,549	1,637,000	33,700	368
1982	843	1,740	5,690	31,908,947	104,351	8,383	398,368,885	2,009	48,120,810	25,284,531	22,836,279	291,173,829	1,528	1,624,000	52,400	368
1983	836	1,732	5,746	30,097,103	103,099	8,326	395,014,429	1,992	38,277,505	6,390,726	31,886,779	290,279,453	1,551	1,610,000	72,500	367
1984	827	1,684	5,837	29,298,731	101,260	8,186	375,612,929	1,901	43,921,493	12,479,532	31,441,962	288,449,640	1,591	1,592,000	71,640	363
1985	838	1,701	5,802	27,525,127	101,209	8,194	367,271,761	1,856	49,394,107	18,681,660	30,712,447	282,731,041	1,626	1,610,000	72,450	376
1986	843	1,656	5,776	25,864,382	101,719	8,233	360,156,678	1,817	81,835,889	31,674,654	50,161,235	273,617,361	1,714	1,593,000	71,685	390
1987	866	1,625	5,810	20,476,478	102,933	8,325	360,632,910	1,821	81,257,168	21,511,055	59,746,113	304,809,500	1,760	1,600,000	72,000	403
1988	832	1,560	5,695	17,829,694	100,902	8,228	352,921,354	1,780	37,737,951	6,103,883	31,634,069	279,968,216	1,828	1,647,000	74,115	408
1989	829	1,550	5,574	18,752,950	97,295	8,034	358,247,961	1,641	112,659,238	32,416,142	80,243,097	271,467,357	1,909	1,610,000	72,450	412
1990	832	1,588	5,391	20,809,657	96,501	7,979	344,158,867	1,625	72,642,770	43,597,274	29,045,495	283,835,971	2,013	1,693,000	76,185	412
1991	840	1,590	5,420	23,366,578	102,043	8,495	357,069,215	1,694	55,437,289	23,388,745	32,048,543	283,263,578	2,288	1,670,000	75,150	411
1992	852	1,653	5,720	23,089,802	106,173	8,840	363,001,764	1,720	118,543,593	68,201,525	50,342,068	286,707,653	2,355	1,712,000	77,040	414
1993	862	1,555	5,743	21,917,170	109,053	9,069	372,017,989	1,763	59,437,501	8,100,777	51,336,724	288,521,589	2,340	1,700,000	76,500	416
1994	861	1,545	5,619	20,873,943	111,726	9,353	376,997,127	1,776	56,018,727	2,998,313	53,020,414	303,297,175	2,391	1,710,000	76,950	419
1995	859	1,538	5,404	20,332,264	110,940	9,363	380,882,729	1,793	64,581,708	19,717,213	44,864,494	301,176,768	2,434	1,710,000	78,112	419
1996	847	1,498	5,111	20,838,932	109,469	9,311	378,607,607	1,784	62,694,166	14,810,570	47,883,596	305,125,879	2,446	1,710,000	83,900	418
1997	865	1,544	4,810	17,421,446	110,703	9,491	377,800,000	1,780	84,199,407	19,652,154	64,547,253	302,069,446	2,447	1,710,000	92,900	417
1998	796	1,494	4,616	15,364,633	104,261	9,084	350,372,000	1,572	77,514,377	17,534,657	59,979,720	274,372,739	2,483	1,700,000	90,480	419
1999	808	1,521	4,420	15,107,849	105,870	9,244	355,346,000	1,588	60,724,746	19,772,972	40,951,774	331,886,750	2,534	1,700,000	88,400	441
2000	808	1,503	4,400	16,436,509	108,010	9,494	359,135,000	1,609	81,508,075	24,845,963	56,662,112	331,750,311	2,543	1,710,000	76,095	462
2001	808	1,515	4,448	17,525,280	112,192	9,851	364,809,000	1,630	105,090,087	17,272,348	87,817,739	328,534,957	2,559	1,720,000	71,380	477
2002	816	1,521	4,402	15,562,477	113,289	9,879	366,979,000	1,640	122,853,814	41,067,752	81,786,062	318,633,553	2,569	1,730,000	77,850	480
2003	817	1,486	4,409	15,998,841	117,508	10,206	369,282,000	1,648	131,369,739	42,929,292	88,440,447	326,559,801	2,561	1,740,000	86,130	483
2004	826	1,516	4,343	17,212,032	116,631	10,404	374,330,000	1,671	86,599,106	47,935,329	38,663,776	321,082,981	2,564	1,740,000	84,390	483
2005	811	1,422	4,340	18,563,984	117,153	10,619	375,034,000	1,652	73,138,435	8,500,547	64,637,888	305,183,255	2,570	1,740,000	98,310	483
2006	829	1,470	4,392	20,275,172	118,264	10,743	375,076,000	1,684	103,751,304	56,277,565	47,473,739	325,166,174	2,616	1,745,000	95,975	481
2007	832	1,468	4,398	20,804,765	117,912	10,634	383,326,000	1,717	71,470,870	30,181,503	41,289,366	331,490,174	2,685	1,761,500	80,148	477
2008	838	1,485	4,416	21,791,596	121,313	10,880	393,154,000	1,764	81,306,291	34,334,277	46,972,014	330,062,053	2,664	1,770,400	71,701	403
2009	847	1,477	4,413	22,175,585	124,514	11,155	401,626,000	1,789	86,091,965	25,001,262	61,090,703	347,662,867	2,548	1,777,400	76,428	400
2010	841	1,466	4,447	23,247,106	131,251	11,781	413,851,000	1,873	64,008,626	19,892,365	44,116,261	348,868,017	2,647	1,780,000	72,980	402
2011	842	1,482	4,455	23,466,008	128,542	11,529	418,698,000	1,872	45,800,586	10,366,465	35,434,122	365,136,596	2,704	1,792,300	69,900	405
2012	848	1,499	4,551	24,766,133	129,581	11,728	432,845,000	1,947	54,787,709	20,233,560	34,554,149	387,876,293	2,709	1,808,500	68,723	408
2013	852	1,560	4,836	24,802,296	133,992	11,877	435,396,000	1,978	108,567,000	26,056,000	82,511,000	387,178,000	2,738	1,817,543	69,823	412
mean	752	1,655	5,816	24,382,958	103,032	8,525	387,094,720	1,979	63,489,154	24,693,210	38,795,945	280,957,271	1,604	1,732,713	55,099	310
SD	155	136	1,363	5,677,449	13,813	1,731	24,260,610	296	26,460,264	15,502,709	19,285,801	46,622,700	816	76,569	34,030	143
Min	337	1,422	4,340	14,003,773	72,645	3,779	344,158,867	1,572	18,049,050	819,333	10,058,918	169,852,537	248	1,592,000	4,200	22
Max	871	1,899	8,999	32,907,071	133,992	11,877	440,570,840	2,520	131,369,739	71,397,059	88,440,447	387,876,293	2,738	1,858,000	130,000	483

PORTO

Table A37: Key data Porto 1950-2013. In prices of 2013. Rounded. From:

variable	net length	vehicles	staff	energy	vehicle-km	seat-km	pax	pax-km	invest_sum	invest_vehicles	invest_infra	revenue	GDP	population	unemployment	motorization rate
year/unit	#	#	#	EUR	x10^3	x10^6	#	x10^6	EUR	EUR	EUR	EUR	x10^9 EUR	#	#	#
1950	120	272	2,716	6,210,253	13,236	662	56,920,270	299	19,246,571	7,313,697	11,932,874	51,541,657	20	631,855	3	11
1951	121	277	2,702	5,851,307	13,537	615	56,010,054	304	6,705,859	2,145,875	4,559,984	51,092,736	22	658,222	3	11
1952	135	275	2,670	5,933,136	14,111	635	57,255,374	310	1,546,632	402,124	1,144,508	50,626,329	21	689,861	3	12
1953	143	268	2,661	6,823,287	14,448	642	57,419,889	309	13,158,400	2,631,680	10,526,720	49,296,840	23	703,061	3	12
1954	160	282	2,673	5,977,197	14,517	648	58,327,930	311	35,066,461	4,909,305	30,157,156	48,484,323	24	716,087	4	12
1955	164	285	2,723	6,056,331	14,907	666	61,251,433	327	3,226,702	978,766	2,247,936	49,414,673	25	734,826	4	13
1956	165	286	2,747	6,242,580	16,194	699	62,239,488	333	2,627,184	1,210,907	1,416,277	48,606,125	26	758,443	3	13
1957	180	289	2,739	7,492,161	16,855	725	64,298,693	346	1,333,707	840,235	493,471	48,617,988	27	775,290	3	13
1958	189	294	2,796	6,534,187	17,036	738	65,488,119	350	2,792,547	1,549,863	1,242,683	47,689,974	28	796,855	3	17
1959	234	304	2,874	6,527,627	18,034	768	65,207,536	309	9,892,634	4,748,464	5,144,170	50,451,902	29	827,010	3	21
1960	208	319	2,915	5,779,469	18,015	766	63,004,269	293	8,899,649	3,604,358	5,295,291	47,590,272	31	835,674	2	25
1961	214	318	2,947	6,043,587	19,123	817	67,162,129	315	5,247,430	0	5,247,430	51,138,554	32	856,012	3	27
1962	214	326	3,011	6,047,403	19,764	961	69,387,161	326	6,802,236	1,700,559	5,101,677	51,959,760	35	874,678	3	30
1963	213	332	3,082	6,123,525	20,354	1,209	73,087,560	367	5,477,701	985,986	4,491,715	54,124,229	36	885,327	3	32
1964	212	355	3,163	6,350,211	21,562	1,299	78,291,141	391	13,463,375	4,173,646	9,289,729	56,860,722	39	886,806	3	35
1965	255	354	3,311	6,566,920	22,345	1,365	83,642,047	406	960,586	422,658	537,928	58,504,966	42	875,940	3	37
1966	256	419	3,528	7,174,816	23,145	1,515	88,212,744	428	14,141,499	8,060,654	6,080,845	58,444,691	44	856,127	2	39
1967	283	462	3,835	8,014,469	24,312	1,621	87,133,750	420	21,089,191	14,762,434	6,326,757	66,079,433	46	839,828	3	42
1968	289	474	3,958	8,752,700	25,704	1,746	91,819,504	440	2,875,255	1,610,143	1,265,112	66,626,670	48	829,038	3	44
1969	293	474	3,773	8,029,090	25,641	1,774	92,560,000	441	1,251,787	0	1,251,787	62,179,589	50	806,739	3	47
1970	305	473	3,656	7,248,416	25,550	1,799	88,996,250	421	1,282,768	0	1,282,768	65,366,873	54	785,307	3	49
1971	307	471	3,697	6,223,287	25,765	1,846	83,783,750	394	1,230,871	0	1,230,871	65,620,452	59	775,318	2	57
1972	306	460	3,715	5,779,678	25,165	1,834	85,541,250	399	1,175,036	0	1,175,036	60,393,484	66	771,719	2	65
1973	308	461	3,606	5,104,700	24,371	1,807	88,425,000	410	3,925,811	67,964	3,857,846	55,461,941	69	772,438	1	73
1974	317	479	3,587	5,713,393	24,539	1,849	94,578,750	443	8,363,577	1,346,492	7,017,085	47,849,498	71	805,105	2	81
1975	321	495	3,762	5,601,868	24,649	1,888	94,502,500	496	4,761,339	2,253,572	2,507,767	51,084,059	67	899,000	4	89
1976	309	493	4,034	5,822,290	23,663	1,842	103,150,000	516	3,990,611	1,402,986	2,587,625	55,017,131	69	977,087	6	97
1977	312	612	4,217	8,395,793	24,088	1,905	112,555,000	559	34,546,176	26,662,608	7,883,568	54,516,230	73	1,008,488	7	105
1978	326	652	4,133	8,227,401	26,432	2,123	134,920,000	706	17,821,618	9,571,425	8,250,193	61,639,977	77	1,041,426	7	113

1979	330	633	3,991	8,973,763	27,272	2,217	163,702,500	856	8,430,289	3,506,803	4,923,486	63,964,124	83	1,075,219	7	121
1980	329	630	3,934	9,643,461	28,372	2,308	187,901,250	971	12,434,760	4,542,673	7,892,087	68,464,619	87	1,110,418	7	129
1981	332	619	3,876	9,874,892	27,746	2,264	185,625,000	856	16,445,562	3,610,980	12,834,582	70,480,980	89	1,117,920	7	133
1982	343	630	3,834	10,697,036	28,016	2,317	189,578,750	862	9,630,080	5,358,200	4,271,880	75,345,100	91	1,145,707	7	138
1983	343	623	3,859	10,565,066	29,561	2,478	194,290,000	870	10,356,500	6,184,310	4,172,190	85,189,610	92	1,167,304	8	142
1984	357	657	3,874	11,926,381	30,013	2,549	183,801,250	811	16,742,810	10,107,867	6,634,943	85,604,813	91	1,185,535	9	146
1985	389	670	3,836	19,009,712	30,958	2,664	188,998,125	821	19,155,459	12,121,697	7,033,762	90,688,474	92	1,198,697	10	151
1986	389	695	3,826	16,240,021	31,354	2,733	185,263,125	792	23,839,600	15,882,224	7,957,376	89,992,992	95	1,203,118	10	155
1987	391	707	3,866	16,668,912	33,138	2,926	198,935,000	837	16,901,820	14,127,360	2,774,460	93,620,280	102	1,201,805	9	159
1988	403	706	3,853	16,836,435	32,593	2,914	183,727,500	761	10,063,548	7,892,478	2,171,070	86,134,696	108	1,196,744	8	163
1989	410	677	3,774	15,976,870	30,979	2,804	186,012,500	757	6,410,924	3,291,210	3,119,714	82,371,472	115	1,189,671	7	168
1990	410	661	3,701	15,917,400	30,887	2,809	182,856,250	728	5,250,300	1,365,300	3,885,000	77,711,100	124	1,179,172	7	172
1991	435	671	3,642	15,282,270	31,912	2,911	177,016,875	689	15,361,710	9,016,440	6,345,270	75,279,330	128	1,168,000	6	189
1992	450	674	3,580	14,629,910	32,988	3,006	175,216,875	666	13,178,710	8,480,450	4,698,260	75,770,780	132	1,166,217	5	207
1993	456	666	3,386	13,940,580	33,000	3,050	165,691,875	630	9,627,660	6,257,979	3,369,681	73,081,920	131	1,169,020	7	224
1994	453	654	3,130	13,057,100	33,700	3,160	156,250,000	597	10,609,900	8,058,050	2,551,850	72,454,025	133	1,175,206	8	242
1995	454	620	2,986	12,043,340	34,700	3,223	155,994,765	599	16,209,810	10,767,890	5,441,920	69,971,960	137	1,183,210	8	258
1996	445	603	2,944	11,782,500	35,097	3,257	154,456,875	596	6,585,000	2,505,000	4,080,000	68,670,000	141	1,191,960	8	277
1997	451	603	2,930	10,918,563	35,784	3,314	153,840,625	597	10,987,670	7,865,090	3,122,580	67,604,590	148	1,202,435	7	297
1998	448	592	2,860	10,091,608	36,223	3,356	153,825,625	600	24,176,040	8,439,480	15,736,560	67,922,820	155	1,214,399	5	316
1999	466	623	2,709	9,498,559	34,765	3,219	152,750,000	599	18,266,660	8,027,000	10,239,660	67,056,860	161	1,227,925	4	335
2000	469	627	2,546	10,407,809	34,021	3,129	150,221,000	592	20,326,829	9,743,113	10,583,716	65,473,227	167	1,244,932	4	337
2001	483	627	2,455	11,317,058	35,310	3,028	146,482,000	581	20,763,220	164,208	20,599,011	63,785,779	170	1,260,680	4	347
2002	496	599	2,332	10,476,839	33,876	2,930	143,464,000	571	6,426,867	0	6,426,867	62,476,087	171	1,267,619	5	374
2003	493	599	2,219	10,091,275	34,322	3,185	138,339,000	551	3,384,385	290,055	3,094,330	62,007,255	170	1,272,398	6	380
2004	492	559	2,021	10,667,456	33,827	3,140	135,773,000	544	5,107,502	1,513,202	3,594,301	63,234,213	173	1,275,451	7	389
2005	496	554	1,798	11,662,726	32,748	3,040	128,963,000	519	4,674,825	144,342	4,530,483	61,034,634	174	1,277,825	8	398
2006	496	516	1,712	12,056,271	32,040	2,955	117,701,000	471	1,294,929	415,461	879,468	57,449,896	177	1,280,137	8	405
2007	540	501	1,648	10,512,508	29,715	2,601	109,102,000	433	27,204,695	25,523,134	1,681,560	51,478,229	181	1,282,657	8	415
2008	544	481	1,572	11,429,817	29,535	2,570	111,254,000	441	6,015,128	5,235,310	779,818	52,253,202	182	1,284,513	8	424
2009	548	480	1,506	9,577,478	28,877	2,517	108,243,000	410	1,631,269	176,558	1,454,711	51,496,544	176	1,285,741	9	434
2010	552	494	1,493	10,902,049	29,848	2,607	109,220,000	389	13,090,791	12,567,373	523,418	52,519,121	179	1,286,332	11	444
2011	528	473	1,407	10,711,433	28,663	2,539	108,389,000	383	977,982	119,543	858,440	52,162,843	176	1,287,282	13	446
2012	491	481	1,290	10,650,102	25,731	2,306	93,761,000	348	2,347,414	18,049	2,329,365	50,028,704	169	1,282,073	16	405
2013	487	480	1,247	9,837,000	23,457	2,119	80,421,000	294	67,000	0	67,000	46,202,000	166	1,307,446	17	414
mean	351	505	3,045	9,601,895	26,533	2,108	119,409,990	522	10,107,513	4,948,050	5,159,463	62,269,740	96	1,034,974	6	171
SD	123	139	811	3,399,520	6,557	882	45,670,359	183	8,193,949	5,703,620	4,999,816	12,246,011	55	213,328	3	146
Min	120	268	1,247	5,104,700	13,236	615	56,010,054	293	67,000	0	67,000	46,202,000	20	631,855	1	11
Max	552	707	4,217	19,009,712	36,223	3,356	198,935,000	971	35,066,461	26,662,608	30,157,156	93,620,280	182	1,307,446	17	446

DRESDEN

Table A38: Key data Dresden 1957-2013. In prices of 2013. Rounded. From:

variable	net length	vehicles	staff	vehicle-km	seat-km	pax	pax-km	invest_sum	invest_vehicles	invest_infra	revenue	GDP	population	unemployment	motorization rate
year/unit	km	#	#	x10^3	x10^6	#	x10^6	EUR	EUR	EUR	EUR	x10^9 EUR	#	#	#
1957	308	490	5,640	33,860	3,633	395,354,206	2,172	1,467,185	352,124	1,115,061	15,754,718	86	491,714	0	11
1958	315	498	5,450	35,148	3,670	397,460,463	2,194	1,030,624	292,488	738,136	17,052,492	88	491,646	0	13
1959	323	508	5,879	36,075	3,702	399,577,941	2,213	982,942	322,006	660,936	18,998,793	90	493,515	0	15
1960	330	507	5,671	37,287	3,738	401,706,700	2,234	1,104,118	410,060	694,059	21,225,180	92	493,603	0	17
1961	356	512	4,911	36,769	3,749	403,846,800	2,241	1,472,404	611,324	861,079	23,684,046	92	491,699	0	21
1962	310	518	5,302	36,702	3,691	397,295,100	2,206	3,490,869	1,602,257	1,888,612	27,996,583	93	494,588	0	25
1963	323	534	4,689	36,148	3,559	383,225,600	2,128	5,050,835	2,539,469	2,511,366	31,023,655	95	499,014	0	29
1964	316	546	4,753	35,876	3,560	383,717,100	2,128	6,038,379	3,300,452	2,737,928	30,880,459	96	503,810	0	33
1965	336	523	4,615	35,007	3,511	379,561,200	2,099	8,717,417	5,146,554	3,570,863	31,107,471	99	508,119	0	39
1966	339	503	4,326	34,286	3,911	367,213,600	2,028	11,984,244	7,600,085	4,384,160	30,504,597	103	505,188	0	45
1967	347	496	4,202	33,888	4,288	358,460,000	1,978	15,703,391	10,646,429	5,056,962	30,780,788	106	500,158	0	51
1968	350	484	4,065	32,233	4,554	347,525,283	1,907	16,232,802	11,716,302	4,516,500	30,991,659	110	500,242	0	57
1969	304	530	3,911	30,497	4,546	340,451,100	1,855	20,811,677	15,932,672	4,879,005	31,112,106	114	501,184	0	63
1970	316	574	3,807	30,694	4,627	329,479,100	1,799	27,012,499	21,862,865	5,149,634	31,191,677	118	502,432	0	68
1971	313	571	3,750	29,423	5,145	322,861,900	1,753	23,260,425	19,844,819	3,415,606	27,988,798	121	504,209	0	89
1972	290	571	3,687	27,821	5,710	319,030,400	1,719	27,379,149	24,557,867	2,821,282	24,260,395	126	505,385	0	110
1973	294	585	3,679	33,042	6,438	346,385,600	1,908	18,475,508	17,380,873	1,094,635	22,938,437	132	506,067	0	121
1974	297	616	3,668	32,466	6,584	307,390,700	1,698	19,119,229	17,708,441	1,410,788	20,753,802	135	507,692	0	132
1975	323	677	3,726	31,719	6,707	309,617,200	1,703	16,344,890	14,251,917	2,092,973	18,879,992	139	509,331	0	143
1976	323	694	4,014	32,906	7,120	318,400,000	1,668	11,273,685	9,700,545	1,573,140	18,397,513	145	510,408	0	154
1977	346	719	3,924	31,652	6,887	327,600,000	1,710	7,823,900	5,908,109	1,915,791	17,305,533	148	512,490	0	163
1978	355	767	3,925	31,106	6,827	327,100,000	1,706	9,928,300	8,040,378	1,887,922	16,541,843	150	514,508	0	174
1979	356	775	3,937	30,018	6,556	323,700,000	1,686	4,825,225	2,584,170	2,241,055	15,187,708	153	515,881	0	185
1980	374	774	3,858	28,712	6,335	319,100,000	1,647	3,365,802	1,623,899	1,741,903	14,013,356	152	516,225	0	196
1981	383	788	3,950	28,786	6,464	314,200,000	1,624	5,147,480	4,415,706	731,773	11,951,911	153	521,060	0	207
1982	394	786	3,840	28,482	6,237	312,000,000	1,608	996,128	21,772	974,357	10,401,987	152	521,786	0	220
1983	400	786	3,936	29,070	6,400	307,700,000	1,588	1,614,094	504,510	1,109,584	8,330,028	153	522,532	0	226
1984	409	820	4,068	30,204	6,660	313,400,000	1,741	3,586,267	2,580,990	1,005,276	7,290,274	156	520,061	0	232
1985	415	828	4,098	29,899	6,648	319,900,000	1,848	1,786,733	711,003	1,075,730	7,973,555	160	519,769	0	238
1986	421	839	4,062	29,817	8,373	315,200,000	1,847	2,734,354	1,164,789	1,569,565	7,501,722	159	519,810	0	244
1987	424	844	4,135	27,561	8,418	310,500,000	1,831	1,532,364	361,972	1,170,392	6,960,238	158	521,205	0	250

1988	427	852	4,124	29,573	8,499	308,900,000	1,825	1,736,506	874,210	862,296	6,305,201	159	518,057	0	276
1989	436	865	3,980	30,340	8,371	301,500,000	1,776	1,582,920	709,515	873,405	6,320,729	158	501,407	0	302
1990	411	848	3,728	29,458	7,169	260,025,000	1,528	1,686,800	759,060	927,740	32,899,162	138	490,571	7	328
1991	386	831	3,476	28,575	5,968	218,550,000	1,280	3,264,773	652,955	2,611,819	37,602,790	145	485,132	8	355
1992	361	814	3,224	27,692	4,766	177,075,000	1,033	9,386,223	1,877,245	7,508,979	41,560,694	154	481,676	11	383
1993	336	795	2,970	26,810	3,564	135,600,000	785	67,963,076	20,727,328	47,235,748	45,447,628	167	479,273	12	410
1994	335	745	2,605	25,580	3,947	137,600,000	796	98,366,206	38,362,821	60,003,386	43,808,975	181	474,443	12	440
1995	327	705	2,354	24,527	4,022	139,400,000	804	99,372,276	47,698,693	51,673,584	50,950,307	187	469,110	11	445
1996	325	693	2,276	25,171	3,391	139,000,000	672	107,638,056	61,621,787	46,016,269	56,939,598	190	461,303	13	435
1997	325	647	2,263	24,000	3,422	139,000,000	673	107,288,726	69,541,412	37,747,314	63,588,196	191	459,222	14	430
1998	336	598	2,223	24,000	3,289	133,000,000	642	67,764,911	31,849,508	35,915,403	61,675,139	192	452,827	14	447
1999	355	564	2,124	25,200	3,359	135,500,000	651	68,931,038	19,990,001	48,941,037	62,517,341	195	476,668	14	450
2000	364	497	1,936	26,000	3,418	136,900,000	658	66,499,702	6,605,510	59,894,192	65,801,042	198	477,807	14	449
2001	370	496	1,925	26,700	3,462	137,900,000	662	117,478,261	51,495,652	65,982,609	66,713,043	197	478,631	14	448
2002	379	474	1,847	26,500	3,471	137,400,000	660	67,237,267	14,821,118	52,416,149	69,888,199	197	480,228	15	449
2003	377	469	1,795	26,400	3,491	138,100,000	662	97,073,292	36,887,851	60,185,441	71,910,559	196	483,632	15	450
2004	379	459	1,741	26,400	3,633	138,200,000	663	102,057,143	54,648,447	47,408,696	72,631,056	199	487,421	14	449
2005	379	440	1,713	26,300	3,695	138,500,000	664	94,039,752	24,491,925	69,547,826	78,054,149	200	495,181	15	450
2006	382	445	1,691	26,200	3,744	140,000,000	672	68,730,435	26,117,565	42,612,870	78,532,435	208	504,795	15	449
2007	378	381	1,681	26,400	3,844	142,000,000	681	72,968,944	23,807,039	49,161,905	80,119,901	214	507,513	13	448
2008	382	371	1,673	26,800	3,908	144,500,000	692	71,514,037	46,527,205	24,986,832	82,944,436	217	516,256	11	448
2009	400	405	1,689	26,900	3,931	145,700,000	698	39,604,472	12,718,509	26,885,963	84,491,687	206	523,058	12	447
2010	401	383	1,703	27,100	4,048	148,300,000	710	34,902,609	14,693,043	20,209,565	91,543,496	214	512,354	11	451
2011	401	344	1,731	27,300	4,091	151,700,000	726	38,850,932	7,252,174	31,598,758	94,627,401	221	517,765	10	425
2012	401	342	1,755	27,000	4,052	150,800,000	722	21,237,516	914,534	20,322,981	95,751,727	223	525,105	10	424
2013	402	356	1,753	27,200	4,027	152,800,000	733	32,500,000	0	32,500,000	99,335,000	223	530,754	9	418
mean	359	605	3,394	29,672	4,927	261,875,614	1,413	32,280,154	14,549,859	17,730,295	39,841,074	155	500,272	5	254
SD	38	158	1,218	3,616	1,580	100,102,606	587	36,111,849	17,271,899	22,136,053	27,627,955	41	17,948	6	167
Min	290	342	1,673	24,000	3,289	133,000,000	642	982,942	0	660,936	6,305,201	86	452,827	0	11
Max	436	865	5,879	37,287	8,499	403,846,800	2,241	117,478,261	69,541,412	69,547,826	99,335,000	223	530,754	15	451

9 Database 3 - Complementary Data

HAMBURG, PORTO, DRESDEN

Table A39: Complementary data all operators 1950-2013, 1957-2013. In prices of 2013.

city	Hamburg	Hamburg	Hamburg	Hamburg	Porto	Porto	Porto	Porto	Porto	Porto	Porto	Porto	Dresden	Dresden	Dresden
variable	stops	seats	system speed	occupancy	share of	average fleet	training & education	change of	annual result	subsidies	system speed	occupancy	occupancy	cost per vkm	costs
year/unit	#	#	km/h	#	#	years	people trained	%	EUR	EUR	km/h	#	EUR	#	EUR
1950	546	91,289	22	0.66	0.3		69	3	1,500,014	-	12.39	0.45			
1951	563	95,281	21	0.63	0.27		55	-3.13	1,109,364	-	12.47	0.49			
1952	580	99,273	22	0.59	0.27		100	6.45	1,263,503	-	12.56	0.49			
1953	594	103,265	23	0.56	0.26		86	-1.52	734,361	-	12.64	0.48			
1954	610	107,257	23	0.54	0.26		31	1.54	747,243	-	12.72	0.48			
1955	677	111,249	23	0.38	0.25		-	1.52	880,889	-	12.81	0.49			
1956	701	113,937	23	0.36	0.25		-	1.49	135,137	-	12.89	0.48			
1957	735	116,625	23	0.35	0.25		-	-7.35	- 382,226	-	12.97	0.48	0.6	0.25	14,745,898
1958	808	119,313	23	0.35	0.22		73	11.11	- 1,812,242	-	13.06	0.47	0.6	0.3	17,726,522
1959	931	122,001	23	0.33	0.23		86	28.57	- 1,312,636	-	13.14	0.4	0.6	0.35	21,687,667
1960	929	124,689	23	0.32	0.23		70	4.44	706,124	-	13.22	0.38	0.6	0.42	26,794,658
1961	988	129,407	23	0.33	0.21		159	2.13	772,589	-	13.3	0.39	0.6	0.39	24,265,641
1962	1,022	134,125	24	0.33	0.21		199	2.08	192,576	-	13.39	0.34	0.6	0.44	27,781,054
1963	1,054	138,844	23	0.28	0.2		233	6.12	23,676	-	13.47	0.3	0.6	0.56	34,308,485
1964	1,087	143,562	24	0.26	0.19		247	28.1	221,672	-	13.55	0.3	0.6	0.61	37,592,221
1965	1,124	148,281	24	0.25	0.19		350	41.3	233,935	-	13.64	0.3	0.6	0.67	39,887,922
1966	1,155	148,081	24	0.26	0.18		590	5.4	- 1,389,991	-	13.72	0.28	0.52	0.68	40,023,288
1967	1,218	147,882	25	0.23	0.17		501	16.3	- 1,088,631	-	13.8	0.26	0.46	1.01	58,666,789
1968	1,251	147,683	25	0.24	0.16		487	4.7	- 1,343,554	-	13.62	0.25	0.42	1.05	57,957,404
1969	1,286	147,483	26	0.24	0.17	14	472	16.3	- 5,798,938	-	13.82	0.25	0.41	1.18	61,226,825
1970	1,306	147,284	26	0.24	0.15		457	1.8	- 2,951,998	-	14.01	0.23	0.39	1.28	67,027,825
1971	1,466	147,512	26	0.23	0.16		442	19.8	- 3,553,904	-	14.21	0.21	0.34	1.07	53,828,264
1972	1,471	147,741	26	0.23	0.2		427	12.1	- 13,121,127	2,305,800	14.4	0.22	0.3	1.01	48,136,456
1973	1,332	147,969	26	0.22	0.19		412	14.4	- 9,835,555	3,059,550	14.6	0.23	0.3	0.92	51,809,347
1974	1,325	150,050	27	0.22	0.33	16	397	50.8	- 21,266,395	3,232,800	14.79	0.24	0.26	0.89	49,519,316
1975	1,341	146,994	27	0.21	0.47		382	52.1	- 28,899,535	11,096,925	14.43	0.26	0.25	0.97	52,403,136
1976	1,342	144,530	27	0.23	0.57		398	-0.62	- 31,715,069	9,370,870	14.77	0.28	0.23	0.97	54,492,900

Appendix

1977	1,363	146,287	26	0.23	0.64		413	23.08	-	6,494,694	29,937,509	14.25	0.29	0.25	0.96	52,068,740
1978	1,348	142,224	26	0.24	0.64	13	321	12.3	-	6,252,492	26,274,500	14.41	0.33	0.25	0.94	50,130,793
1979	1,355	143,074	27	0.24	0.61	13	229	11.8	-	209,808	28,220,192	14.73	0.39	0.26	0.92	47,430,585
1980	1,344	145,037	26	0.23	0.6	14	151	25	-	1,318,982	24,322,178	15.02	0.42	0.26	0.95	46,555,966
1981	1,356	144,126	26	0.24	0.67	14	143	21	-	2,364,584	23,007,738	14.9	0.38	0.25	0.86	42,397,828
1982	1,362	144,226	26	0.24	0.71		377	23.8	-	4,708,156	24,779,840	15.02	0.37	0.26	0.79	38,328,792
1983	1,350	142,488	26	0.24	0.65		489	25.29	-	1,164,684	15,306,907	15.15	0.35	0.25	0.74	36,618,976
1984	1,349	141,113	26	0.23	0.74		558	21.56	-	6,204,073	9,212,000	15.27	0.32	0.26	0.67	34,584,528
1985	1,365	141,656	26	0.23	0.75		501	21.9	-	259,262	19,919,399	15.4	0.31	0.28	0.61	30,988,135
1986	1,380	140,181	26	0.22	0.75		761	18.8	-	2,212,419	16,688,576	15.52	0.29	0.22	0.79	40,236,507
1987	1,388	140,329	27	0.22	0.76		713	20.5	-	9,395,294	16,224,000	15.65	0.29	0.22	0.78	36,590,963
1988	1,385	137,873	26	0.22	0.65	15	590	10.09	-	9,218,752	18,139,077	15.77	0.26	0.21	0.69	34,869,670
1989	1,396	137,978	26	0.2	0.66	15	618	12.83	-	5,603,118	20,932,600	15.56	0.27	0.21	0.67	34,670,584
1990	1,399	143,020	26	0.2	0.66	15	303	20.44	-	17,525,619	15,540,000	15.6	0.26	0.21	3.94	60,432,960
1991	1,391	142,643	26	0.2	0.66	15	172	15.89	-	19,650,507	19,363,500	15.6	0.24	0.21	4.57	86,195,335
1992	1,539	146,020	26	0.19	0.66	15	517	12.5	-	23,915,885	19,954,000	15.5	0.22	0.22	5.11	111,957,710
1993	1,503	148,703	26	0.19	0.66	15	861	11.92	-	28,805,959	19,503,992	15.6	0.21	0.22	5.14	137,720,086
1994	1,505	150,986	27	0.19	0.69	15	1,206	6.94	-	20,940,352	19,320,000	16	0.19	0.2	4.38	112,043,413
1995	1,508	150,185	27	0.19	0.69	13	761	4.06	-	18,289,860	19,525,980	16.2	0.19	0.2	4.62	113,222,905
1996	1,509	150,020	27	0.19	0.69	14	679	6.1	-	23,987,918	14,077,500	16.1	0.18	0.2	4.64	116,679,504
1997	1,499	150,036	27	0.19	0.7		364	7.5	-	38,841,413	10,687,140	15.8	0.18	0.2	5.25	125,917,220
1998	1,289	147,216	28	0.17	0.7	14	224	8	-	32,433,529	8,403,780	15.6	0.18	0.2	4.89	117,253,116
1999	1,314	147,598	28	0.17	0.71	14	376	6	-	40,474,584	7,580,280	15.69	0.19	0.19	4.38	110,259,861
2000	1,373	150,023	28	0.17	0.72	14	824	2.86	-	36,005,854	7,392,687	15.08	0.19	0.19	4.22	109,668,404
2001	1,345	146,203	28	0.17	0.72	10	514	1.37	-	35,381,663	9,946,328	14.87	0.19	0.19	4.03	107,601,683
2002	1,356	145,340	28	0.17	0.73	8	305	7.6	-	43,849,621	8,488,647	14.87	0.19	0.19	4.17	110,407,897
2003	1,354	147,251	28	0.16	0.72	9	811	4	-	54,331,756	14,365,053	14.58	0.17	0.19	4.13	109,120,727
2004	1,343	146,481	28	0.16	0.74	9	785	14.4	-	12,234,195	25,672,045	14.87	0.17	0.18	4.11	108,404,561
2005	1,384	146,464	28	0.16	0.76	10	1,254	-0.14	-	19,959,965	16,907,826	14.87	0.17	0.18	4.29	112,795,013
2006	1,384	151,599	28	0.16	0.76	10	1,644	0.7	-	28,902,220	17,567,902	15.48	0.16	0.18	4.09	107,284,747
2007	1,388	150,764	28	0.16	0.79	8	563	-0.02	-	29,400,146	18,921,412	15.97	0.17	0.18	4.09	107,978,303
2008	1,392	160,213	28	0.16	0.79	9	894	7.64	-	30,278,651	20,728,561	16.17	0.17	0.18	4.17	111,634,503
2009	1,414	159,188	28	0.16	0.81	10	773	7.22	-	21,122,010	21,811,996	16.17	0.16	0.18	4.19	112,655,583
2010	1,404	157,884	28	0.16	0.8	10	783	-2.19	-	40,246,571	22,373,449	16.07	0.15	0.18	4.34	117,665,162
2011	1,401	150,459	28	0.16	0.81	10	526	4.81	-	56,210,804	20,644,808	15.87	0.15	0.18	4.44	121,161,845
2012	1,405	152,066	28	0.17	0.8	11	464	-12.47	-	73,640,223	11,486,387	15.77	0.15	0.18	4.55	122,758,624
2013	1,408	159,420	28	0.17	0.79	12	402	4.78	-	15,224,000	13,284,000	15.77	0.14	0.18	4.65	126,541,401
check sum	78,990	8,967,985	1649	16	33	381	28,592	707	-	933,010,342	685,577,733	935	18	17	132	4,042,714,250
MW	1,234	140,125	26	0	1	12	447	11	-	14,578,287	10,712,152	15	0	0	2	70,924,811
SD	273	15,535	2	0	0	3	319	12		17,003,729	9,527,170	1	0	0	2	37,101,902
Min	546	91,289	21	0	0	8	-	-12	-	73,640,223	-	12	0	0	0	14,745,898
Max	1,539	160,213	28	1	1	16	1,644	52		1,500,014	29,937,509	16	0	1	5	137,720,086

10 Plots Socio-Economic Data

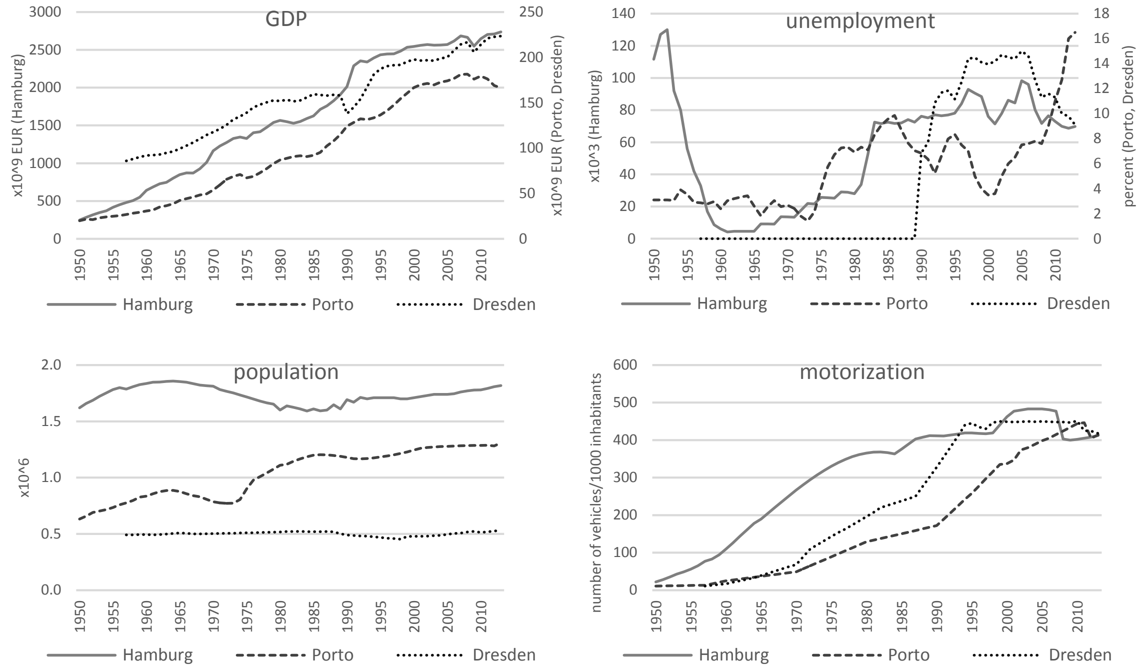


Figure A5: Socio Economic Data

11 Plots Auxiliary Data Hamburg and Dresden

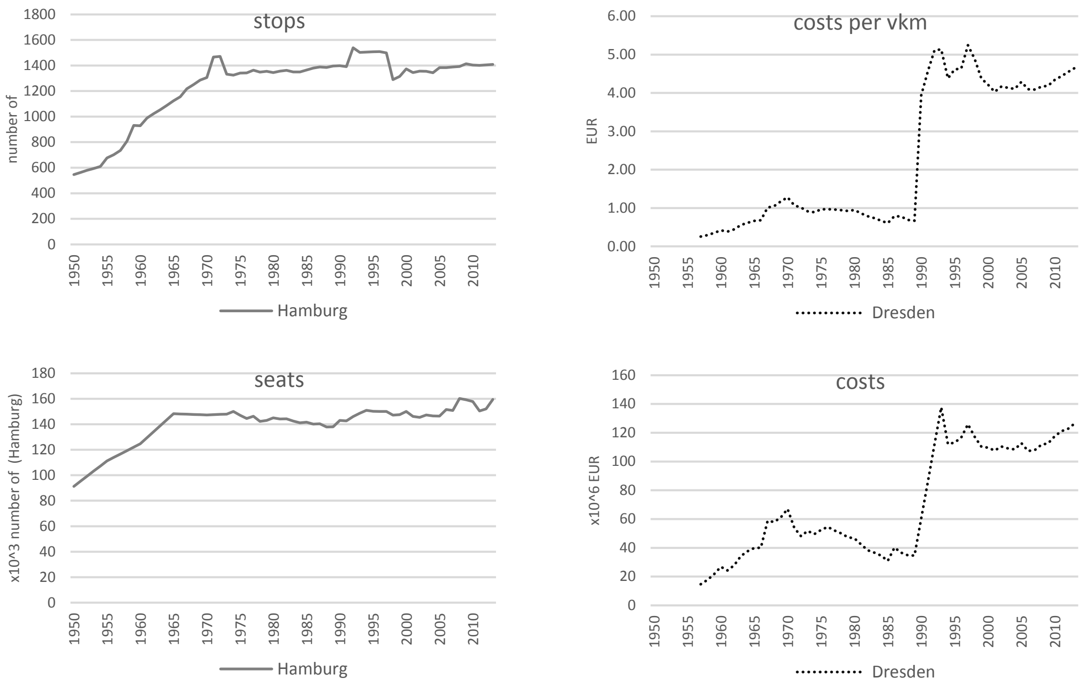
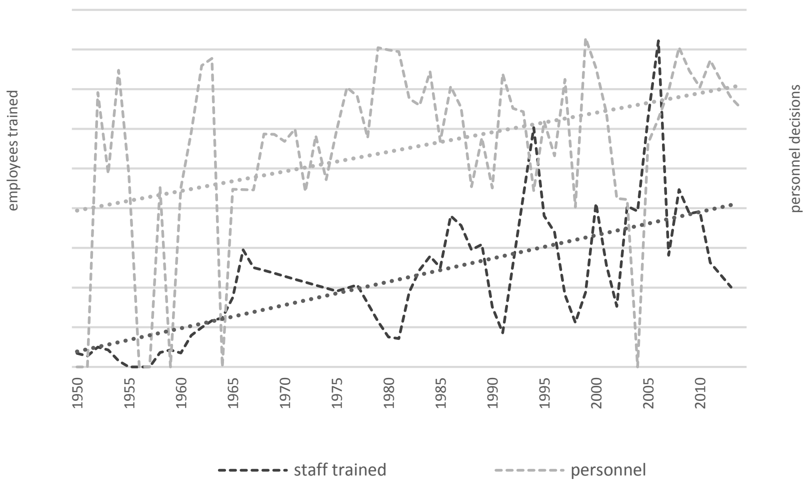


Figure A6: Auxiliary Data

12 Relation Training and Personnel Decisions



13 Database 4 - DEA results

Hamburg

EFFECTIVENESS

Table A40: DEA modelling results - Effectiveness Hamburg.

DMU Name	Variables				Theta	Slacks				Weights			
	net length	vehicles	staff	paxkm	Objective Value	net length	vehicles	staff	paxkm	net length	vehicles	staff	paxkm
DMU1950	0.4481	0.93633	1.54718	1.26391	1	0	0	0	0	0.195203954	0.470075693	0.305318796	0.791195576
DMU1951	0.4641	0.9919	1.50368	1.26606	0.993951099	0	0.005232946	0	0.000894835	1.188675804	0	0.29815889	0
DMU1952	0.47101	1.00761	1.48993	1.2682	0.991074589	0	0	0.003425776	0	0.88791488	0.57738928	0	12.25478489
DMU1953	0.47596	1.02996	1.43611	1.27034	1	0	0	0	0	0.283284644	0.260749884	0.415431889	0.415666567
DMU1954	0.50287	0.98949	1.44076	1.26794	1	0	0	0	0	0.194583521	0.468581612	0.304348375	0.788680852
DMU1955	0.56337	0.96834	1.45675	1.27377	1	0	0	0	0	0.184605725	0.478950716	0.296695752	0.991938898
DMU1956	0.58838	0.98828	1.44419	1.27074	0.986692597	0	0	0	0	0.182698215	0.474001774	0.293630029	0.981689308
DMU1957	0.63841	1.0209	1.51039	1.2677	0.943958007	0.009974144	0	0	0	0	0.779298971	0.135338344	1.288713351
DMU1958	0.73581	1.08433	1.48769	1.26467	0.903705522	0	0	0	0	0.168348838	0.436773001	0.270567909	0.904586036
DMU1959	0.79036	1.01848	1.40087	1.25183	0.947650057	0.056475514	0	0	0	0	0.802872099	0.130126867	0.449740247
DMU1960	0.80194	1.02392	1.2843	1.23521	0.959137556	0	0	0	0	0.274676387	0.253411655	0.405086628	0.408489702
DMU1961	0.84678	0.99069	1.19903	1.26022	1	0	0	0	0	0.195775523	0.471452103	0.306212788	0.793512244
DMU1962	0.86594	1.03902	1.18613	1.24066	0.990636881	0	0.043736853	0	0	0.357966434	0	0.581742765	0.511705722
DMU1963	0.88328	1.05835	1.17152	1.13554	0.938998677	0	0.027025237	0	0	0.358788822	0	0.583079255	0.512881309
DMU1964	0.91038	1.08251	1.09363	1.07934	0.946624575	0	0.07977302	0	0	0.40717337	0	0.575439141	0.385170508
DMU1965	0.91677	1.12601	1.06286	1.04634	0.951370372	0	0.136897446	0	0	0.450862775	0	0.551965954	0.249580806
DMU1966	0.93885	1.11513	0.9695	1.029	0.988125429	0	0.17714853	0	0	0.470421239	0	0.575910283	0.260407643
DMU1967	0.9829	1.12782	0.92704	0.96436	0.974930237	0	0.194926104	0	0	0.472182999	0	0.578067106	0.261382887
DMU1968	1.05089	1.11815	0.90537	0.96148	0.955472168	0	0.168602703	0	0	0.463116562	0	0.566967578	0.256364046
DMU1969	1.0465	1.14715	0.89351	0.98538	0.970094695	0	0.20764383	0	0	0.467208051	0	0.571976558	0.258628942
DMU1970	1.09187	1.13688	0.87305	1.02349	0.978599472	0	0.19283276	0	0	0.398296623	0	0.647284653	0.569356905
DMU1971	1.10384	1.14051	0.87614	1.01005	0.964678374	0	0.1835228	0	0	0.426976765	0	0.603426356	0.403903767
DMU1972	1.10478	1.13869	0.87614	1.00823	0.963556538	0	0.18146368	0	0	0.426805463	0	0.603184263	0.403741721
DMU1973	1.12114	1.1097	0.87047	0.99208	0.953638787	0	0.150856706	0	0	0.425290374	0	0.601043058	0.402308504
DMU1974	1.12221	1.12601	0.92342	0.9981	0.926163847	0	0.133516649	0	0	0.411991179	0	0.582247926	0.389727972

Appendix

DMU1975	1.1423	1.06741	0.91569	0.97345	0.914477139	0	0.0767535	0	0	0.441827295	0	0.540904324	0.244579102
DMU1976	1.14256	1.06862	0.90623	0.9611	0.916038686	0	0.083032617	0	0	0.444048461	0	0.543623573	0.245808657
DMU1977	1.15946	1.0946	0.92377	0.95428	0.89904296	0	0.089686571	0	0	0.436608831	0	0.534515653	0.241690355
DMU1978	1.14855	1.05593	0.92704	0.97397	0.906535533	0	0.057425966	0	0	0.437929423	0	0.536132379	0.242421386
DMU1979	1.11649	1.07587	0.95128	0.99546	0.91269818	0	0.074371566	0	0	0.438387173	0	0.536692777	0.242674779
DMU1980	1.11409	1.07285	0.97002	0.98948	0.903113997	0	0.061795053	0	0	0.434474516	0	0.53190273	0.240508878
DMU1981	1.11928	1.05956	0.99323	1.01916	0.898918536	0	0.033350588	0	0	0.396358943	0	0.560155616	0.374940472
DMU1982	1.12194	1.0511	0.97827	1.0156	0.904207623	0	0.032843042	0	0	0.399283943	0	0.564289381	0.377707411
DMU1983	1.11223	1.04627	0.9879	1.00699	0.899554902	0	0.028722205	0	0	0.3986632	0	0.563412115	0.377120212
DMU1984	1.09985	1.01727	1.00354	0.96076	0.886170758	0	0	0	0	0.323636329	0.27148063	0.366581784	0.238817572
DMU1985	1.11462	1.02754	0.99753	0.93814	0.877720781	0	0.006118667	0	0	0.42811153	0	0.524112885	0.236986567
DMU1986	1.12194	1.00036	0.99306	0.91852	0.877966621	0	0	0	0	0.286400949	0.361729137	0.319030028	0.239336303
DMU1987	1.15241	0.98163	0.9989	0.92009	0.891201661	0.056769528	0	0	0	0	0.984935769	0.033194014	0.239603172
DMU1988	1.10717	0.94237	0.97913	0.89944	0.923850469	0.03801084	0	0.03815015	0	0	1.061154324	0	0.191346774
DMU1989	1.10278	0.93633	0.95833	0.8293	0.925178218	0	0	0.065128982	0.046089096	0.114287563	0.933395235	0	0
DMU1990	1.10677	0.95928	0.92686	0.82141	0.907087426	0	0	0	0.065559139	0.428213854	0.245036265	0.31397122	0
DMU1991	1.11821	0.96049	0.93185	0.85597	0.903217138	0	0	0.007125639	0.02640064	0.111574704	0.911239107	0	0
DMU1992	1.13298	0.99855	0.98343	0.86924	0.873368913	0	0	0	0.027574341	0.412296166	0.235927707	0.302300192	0
DMU1993	1.14629	0.93935	0.98738	0.89123	0.925244631	0.063659258	0	0.062483198	0	0	1.064565923	0	0.191961951
DMU1994	1.14602	0.93331	0.96606	0.89742	0.932428369	0.080758057	0	0.038135165	0	0	1.071455358	0	0.19320425
DMU1995	1.14243	0.92908	0.9291	0.90636	0.938670832	0.089966626	0	0	0	0	1.041241218	0.035091604	0.253300476
DMU1996	1.12686	0.90491	0.87872	0.9014	0.963362353	0.078376661	0	0	0	0	1.070063062	0.036062949	0.260311903
DMU1997	1.15148	0.9327	0.82697	0.89982	0.938230843	0	0	0	0	0.307627891	0.388539116	0.342675312	0.257074994
DMU1998	1.059	0.9025	0.79362	0.79469	0.988103867	0	0.023345505	0	0.064349699	0.570313893	0	0.499026723	0
DMU1999	1.07444	0.91881	0.75992	0.80242	0.996084048	0	0.053542251	0	0.039437387	0.574919895	0	0.503056991	0
DMU2000	1.07457	0.90793	0.75648	0.81337	0.997736076	0	0.044744172	0	0.027114052	0.575873412	0	0.503891322	0
DMU2001	1.07457	0.91518	0.76474	0.82381	0.993600569	0	0.046934573	0	0.019878189	0.57348648	0	0.501802748	0
DMU2002	1.08535	0.91881	0.75683	0.82908	0.991406661	0	0.050884465	0	0.008602193	0.5722202	0	0.500694748	0
DMU2003	1.08721	0.89766	0.75803	0.83266	0.989758551	0	0.028451548	0	0.004984573	0.571268944	0	0.499862396	0
DMU2004	1.09919	0.91579	0.74668	0.84455	1	0	0	0	0	0.079358718	0	1.222437578	0.229011478
DMU2005	1.07966	0.859	0.74617	0.83506	1	0	0	0	0	0.333803903	0.421599852	0.371833504	0.278949467
DMU2006	1.10273	0.888	0.75511	0.85086	0.991158318	0.002592471	0	0	0	0	0.024954018	1.29496475	0.218922096
DMU2007	1.1066	0.88679	0.75614	0.86801	0.993617533	0.004028156	0	0	0	0	0.02492153	1.293278807	0.218637076
DMU2008	1.11443	0.89706	0.75923	0.89158	0.994541842	0.002924853	0	0	0	0	0.024816008	1.287802843	0.21771133
DMU2009	1.12688	0.89223	0.75872	0.90398	0.998016563	0.016235784	0	0	0	0	0.024835296	1.28880378	0.217880544
DMU2010	1.11904	0.88558	0.76456	0.94687	1	0	0	0	0	0.323707674	0.408848148	0.360587033	0.270512365
DMU2011	1.12065	0.89525	0.76594	0.94631	0.998246432	0	0.008219168	0	0	0.485826665	0	0.59477028	0.268935511
DMU2012	1.1288	0.90552	0.78244	0.9839	1	0	0	0	0	0.314356243	0.311587348	0.463941129	0.474653957
DMU2013	1.13373	0.94237	0.83144	0.99963	0.975019109	0	0.007724529	0	0	0.402425841	0	0.653995178	0.575259539

Table A41: Lambdas - Effectiveness Hamburg.

DMU Name	DMU1950	DMU1953	DMU1954	DMU1955	DMU1961	DMU2004	DMU2005	DMU2010	DMU2012
DMU1950	1	0	0	0	0	0	0	0	0
DMU1951	0.526464287	0.473535713	0	0	0	0	0	0	0
DMU1952	0.333684523	0.664685307	0	0.00163017	0	0	0	0	0
DMU1953	0	1	0	0	0	0	0	0	0
DMU1954	0	0	1	0	0	0	0	0	0
DMU1955	0	0	0	1	0	0	0	0	0
DMU1956	0.016467955	0	0.224186271	0.644170866	0.115174908	0	0	0	0
DMU1957	0.303798102	0	0	0.469297786	0.226904112	0	0	0	0
DMU1958	0.131862809	0	0.254083557	0.147741784	0.46631185	0	0	0	0
DMU1959	0.408524136	0	0	0	0.559889924	0	0	0.031585939	0
DMU1960	0	0.004940742	0.301621346	0	0.594319075	0	0	0	0.099118837
DMU1961	0	0	0	0	1	0	0	0	0
DMU1962	0	0.024720124	0	0	0.903587029	0	0	0	0.071692848
DMU1963	0	0.401211356	0	0	0.132878616	0	0	0	0.465910028
DMU1964	0	0.401142662	0	0	0	0	0	0.525609074	0.073248264
DMU1965	0	0.372368741	0	0	0	0	0.187640788	0.439990471	0
DMU1966	0	0.290968014	0	0	0	0	0.107230332	0.601801655	0
DMU1967	0	0.22052767	0	0	0	0	0.481567708	0.297904622	0
DMU1968	0	0.158637189	0	0	0	0	0.328274499	0.513088312	0
DMU1969	0	0.155083379	0	0	0	0	0.10423773	0.740678891	0
DMU1970	0	0.055174495	0	0	0.086080695	0	0	0	0.85874481
DMU1971	0	0.097265112	0	0	0	0	0	0.046195482	0.856539406
DMU1972	0	0.097063127	0	0	0	0	0	0.093782396	0.809154476
DMU1973	0	0.084841786	0	0	0	0	0	0.435378915	0.479779299
DMU1974	0	0.127952257	0	0	0	0	0	0.606282597	0.265765146
DMU1975	0	0.11069157	0	0	0	0	0.082509633	0.806798797	0
DMU1976	0	0.102274677	0	0	0	0	0.168614522	0.729110801	0
DMU1977	0	0.104682546	0	0	0	0	0.2365769	0.658740553	0
DMU1978	0	0.115432599	0	0	0	0	0.091574841	0.79299256	0
DMU1979	0	0.154734546	0	0	0	0	0.013075608	0.832189846	0
DMU1980	0	0.16895096	0	0	0	0	0.107687747	0.723361292	0
DMU1981	0	0.181168799	0	0	0	0	0	0.449203101	0.3696281
DMU1982	0	0.168450138	0	0	0	0	0	0.446958079	0.384591783
DMU1983	0	0.184494104	0	0	0	0	0	0.803577942	0.011927954
DMU1984	0	0.178806617	0.019087001	0	0	0	0.447874427	0.354231955	0
DMU1985	0	0.181821306	0	0	0	0	0.604093889	0.214084805	0
DMU1986	0.096812643	0	0.066181847	0	0	0	0.718115428	0.118890082	0
DMU1987	0.178056805	0	0	0	0	0	0.744397902	0.077545293	0
DMU1988	0.15012242	0	0	0	0	0	0.84987758	0	0

DMU1989	0.094040099	0	0	0	0	0	0.905959901	0	0
DMU1990	0.101388328	0.019363983	0	0	0	0	0.879247688	0	0
DMU1991	0.110319786	0	0	0	0	0	0.889680214	0	0
DMU1992	0.122409076	0.021271844	0	0	0	0	0.856319079	0	0
DMU1993	0.130978198	0	0	0	0	0	0.869021802	0	0
DMU1994	0.145412149	0	0	0	0	0	0.854587851	0	0
DMU1995	0.156366771	0	0	0	0	0	0.805692882	0.037940347	0
DMU1996	0.12244704	0	0	0	0	0	0.75387362	0.12367934	0
DMU1997	0.002648963	0	0.027482441	0	0	0	0.50723204	0.462636556	0
DMU1998	0	0.055090285	0	0	0	0	0.944909715	0	0
DMU1999	0	0.015616126	0	0	0	0	0.984383874	0	0
DMU2000	0	0.012461065	0	0	0	0	0.987538935	0	0
DMU2001	0	0.019822157	0	0	0	0	0.980177843	0	0
DMU2002	0	0.006024152	0	0	0	0	0.993975848	0	0
DMU2003	0	0.005937726	0	0	0	0	0.994062274	0	0
DMU2004	0	0	0	0	0	1	0	0	0
DMU2005	0	0	0	0	0	0	1	0	0
DMU2006	0	0	0	0	0	0.318930174	0.566828232	0.114241594	0
DMU2007	0	0	0	0	0	0.262167905	0.465387532	0.272444563	0
DMU2008	0	0	0	0	0	0.361746925	0.163456352	0.474796724	0
DMU2009	0	0	0	0	0	0.276457491	0.130604325	0.592938185	0
DMU2010	0	0	0	0	0	0	0	1	0
DMU2011	0	0.000208586	0	0	0	0	0.005611943	0.994179471	0
DMU2012	0	0	0	0	0	0	0	0	1
DMU2013	0	0.020353068	0	0	0.035828269	0	0	0	0.943818663

EFFICIENCY

Table A42: DEA modelling results - Efficiency Hamburg.

DMU Name	**Variables**				**Theta**	**Slacks**				**Weights**			
	net length	vehicles	staff	seatkm	Objective Value	net length	vehicles	staff	seatkm	net length	vehicles	staff	seatkm
DMU1950	0.4481	0.93633	1.54718	0.44327	1	0	0	0	0	0.472075614	0.270135224	0.346131157	0
DMU1951	0.4641	0.9919	1.50368	0.46837	0.993951099	0	0.005232946	0	0.016026577	1.188675804	0	0.29815889	0
DMU1952	0.47101	1.00761	1.48993	0.50155	0.991072554	0	0	0.003420138	0	2.044051973	0.036949891	0	0.695531449
DMU1953	0.47596	1.02996	1.43611	0.53012	1	0	0	0	0	0.472075614	0.270135224	0.346131157	0
DMU1954	0.50287	0.98949	1.44076	0.54465	0.997254137	0	0	0	0	0.588386635	0.300999464	0.281991486	0.152610674
DMU1955	0.56337	0.96834	1.45675	0.78373	1	0	0	0	0	1.36735563	0.237182042	0	1.237348195
DMU1956	0.58838	0.98828	1.44419	0.81519	1	0	0	0	0	1.350330725	0.20792934	0	1.226707884
DMU1957	0.63841	1.0209	1.51039	0.83471	0.953372865	0	0	0.030416341	0	1.226248015	0.21270546	0	1.109657017
DMU1958	0.73581	1.08433	1.48769	0.84186	0.885674655	0	0	0	0	0.657476659	0.045295909	0.313980995	0.241155588
DMU1959	0.79036	1.01848	1.40087	0.87328	0.907530489	0	0	0.040242627	0	0.313497012	0.738575624	0	0.175581878

DMU1960	0.80194	1.02392	1.2843	0.9014	0.921332411	0	0	0	0	0.673035896	0.04636784	0.32141138	0.246862553
DMU1961	0.84678	0.99069	1.19903	0.88816	0.925194829	0	0	0	0	0.518609105	0.265303549	0.248549752	0.134512378
DMU1962	0.86594	1.03902	1.18613	0.87842	0.910050494	0	0.003980251	0	0.021585321	0.525263039	0	0.459607062	0
DMU1963	0.88328	1.05835	1.17152	0.94702	0.915283217	0	0.023274349	0	0	0.678146321	0	0.342296262	0.242114676
DMU1964	0.91038	1.08251	1.09363	0.95708	0.927838043	0	0.078852148	0	0.010049904	0.535529658	0	0.468590391	0
DMU1965	0.91677	1.12601	1.06286	0.95331	0.938154451	0	0.135186783	0	0.032056038	0.541484083	0	0.473800535	0
DMU1966	0.93885	1.11513	0.9695	0.91087	0.969446286	0	0.174059754	0	0.133865577	0.559545108	0	0.489603997	0
DMU1967	0.9829	1.12782	0.92704	0.95684	0.965719212	0	0.193214397	0	0.134166357	0.557393915	0	0.487721696	0
DMU1968	1.05089	1.11815	0.90537	0.93082	0.940029811	0	0.166100011	0	0.206008833	0.542566504	0	0.474747657	0
DMU1969	1.0465	1.14715	0.89351	0.96867	0.947622517	0	0.20315235	0	0.172685122	0.546948863	0	0.478582237	0
DMU1970	1.09187	1.13688	0.87305	1.00652	0.933596833	0	0.185313196	0	0.167640518	0.538853517	0	0.47149878	0
DMU1971	1.10384	1.14051	0.87614	1.03397	0.926272787	0	0.181224217	0	0.143853446	0.534626224	0	0.467799883	0
DMU1972	1.10478	1.13869	0.87614	1.02901	0.925807524	0	0.179109617	0	0.149236183	0.534357683	0	0.467564909	0
DMU1973	1.12114	1.1097	0.87047	1.02772	0.920202571	0	0.148560322	0	0.161029674	0.531122616	0	0.464734213	0
DMU1974	1.12221	1.12601	0.92342	1.04937	0.8976045	0	0.131220442	0	0.11049044	0.518079459	0	0.453321404	0
DMU1975	1.1423	1.06741	0.91569	1.06599	0.891449893	0	0.075167085	0	0.106910468	0.514527142	0	0.450213113	0
DMU1976	1.14256	1.06862	0.90623	0.98563	0.89514257	0	0.08145224	0	0.192545615	0.516658482	0	0.452078043	0
DMU1977	1.15946	1.0946	0.92377	0.96301	0.880473029	0	0.088118135	0	0.212936464	0.508191514	0	0.444669416	0
DMU1978	1.14855	1.05593	0.92704	0.95891	0.884089219	0	0.056344586	0	0.210574107	0.510278708	0	0.446495718	0
DMU1979	1.11649	1.07587	0.95128	0.97092	0.889011211	0	0.072798337	0	0.171484209	0.513119583	0	0.448981495	0
DMU1980	1.11409	1.07285	0.97002	0.9823	0.882671489	0	0.06070758	0	0.149204421	0.509460422	0	0.445779715	0
DMU1981	1.11928	1.05956	0.99323	0.99564	0.871352062	0	0.034692694	0	0.12627795	0.502927074	0	0.440063012	0
DMU1982	1.12194	1.0511	0.97827	0.98332	0.875946891	0	0.034266914	0	0.147454789	0.505579117	0	0.44238356	0
DMU1983	1.11223	1.04627	0.9879	0.97669	0.876515767	0	0.028401835	0	0.144754105	0.505907461	0	0.442670862	0
DMU1984	1.09985	1.01727	1.00354	0.96023	0.876140627	0	0	0	0.147552211	0.413604624	0.236676444	0.303259569	0
DMU1985	1.11462	1.02754	0.99753	0.96113	0.871745541	0	0.006170636	0	0.156495281	0.503154182	0	0.440261732	0
DMU1986	1.12194	1.00036	0.99306	0.96572	0.874430095	0	0	0	0.156580583	0.412797124	0.236214369	0.3026675	0
DMU1987	1.15241	0.98163	0.9989	0.97655	0.882841639	0	0	0.056730248	0.189967627	0.109057712	0.890682642	0	0
DMU1988	1.10717	0.94237	0.97913	0.96511	0.919532811	0	0	0.07606892	0.202276101	0.113590184	0.927699688	0	0
DMU1989	1.10278	0.93633	0.95833	0.94245	0.925178218	0	0	0.065128982	0.227716927	0.114287563	0.933395235	0	0
DMU1990	1.10677	0.95928	0.92686	0.9359	0.907087426	0	0	0	0.214516145	0.428213854	0.245036265	0.31397122	0
DMU1991	1.11821	0.96049	0.93185	0.99645	0.903217138	0	0	0.007125639	0.16065492	0.111574704	0.911239107	0	0
DMU1992	1.13298	0.99855	0.98343	1.03693	0.873368913	0	0	0	0.095255073	0.412296166	0.235927707	0.302300192	0
DMU1993	1.14629	0.93935	0.98738	1.0638	0.918025418	0	0	0.125598766	0.147090828	0.113403976	0.926178907	0	0
DMU1994	1.14602	0.93331	0.96606	1.09712	0.92321828	0	0	0.118276544	0.121016392	0.114045452	0.931417891	0	0
DMU1995	1.14243	0.92908	0.9291	1.09829	0.927251193	0	0	0.089541251	0.12148901	0.114543639	0.935486622	0	0
DMU1996	1.12686	0.90491	0.87872	1.09219	0.950436284	0	0	0.078024808	0.14243908	0.117407701	0.958877633	0	0
DMU1997	1.15148	0.9327	0.82697	1.1133	0.924401661	0	0	0	0.113673831	0.436387482	0.249713449	0.319964216	0
DMU1998	1.059	0.9025	0.79362	1.06556	0.988103867	0	0.023345505	0	0.140642901	0.570313893	0	0.499026723	0
DMU1999	1.07444	0.91881	0.75992	1.08433	0.996084048	0	0.053542251	0	0.150116662	0.574919895	0	0.503056991	0
DMU2000	1.07457	0.90793	0.75648	1.11365	0.997736076	0	0.044744172	0	0.123054108	0.575873412	0	0.503891322	0
DMU2001	1.07457	0.91518	0.76474	1.15553	0.993600569	0	0.046934573	0	0.075907246	0.57348648	0	0.501802748	0
DMU2002	1.08535	0.91881	0.75683	1.15882	0.991406661	0	0.050884465	0	0.082489719	0.5722202	0	0.500694748	0
DMU2003	1.08721	0.89766	0.75803	1.19717	0.989758551	0	0.028451548	0	0.044201557	0.571268944	0	0.499862396	0
DMU2004	1.09919	0.91579	0.74668	1.2204	0.999316976	0.018779227	0.056164494	0	0.02522	0	0	1.339261799	0
DMU2005	1.07966	0.859	0.74617	1.24562	1	0	0	0	0	0.686675755	0	0.346601518	0.245159891

DMU2006	1.10273	0.888	0.75511	1.26016	0.990758671	0.00867839	0.01795824	0	0	0	0	1.324310365	0.17867988
DMU2007	1.1066	0.88679	0.75614	1.24738	0.987128659	0.012188073	0.016032604	0	0	0	0	1.322506414	0.178436485
DMU2008	1.11443	0.89706	0.75923	1.27623	0.988238073	0.012818268	0.021539559	0	0	0	0	1.317123928	0.177710264
DMU2009	1.12688	0.89223	0.75872	1.30849	0.994639138	0.023014457	0.016186536	0	0	0	0	1.318009279	0.177829719
DMU2010	1.11904	0.88558	0.76456	1.38192	1	0	0	0	0	0.785760108	0.136298256	0	0.711050461
DMU2011	1.12065	0.89525	0.76594	1.35236	0.992991197	0.002296104	0.009159894	0	0	0	0	1.305585294	0.176153438
DMU2012	1.1288	0.90552	0.78244	1.37571	0.986265215	0	0.006639286	0	0	0.667599375	0	0.314929995	0.255727363
DMU2013	1.13373	0.94237	0.83144	1.39318	1	0	0	0	0	0.882044226	0	0	1.150730877

Table A43: Lambdas - Efficiency Hamburg.

DMU Name	**DMU1950**	**DMU1953**	**DMU1955**	**DMU1956**	**DMU2005**	**DMU2010**	**DMU2013**
DMU1950	1	0	0	0	0	0	0
DMU1951	0.526464287	0.473535713	0	0	0	0	0
DMU1952	0.333708598	0.664664528	0.001626875	0	0	0	0
DMU1953	0	1	0	0	0	0	0
DMU1954	0.347040428	0.577813337	0.019694451	0	0.055451784	0	0
DMU1955	0	0	1	0	0	0	0
DMU1956	0	0	0	1	0	0	0
DMU1957	0	0	0.446328679	0.494451763	0	0.059219558	0
DMU1958	0	0.173002249	0.633786701	0	0.099573129	0.093637921	0
DMU1959	0.202831641	0	0.453783439	0	0.34338492	0	0
DMU1960	0	0.248578525	0.372673272	0	0.336400499	0.042347704	0
DMU1961	0.242903899	0.19838615	0.044644324	0	0.514065628	0	0
DMU1962	0	0.483039383	0	0	0.516960617	0	0
DMU1963	0	0.465862847	0	0	0.279369238	0.254767915	0
DMU1964	0	0.389224453	0	0	0.610775547	0	0
DMU1965	0	0.363737194	0	0	0.636262806	0	0
DMU1966	0	0.280760898	0	0	0.719239102	0	0
DMU1967	0	0.216091745	0	0	0.783908255	0	0
DMU1968	0	0.15204915	0	0	0.84795085	0	0
DMU1969	0	0.1457231	0	0	0.8542769	0	0
DMU1970	0	0.099873489	0	0	0.900126511	0	0
DMU1971	0	0.094754094	0	0	0.905245906	0	0
DMU1972	0	0.094163266	0	0	0.905836734	0	0
DMU1973	0	0.079483335	0	0	0.920516665	0	0
DMU1974	0	0.119859622	0	0	0.880140378	0	0
DMU1975	0	0.101634566	0	0	0.898365434	0	0
DMU1976	0	0.094261894	0	0	0.905738106	0	0
DMU1977	0	0.097377409	0	0	0.902622591	0	0
DMU1978	0	0.106409354	0	0	0.893590646	0	0
DMU1979	0	0.14425687	0	0	0.85574313	0	0
DMU1980	0	0.159490676	0	0	0.840509324	0	0
DMU1981	0	0.172888959	0	0	0.827111041	0	0

DMU1982	0	0.160510428	0	0	0.839489572	0	0
DMU1983	0	0.173551216	0	0	0.826448784	0	0
DMU1984	0.005797111	0.186144623	0	0	0.808058267	0	0
DMU1985	0	0.178888497	0	0	0.821111503	0	0
DMU1986	0.119956033	0.037837447	0	0	0.84220652	0	0
DMU1987	0.098588363	0	0	0	0.901411637	0	0
DMU1988	0.09750595	0	0	0	0.90249405	0	0
DMU1989	0.094040099	0	0	0	0.905959901	0	0
DMU1990	0.101388328	0.019363983	0	0	0.879247688	0	0
DMU1991	0.110319786	0	0	0	0.889680214	0	0
DMU1992	0.122409076	0.021271844	0	0	0.856319079	0	0
DMU1993	0.043284318	0	0	0	0.956715682	0	0
DMU1994	0.034253889	0	0	0	0.965746111	0	0
DMU1995	0.03220663	0	0	0	0.96779337	0	0
DMU1996	0.013698411	0	0	0	0.986301589	0	0
DMU1997	0.011066848	0.013650152	0	0	0.975283	0	0
DMU1998	0	0.055090285	0	0	0.944909715	0	0
DMU1999	0	0.015616126	0	0	0.984383874	0	0
DMU2000	0	0.012461065	0	0	0.987538935	0	0
DMU2001	0	0.019822157	0	0	0.980177843	0	0
DMU2002	0	0.006024152	0	0	0.993975848	0	0
DMU2003	0	0.005937726	0	0	0.994062274	0	0
DMU2004	0	0	0	0	1	0	0
DMU2005	0	0	0	0	1	0	0
DMU2006	0	0	0	0	0.893323551	0.106676449	0
DMU2007	0	0	0	0	0.987087307	0.012912693	0
DMU2008	0	0	0	0	0.775421864	0.224578136	0
DMU2009	0	0	0	0	0.538738078	0.461261922	0
DMU2010	0	0	0	0	0	1	0
DMU2011	0	0	0	0	0.216874541	0.783125459	0
DMU2012	0	0.000167108	0.010143361	0	0	0.989689531	0
DMU2013	0	0	0	0	0	0	1

MIXED PERFORMANCE

Table A44: DEA modelling results - Mixed Performance Hamburg.

			Variables			Theta			Slacks					Weights		
DMU Name	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**	**Objective Value**	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**
DMU1950	0.4481	0.93633	1.54718	1.26391	0.44327	1	0	0	0	0	0	0	0.924286543	0.086972932	0.507984374	0.049088657
DMU1951	0.4641	0.9919	1.50368	1.26606	0.46837	0.993951099	0	0.005232946	0	0.000894835	0.016026577	1.188675804	0	0.29815889	0	0
DMU1952	0.47101	1.00761	1.48993	1.2682	0.50155	0.991074589	0	0	0.003425776	0	2.9266E-06	0.88791488	0.57738928	0	12.25478489	0
DMU1953	0.47596	1.02996	1.43611	1.27034	0.53012	1	0	0	0	0	0	0.270058366	0.273445315	0.41071038	0.787190831	0
DMU1954	0.50287	0.98949	1.44076	1.26794	0.54465	1	0	0	0	0	0	0.194583521	0.468581612	0.304348375	0.788680852	0
DMU1955	0.56337	0.96834	1.45675	1.27377	0.78373	1	0	0	0	0	0	0	0.877826407	0.102945307	0.764740781	0.033042164
DMU1956	0.58838	0.98828	1.44419	1.27074	0.81519	1	0	0	0	0	0	0.510142705	0	0.484591525	0.703722356	0.279862627
DMU1957	0.63841	1.0209	1.51039	1.2677	0.83471	1	0	0	0	0	0	0.841014787	0.453607356	0	6.881380776	3.985247915

Appendix

DMU1958	0.73581	1.08433	1.48769	1.26467	0.84186	0.915079292	0	0.005323588	0	0	0	0.465335516	0	0.442028564	0.641912552	0.255281549
DMU1959	0.79036	1.01848	1.40087	1.25183	0.87328	0.960573791	0.003234444	0	0.071782693	0	0	0	0.981855314	0	0.873353808	0.323455045
DMU1960	0.80194	1.02392	1.2843	1.23521	0.9014	0.968834058	0	0.017669646	0	0	0	0.480185505	0	0.478797817	0.578724918	0.196641991
DMU1961	0.84678	0.99069	1.19903	1.26022	0.88816	1	0	0	0	0	0	0	0.840402969	0.13963052	0.793512244	0
DMU1962	0.86594	1.03902	1.18613	1.24066	0.87842	0.990636881	0	0.043736853	0	0	0.035843055	0.357966434	0	0.581742765	0.511705722	0
DMU1963	0.88328	1.05835	1.17152	1.13554	0.94702	0.938998677	0	0.027025237	0	0	0.02464472	0.358788822	0	0.583079255	0.512881309	0
DMU1964	0.91038	1.08251	1.09363	1.07934	0.95708	0.946624575	0	0.07977302	0	0	0.082691809	0.40717337	0	0.575439141	0.385170508	0
DMU1965	0.91677	1.12601	1.06286	1.04634	0.95331	0.951370372	0	0.136897446	0	0	0.085850867	0.450862775	0	0.551965954	0.249580806	0
DMU1966	0.93885	1.11513	0.9695	1.029	0.91087	0.988125429	0	0.17714853	0	0	0.208587952	0.470421239	0	0.575910283	0.260407643	0
DMU1967	0.9829	1.12782	0.92704	0.96436	0.95684	0.974930237	0	0.194926104	0	0	0.171596852	0.472182999	0	0.578067106	0.261382887	0
DMU1968	1.05089	1.11815	0.90537	0.96148	0.93082	0.955472168	0	0.168602703	0	0	0.271229028	0.463116562	0	0.566967578	0.256364046	0
DMU1969	1.0465	1.14715	0.89351	0.98538	0.96867	0.970094695	0	0.20764383	0	0	0.266942375	0.467208051	0	0.571976558	0.258628942	0
DMU1970	1.09187	1.13688	0.87305	1.02349	1.00652	0.978599472	0	0.19283276	0	0	0.280566356	0.398296623	0	0.647284653	0.569356905	0
DMU1971	1.10384	1.14051	0.87614	1.01005	1.03397	0.964678374	0	0.1835228	0	0	0.259780468	0.426976765	0	0.603426356	0.403903767	0
DMU1972	1.10478	1.13869	0.87614	1.00823	1.02901	0.963556538	0	0.18146368	0	0	0.265206779	0.426805463	0	0.603184263	0.403741721	0
DMU1973	1.12114	1.1097	0.87047	0.99208	1.02772	0.953638787	0	0.150856706	0	0	0.278952337	0.425290374	0	0.601043058	0.402308504	0
DMU1974	1.12221	1.12601	0.92342	0.9981	1.04937	0.926163847	0	0.133516649	0	0	0.221909866	0.411991179	0	0.582247926	0.389727972	0
DMU1975	1.1423	1.06741	0.91569	0.97345	1.06599	0.914477139	0	0.0767535	0	0	0.210396858	0.441827295	0	0.540904324	0.244579102	0
DMU1976	1.14256	1.06862	0.90623	0.9611	0.98563	0.916038686	0	0.083032617	0	0	0.286190271	0.444048461	0	0.543623573	0.245808657	0
DMU1977	1.15946	1.0946	0.92377	0.95428	0.96301	0.89904296	0	0.089686571	0	0	0.297495976	0.436608831	0	0.534515653	0.241690355	0
DMU1978	1.14855	1.05593	0.92704	0.97397	0.95891	0.906535533	0	0.057425966	0	0	0.312202861	0.437929423	0	0.536132379	0.242421386	0
DMU1979	1.11649	1.07587	0.95128	0.99546	0.97092	0.91269818	0	0.074371566	0	0	0.277414908	0.438387173	0	0.536692777	0.242674779	0
DMU1980	1.11409	1.07285	0.97002	0.98948	0.9823	0.903113997	0	0.061795053	0	0	0.241029732	0.434474516	0	0.53190273	0.240508878	0
DMU1981	1.11928	1.05956	0.99323	1.01916	0.99564	0.898918536	0	0.033350588	0	0	0.229665026	0.396358943	0	0.560155616	0.374940472	0
DMU1982	1.12194	1.0511	0.97827	1.0156	0.98332	0.904207623	0	0.032843042	0	0	0.252725857	0.399283943	0	0.564289381	0.377707411	0
DMU1983	1.11223	1.04627	0.9879	1.00699	0.97669	0.899554902	0	0.028722205	0	0	0.24800385	0.3986632	0	0.563412115	0.377120212	0
DMU1984	1.09985	1.01727	1.00354	0.96076	0.96023	0.886170758	0	0	0	0	0.192356266	0.323636329	0.27148063	0.366581784	0.238817572	0
DMU1985	1.11462	1.02754	0.99753	0.93814	0.96113	0.877720781	0	0.006118667	0	0	0.183576615	0.42811153	0	0.524112885	0.236986567	0
DMU1986	1.12194	1.00036	0.99306	0.91852	0.96572	0.877966621	0	0	0	0	0.172035605	0.286400949	0.361729137	0.319030028	0.239336303	0
DMU1987	1.15241	0.98163	0.9989	0.92009	0.97655	0.891201661	0.056769528	0	0	0	0.136775546	0	0.984935769	0.033194014	0.239603172	0
DMU1988	1.10717	0.94237	0.97913	0.89944	0.96511	0.923850469	0.03801084	0	0.03815015	0	0.160059276	0	1.061154324	0	0.191346774	0
DMU1989	1.10278	0.93633	0.95833	0.8293	0.94245	0.925178218	0	0	0.065128982	0.046089096	0.227716927	0.114287563	0.933395235	0	0	0
DMU1990	1.10677	0.95928	0.92686	0.82141	0.9359	0.907087426	0	0	0	0.065559139	0.214516145	0.428213854	0.245036265	0.31397122	0	0
DMU1991	1.11821	0.96049	0.93185	0.85597	0.99645	0.903217138	0	0	0.007125639	0.02640064	0.16065492	0.111574704	0.911239107	0	0	0
DMU1992	1.13298	0.99855	0.98343	0.86924	1.03693	0.873368913	0	0	0	0.027574341	0.095255073	0.412296166	0.235927707	0.302300192	0	0
DMU1993	1.14629	0.93935	0.98738	0.89123	1.0638	0.925244631	0.063659258	0	0.062483198	0	0.076729643	0	1.064565923	0	0.191961951	0
DMU1994	1.14602	0.93331	0.96606	0.89742	1.09712	0.932428369	0.080758057	0	0.038135165	0	0.031828562	0	1.071455358	0	0.19320425	0
DMU1995	1.14243	0.92908	0.9291	0.90636	1.09829	0.938670832	0.089966626	0	0	0	0.027040391	0	1.041241218	0.035091604	0.253300476	0
DMU1996	1.12686	0.90491	0.87872	0.9014	1.09219	0.963362353	0.078376661	0	0	0	0.072042112	0	1.070063062	0.036062949	0.260311903	0
DMU1997	1.15148	0.9327	0.82697	0.89982	1.1133	0.938230843	0	0	0	0	0.173987601	0.307627891	0.388539116	0.342675312	0.257074994	0
DMU1998	1.059	0.9025	0.79362	0.79469	1.06556	0.988103867	0	0.023345505	0	0.064349699	0.140642901	0.570313893	0	0.499026723	0	0
DMU1999	1.07444	0.91881	0.75992	0.80242	1.08433	0.996084048	0	0.053542251	0	0.039437387	0.150116662	0.574919895	0	0.503056991	0	0
DMU2000	1.07457	0.90793	0.75648	0.81337	1.11365	0.997736076	0	0.044744172	0	0.027114052	0.123054108	0.575873412	0	0.503891322	0	0
DMU2001	1.07457	0.91518	0.76474	0.82381	1.15553	0.993600569	0	0.046934573	0	0.019878189	0.075907246	0.57348648	0	0.501802748	0	0
DMU2002	1.08535	0.91881	0.75683	0.82908	1.15882	0.991406661	0	0.050884465	0	0.008602193	0.082489719	0.5722202	0	0.500694748	0	0
DMU2003	1.08721	0.89766	0.75803	0.83266	1.19717	0.989758551	0	0.028451548	0	0.004984573	0.044201557	0.571268944	0	0.499862396	0	0
DMU2004	1.09919	0.91579	0.74668	0.84455	1.2204	1	0	0	0	0	0	0.079358718	0	1.222437578	0.229011478	0
DMU2005	1.07966	0.859	0.74617	0.83506	1.24562	1	0	0	0	0	0	0.668817371	0.046077211	0.319396804	0	0.245315243
DMU2006	1.10273	0.888	0.75511	0.85086	1.26016	0.991423586	0.005970511	0.0106303	0	0	0	0	0	1.324310365	0.171701633	0.037829112
DMU2007	1.1066	0.88679	0.75614	0.86801	1.24738	0.993617533	0.004028156	0	0	0	0.028762319	0	0.02492153	1.293278807	0.218637076	0
DMU2008	1.11443	0.89706	0.75923	0.89158	1.27623	0.994541842	0.002924853	0	0	0	0.024981536	0	0.024816008	1.287802843	0.21771133	0
DMU2009	1.12688	0.89223	0.75872	0.90398	1.30849	0.998016563	0.016235784	0	0	0	0.010975217	0	0.024835296	1.28880378	0.217880544	0
DMU2010	1.11904	0.88558	0.76456	0.94687	1.38192	1	0	0	0	0	0	0.675808227	0	0.318802398	0	0.258871806
DMU2011	1.12065	0.89525	0.76594	0.94631	1.35236	0.998246432	0	0.008219168	0	0	0.028617419	0.485826665	0	0.59477028	0.268935511	0
DMU2012	1.1288	0.90552	0.78244	0.9839	1.37571	1	0	0	0	0	0	0	1.032637771	0.08297869	0.612164726	0.095652765
DMU2013	1.13373	0.94237	0.83144	0.99963	1.39318	1	0	0	0	0	0	0.690747682	0	0.260847001	0.402602995	0.564049458

Table A45: Lambdas - Mixed Performance Hamburg.

DMU Name	DMU1950	DMU1953	DMU1954	DMU1955	DMU1956	DMU1957	DMU1961	DMU2004	DMU2005	DMU2010	DMU2012	DMU2013
DMU1950	1	0	0	0	0	0	0	0	0	0	0	0
DMU1951	0.526464287	0.473535713	0	0	0	0	0	0	0	0	0	0
DMU1952	0.333684523	0.664685307	0	0.00163017	0	0	0	0	0	0	0	0
DMU1953	0	1	0	0	0	0	0	0	0	0	0	0
DMU1954	0	0	1	0	0	0	0	0	0	0	0	0
DMU1955	0	0	0	1	0	0	0	0	0	0	0	0
DMU1956	0	0	0	0	1	0	0	0	0	0	0	0
DMU1957	0	0	0	0	0	1	0	0	0	0	0	0
DMU1958	0	0	0	0.062926816	0.61353482	0	0.31319874	0	0	0	0.010339623	0
DMU1959	0	0	0	0.368640972	0	0	0.582918505	0	0	0	0.048440522	0
DMU1960	0	0.010345992	0	0.339896592	0	0	0.542199873	0	0	0	0.107557543	0
DMU1961	0	0	0	0	0	0	1	0	0	0	0	0
DMU1962	0	0.024720124	0	0	0	0	0.903587029	0	0	0	0.071692848	0
DMU1963	0	0.401211356	0	0	0	0	0.132878616	0	0	0	0.465910028	0
DMU1964	0	0.401142662	0	0	0	0	0	0	0	0.525609074	0.073248264	0
DMU1965	0	0.372368741	0	0	0	0	0	0	0.187640788	0.439990471	0	0
DMU1966	0	0.290968014	0	0	0	0	0	0	0.107230332	0.601801655	0	0
DMU1967	0	0.22052767	0	0	0	0	0	0	0.481567708	0.297904622	0	0
DMU1968	0	0.158637189	0	0	0	0	0	0	0.328274499	0.513088312	0	0
DMU1969	0	0.155083379	0	0	0	0	0	0	0.10423773	0.740678891	0	0
DMU1970	0	0.055174495	0	0	0	0	0.086080695	0	0	0	0.85874481	0
DMU1971	0	0.097265112	0	0	0	0	0	0	0	0.046195482	0.856539406	0
DMU1972	0	0.097063127	0	0	0	0	0	0	0	0.093782396	0.809154476	0
DMU1973	0	0.084841786	0	0	0	0	0	0	0	0.435378915	0.479779299	0
DMU1974	0	0.127952257	0	0	0	0	0	0	0	0.606282597	0.265765146	0
DMU1975	0	0.11069157	0	0	0	0	0	0	0.082509633	0.806798797	0	0
DMU1976	0	0.102274677	0	0	0	0	0	0	0.168614522	0.729110801	0	0
DMU1977	0	0.104682546	0	0	0	0	0	0	0.2365769	0.658740553	0	0
DMU1978	0	0.115432599	0	0	0	0	0	0	0.091574841	0.79299256	0	0
DMU1979	0	0.154734546	0	0	0	0	0	0	0.013075608	0.832189846	0	0
DMU1980	0	0.16895096	0	0	0	0	0	0	0.107687747	0.723361292	0	0
DMU1981	0	0.181168799	0	0	0	0	0	0	0	0.449203101	0.3696281	0
DMU1982	0	0.168450138	0	0	0	0	0	0	0	0.446958079	0.384591783	0
DMU1983	0	0.184494104	0	0	0	0	0	0	0	0.803577942	0.011927954	0
DMU1984	0	0.178806617	0.019087001	0	0	0	0	0	0.447874427	0.354231955	0	0
DMU1985	0	0.181821306	0	0	0	0	0	0	0.604093889	0.214084806	0	0
DMU1986	0.096812643	0	0.066181847	0	0	0	0	0	0.718115428	0.118890082	0	0
DMU1987	0.178056805	0	0	0	0	0	0	0	0.744397902	0.077545293	0	0
DMU1988	0.15012242	0	0	0	0	0	0	0	0.84987758	0	0	0

DMU1989	0.094040099	0	0	0	0	0	0	0	0.905959901	0	0	0
DMU1990	0.101388328	0.019363983	0	0	0	0	0	0	0.879247688	0	0	0
DMU1991	0.110319786	0	0	0	0	0	0	0	0.889680214	0	0	0
DMU1992	0.122409076	0.021271844	0	0	0	0	0	0	0.856319079	0	0	0
DMU1993	0.130978198	0	0	0	0	0	0	0	0.869021802	0	0	0
DMU1994	0.145412149	0	0	0	0	0	0	0	0.854587851	0	0	0
DMU1995	0.156366771	0	0	0	0	0	0	0	0.805692882	0.037940347	0	0
DMU1996	0.12244704	0	0	0	0	0	0	0	0.75387362	0.12367934	0	0
DMU1997	0.002648963	0	0.027482441	0	0	0	0	0	0.50723204	0.462636556	0	0
DMU1998	0	0.055090285	0	0	0	0	0	0	0.944909715	0	0	0
DMU1999	0	0.015616126	0	0	0	0	0	0	0.984383874	0	0	0
DMU2000	0	0.012461065	0	0	0	0	0	0	0.987538935	0	0	0
DMU2001	0	0.019822157	0	0	0	0	0	0	0.980177843	0	0	0
DMU2002	0	0.006024152	0	0	0	0	0	0	0.993975848	0	0	0
DMU2003	0	0.005937726	0	0	0	0	0	0	0.994062274	0	0	0
DMU2004	0	0	0	0	0	0	0	1	0	0	0	0
DMU2005	0	0	0	0	0	0	0	0	1	0	0	0
DMU2006	0	0	0	0	0	0	0	0.12831986	0.74126028	0.13041986	0	0
DMU2007	0	0	0	0	0	0	0	0.262167905	0.465387532	0.272444563	0	0
DMU2008	0	0	0	0	0	0	0	0.361746925	0.163456352	0.474796724	0	0
DMU2009	0	0	0	0	0	0	0	0.276457492	0.130604325	0.592938187	0	0
DMU2010	0	0	0	0	0	0	0	0	0	1	0	0
DMU2011	0	0.000208586	0	0	0	0	0	0	0.005611943	0.994179471	0	0
DMU2012	0	0	0	0	0	0	0	0	0	0	1	0
DMU2013	0	0	0	0	0	0	0	0	0	0	0	1

Porto

EFFECTIVENESS

Table A46: DEA modelling results - Effectiveness Porto.

DMU Name	**Variables**				**Theta**	**Slacks**				**Weights**			
	net length	vehicles	staff	paxkm	Objective Value	net length	vehicles	staff	paxkm	net length	vehicles	staff	paxkm
DMU1950	0.34241	0.53818	0.89201	0.57219	1	0	0	0	0	0.272460035	0.29991065	0.835529922	0
DMU1951	0.34563	0.54807	0.88741	0.58315	1	0	0	0	0	0.401670442	0.103392393	0.906575739	0.52537194
DMU1952	0.38367	0.54412	0.8769	0.59332	1	0	0	0	0	0.399535709	0.1028429	0.901757618	0.522579779
DMU1953	0.4065	0.53027	0.87395	0.59143	1	0	0	0	0	0.266192212	0.344028793	0.811676546	0.57252719
DMU1954	0.45654	0.55797	0.87789	0.59694	0.978055633	0	0	0	0	0.115765305	0.574649766	0.713655672	0.46790037

DMU1955	0.46842	0.5639	0.89431	0.62596	0.982416792	0.023458374	0	0	0	0	0.88767949	0.558461311	0.684614126
DMU1956	0.47108	0.56588	0.90219	0.63778	0.984446434	0.035417303	0	0	0	0	0.88224637	0.5550432	0.680423885
DMU1957	0.51435	0.57182	0.89956	0.66416	0.999084329	0.076994571	0	0.00083891	0	0	1.748802071	0	0.986485015
DMU1958	0.53934	0.58171	0.91828	0.67002	0.987780818	0.093417117	0	0.007232491	0	0	1.71906964	0	0.969713193
DMU1959	0.66793	0.6015	0.9439	0.59316	0.907831121	0.162760476	0	0	0	0	0.683947755	0.623588755	0.097544789
DMU1960	0.59275	0.63118	0.95737	0.56155	0.882173392	0.054393192	0	0	0.028124826	0	0.668491524	0.603801582	0
DMU1961	0.61073	0.6292	0.96788	0.60474	0.881016297	0.06633762	0	0	0	0	0.7108539	0.57107361	0.374306335
DMU1962	0.60935	0.64503	0.9889	0.6253	0.872980109	0.060126203	0	0	0	0	0.789159064	0.496479653	0.60863121
DMU1963	0.60695	0.6569	1.01221	0.70336	0.90334724	0.095025548	0	0.003572561	0	0	1.52230172	0	0.858718011
DMU1964	0.6033	0.70241	1.03882	0.74956	0.886495259	0.050277502	0	0	0	0	0.7374862	0.463970966	0.568779019
DMU1965	0.72611	0.70043	1.08742	0.77845	0.907680225	0.174444237	0	0.051500628	0	0	1.427694416	0	0.805350801
DMU1966	0.72856	0.82904	1.15869	0.82042	0.806610663	0.050925073	0	0	0	0	0.641848201	0.403802715	0.495019148
DMU1967	0.80502	0.91412	1.25952	0.80525	0.729557022	0.031743783	0	0	0	0	0.58598942	0.368660562	0.451938609
DMU1968	0.82302	0.93786	1.29992	0.84314	0.725774832	0.054279097	0	0	0	0	0.569582441	0.358338522	0.439284887
DMU1969	0.8358	0.93786	1.23916	0.84449	0.742534816	0.021220731	0	0	0	0	0.582259778	0.366314152	0.44906216
DMU1970	0.86942	0.93588	1.20073	0.80673	0.736799933	0.0030392	0	0	0	0	0.591264937	0.371979522	0.4560073
DMU1971	0.87512	0.93192	1.2142	0.75454	0.711535973	0	0	0	0	0.142146252	0.277553095	0.508110436	0.383252568
DMU1972	0.8717	0.91016	1.22011	0.76532	0.723705133	0.038609917	0	0	0	0	0.596032224	0.374978741	0.459684024
DMU1973	0.87797	0.91214	1.18431	0.78591	0.742258308	0.025694769	0	0	0	0	0.603420562	0.379626929	0.465382208
DMU1974	0.90219	0.94775	1.17807	0.84931	0.757285057	0.01243219	0	0	0	0	0.592100237	0.37250503	0.456651517
DMU1975	0.91388	0.97941	1.23554	0.9503	0.772388012	0.060768136	0	0	0	0	0.569242992	0.358124967	0.439023091
DMU1976	0.88139	0.97545	1.32488	0.98888	0.773456672	0.109174064	0	0.019921195	0	0	1.025167871	0	0.578288853
DMU1977	0.8888	1.21091	1.38498	1.07192	0.726470351	0	0.037244277	0	0	0.267985624	0	0.550054425	0.298141626
DMU1978	0.92869	1.29005	1.35739	1.353	0.813923304	0	0.061267024	0	0	0.26919324	0	0.552533119	0.299485133
DMU1979	0.94038	1.25246	1.31075	1.64105	0.921026636	0	0.015892109	0	0	0.275424239	0	0.565322567	0.306417296
DMU1980	0.93696	1.24652	1.29203	1.86117	1	0	0	0	0	0.24009898	0.062169736	0.53987991	0.315993796
DMU1981	0.94693	1.22476	1.27298	1.64125	0.939452529	0	0.004211551	0	0	0.280915635	0	0.576593943	0.31252663
DMU1982	0.97799	1.24652	1.25919	1.65165	0.94197371	0	0.012216379	0	0	0.280698372	0	0.576147999	0.312284919
DMU1983	0.97799	1.23267	1.2674	1.66752	0.943392893	0	0	0	0	0.126337832	0.246685761	0.451602277	0.340630147
DMU1984	1.01618	1.29994	1.27233	1.55369	0.8950121	0	0.042641112	0	0	0.275656489	0	0.565799273	0.306675681
DMU1985	1.10794	1.32567	1.25985	1.57313	0.884840521	0	0.018745309	0	0	0.270720426	0	0.555667747	0.30118417
DMU1986	1.10965	1.37513	1.25656	1.51804	0.869435251	0	0.067778053	0	0	0.271090523	0	0.55642739	0.301595914
DMU1987	1.11506	1.39887	1.2697	1.60429	0.887656005	0	0.072260896	0	0	0.268731582	0	0.551585542	0.298971525
DMU1988	1.14869	1.3969	1.26543	1.45785	0.838273129	0	0.066481552	0	0	0.266947791	0	0.547924217	0.296987006
DMU1989	1.16778	1.33952	1.23949	1.45188	0.84419676	0	0.020106659	0	0	0.269403979	0	0.552965672	0.299719586
DMU1990	1.16778	1.30786	1.21551	1.39548	0.83840999	0	0.009501872	0	0	0.273024314	0	0.560396596	0.303747311
DMU1991	1.23975	1.32764	1.19613	1.32016	0.808426423	0	0.006042867	0	0	0.27064559	0	0.555514142	0.301100913
DMU1992	1.28242	1.33358	1.17577	1.2763	0.795030777	0	0.003079074	0	0	0.270581143	0	0.555381861	0.301029214
DMU1993	1.29943	1.31775	1.11206	1.20691	0.798727836	0	0.014686689	0	0	0.279174351	0	0.573019867	0.310589402
DMU1994	1.29088	1.29401	1.02798	1.14427	0.820776259	0	0.039820847	0	0	0.294043065	0	0.603538676	0.327131269
DMU1995	1.2949	1.22674	0.98068	1.14853	0.845301798	0	0.000162464	0	0	0.302316042	0	0.620519392	0.336335192
DMU1996	1.2678	1.1931	0.96689	1.14327	0.858796224	0	0	0	0	0.224973023	0.138066057	0.568888486	0.360938281
DMU1997	1.28518	1.1931	0.96229	1.14475	0.858696315	0	0	0	0	0.141751939	0.276783165	0.506700942	0.382189429

DMU1998	1.27749	1.17133	0.9393	1.15067	0.877423461	0	0	0	0	0.144462739	0.28207624	0.51639086	0.389498245
DMU1999	1.3265	1.23267	0.88971	1.14862	0.886924817	0	0.026233083	0	0	0.317190854	0	0.651050716	0.352883842
DMU2000	1.33733	1.24059	0.83618	1.1355	0.910911792	0	0.052572798	0	0	0.327478786	0	0.672167231	0.364329459
DMU2001	1.3758	1.24059	0.80629	1.11299	0.909525785	0	0.047092601	0	0	0.329951099	0	0.677241783	0.367079978
DMU2002	1.41285	1.18519	0.76589	1.09371	0.916827241	0	0	0	0	0.245284105	0.150530978	0.620249047	0.393524619
DMU2003	1.40458	1.18519	0.72878	1.05547	0.928326621	0	0.021212792	0	0	0.344775414	0	0.70766946	0.38357245
DMU2004	1.40316	1.10604	0.66375	1.04223	0.9752326	0	0	0	0	0.169176064	0.317354557	0.620131192	0.464131087
DMU2005	1.41256	1.09615	0.59051	0.9944	1	0	0	0	0	0.330305003	0.085022499	0.745502958	0.432028256
DMU2006	1.41399	1.02096	0.56227	0.90248	0.998321684	0	0	0	0	0.185520263	0.348014366	0.680042429	0.508971063
DMU2007	1.53937	0.99128	0.54125	0.82973	0.96279335	0	0	0	0	0.184854408	0.360944536	0.660773341	0.49840165
DMU2008	1.54877	0.95171	0.51629	0.84612	1	0	0	0	0	0.190382712	0.371739037	0.6805346	0.51330698
DMU2009	1.56245	0.94973	0.49461	0.78666	0.991156973	0.028057175	0	0	0	0	0.742345695	0.596372947	0.390888614
DMU2010	1.57328	0.97743	0.49034	0.74499	0.957615795	0.000512098	0	0	0	0	0.729207946	0.585818569	0.383970818
DMU2011	1.50574	0.93588	0.4621	0.73338	1	0	0	0	0	0.111110235	0.551542369	0.684958671	0.449085502
DMU2012	1.39917	0.95171	0.42367	0.66784	1	0	0	0	0	0.384559928	0.098988044	0.867957074	0.502991943
DMU2013	1.38663	0.94973	0.40955	0.56369	1	0	0	0	0	0.437485199	0	0.960492978	0.182892225

Table A47: Lambdas - Effectiveness Porto.

DMU Name	DMU1950	DMU1951	DMU1952	DMU1953	DMU1980	DMU2005	DMU2008	DMU2011	DMU2012	DMU2013
DMU1950	1	0	0	0	0	0	0	0	0	0
DMU1951	0	1	0	0	0	0	0	0	0	0
DMU1952	0	0	1	0	0	0	0	0	0	0
DMU1953	0	0	0	1	0	0	0	0	0	0
DMU1954	0	0	0	0.962742237	0	0	0.00922014	0.015553369	0.012484254	0
DMU1955	0	0	0	0.960612288	0.02413511	0	0.015252602	0	0	0
DMU1956	0	0	0	0.961588691	0.03602485	0	0.002386459	0	0	0
DMU1957	0	0	0	0.942720557	0.057279443	0	0	0	0	0
DMU1958	0	0	0	0.938105439	0.061894561	0	0	0	0	0
DMU1959	0	0	0	0.962480943	0	0	0	0	0.026603732	0.010915325
DMU1960	0	0	0	0.936727693	0	0	0	0	0	0.063272307
DMU1961	0	0	0	0.942447994	0	0	0.045595997	0.011956009	0	0
DMU1962	0	0	0	0.933832219	0.016765409	0	0.049402372	0	0	0
DMU1963	0	0	0	0.911848095	0.088151905	0	0	0	0	0
DMU1964	0	0	0	0.866214971	0.122216926	0	0.011568103	0	0	0
DMU1965	0	0	0	0.852710004	0.147289996	0	0	0	0	0
DMU1966	0	0	0	0.792974096	0.173649153	0	0.033376752	0	0	0
DMU1967	0	0	0	0.785502565	0.156829366	0	0.057668069	0	0	0
DMU1968	0	0	0	0.777536973	0.1921589	0	0.030304127	0	0	0
DMU1969	0	0	0	0.733428102	0.182421362	0	0.084150536	0	0	0
DMU1970	0	0	0	0.721543296	0.142239163	0	0.136217542	0	0	0

DMU1971	0	0	0	0.755456402	0.100960451	0	0.134312818	0	0.009270329	0
DMU1972	0	0	0	0.775769229	0.115049175	0	0.109181596	0	0	0
DMU1973	0	0	0	0.740151881	0.126397008	0	0.133451111	0	0	0
DMU1974	0	0	0	0.676089619	0.172782883	0	0.151127498	0	0	0
DMU1975	0	0	0	0.648932576	0.265461443	0	0.085605981	0	0	0
DMU1976	0	0	0	0.686983162	0.313016838	0	0	0	0	0
DMU1977	0	0.560379353	0	0	0.355314569	0.084306078	0	0	0	0
DMU1978	0	0.355808384	0	0	0.582537695	0.061653921	0	0	0	0
DMU1979	0	0.148250009	0	0	0.816384757	0.035365234	0	0	0	0
DMU1980	0	0	0	0	1	0	0	0	0	0
DMU1981	0	0.129999366	0	0	0.807956251	0.062044383	0	0	0	0
DMU1982	0	0.101102527	0	0	0.806244349	0.092653124	0	0	0	0
DMU1983	0	0	0	0.088388072	0.842686428	0	0.004659733	0	0.064265767	0
DMU1984	0	0.151775037	0	0	0.717269268	0.130955695	0	0	0	0
DMU1985	0	0.088704795	0	0	0.709772889	0.201522316	0	0	0	0
DMU1986	0	0.124145012	0	0	0.663030142	0.212824846	0	0	0	0
DMU1987	0	0.068174524	0	0	0.735981602	0.195843874	0	0	0	0
DMU1988	0	0.151129205	0	0	0.606391414	0.242479381	0	0	0	0
DMU1989	0	0.135931459	0	0	0.59229301	0.271775531	0	0	0	0
DMU1990	0	0.165101367	0	0	0.541063878	0.293834755	0	0	0	0
DMU1991	0	0.179150841	0	0	0.460832497	0.360016663	0	0	0	0
DMU1992	0	0.184372502	0	0	0.412708321	0.402919177	0	0	0	0
DMU1993	0	0.199649658	0	0	0.339900921	0.460449421	0	0	0	0
DMU1994	0	0.209504381	0	0	0.272308313	0.518187306	0	0	0	0
DMU1995	0	0.180573877	0	0	0.263496668	0.555929454	0	0	0	0
DMU1996	0	0	0.14974947	0	0.348767769	0.215563109	0	0	0.285919652	0
DMU1997	0	0	0	0.110688854	0.405173785	0	0.010442576	0	0.473694785	0
DMU1998	0	0	0	0.10127181	0.402708232	0	0.05611602	0	0.439903938	0
DMU1999	0	0.117155309	0	0	0.233510759	0.649333932	0	0	0	0
DMU2000	0	0.090476275	0	0	0.205715897	0.703807828	0	0	0	0
DMU2001	0	0.074396409	0	0	0.17211662	0.753486971	0	0	0	0
DMU2002	0	0	0.021074954	0	0.195553809	0.594317366	0	0	0.189053871	0
DMU2003	0	0.058132877	0	0	0.098038864	0.843828259	0	0	0	0
DMU2004	0	0	0	0	0.124381177	0.624947729	0.122724254	0	0.12794684	0
DMU2005	0	0	0	0	0	1	0	0	0	0
DMU2006	0	0	0	0	0.067174606	0.330467746	0.261167714	0	0.341189934	0
DMU2007	0	0	0	0.013101987	0.027846728	0	0.727287338	0	0.231763946	0
DMU2008	0	0	0	0	0	0	1	0	0	0
DMU2009	0	0	0	0.005262455	0	0	0.479217718	0.515519826	0	0
DMU2010	0	0	0	0.003909401	0	0	0.107902603	0.888187996	0	0
DMU2011	0	0	0	0	0	0	0	1	0	0
DMU2012	0	0	0	0	0	0	0	0	1	0
DMU2013	0	0	0	0	0	0	0	0	0	1

EFFICIENCY

Table A48: DEA modelling results - Efficiency Porto.

DMU Name	Variables				Theta	Slacks				Weights			
	net length	vehicles	staff	seatkm	Objective Value	net length	vehicles	staff	seatkm	net length	vehicles	staff	seatkm
DMU1950	0.34241	0.53818	0.89201	0.31402	1	0	0	0	0	0.688680246	0	0.856704518	0.41874935
DMU1951	0.34563	0.54807	0.88741	0.29187	1	0	0	0	0	0.508058923	0	0.928995159	0.119071242
DMU1952	0.38367	0.54412	0.8769	0.30132	0.999649293	0	0	0	0.003316895	0.27157127	0.294277797	0.838959762	0
DMU1953	0.4065	0.53027	0.87395	0.30452	1	0	0	0	0	0.213656694	0.726349362	0.604138998	0.311885921
DMU1954	0.45654	0.55797	0.87789	0.30755	0.976860927	0.0049192	0	0	0.021680891	0	0.740243647	0.66861025	0
DMU1955	0.46842	0.5639	0.89431	0.31615	0.962075533	0.015544595	0	0	0.00882899	0	0.729039602	0.658490421	0
DMU1956	0.47108	0.56588	0.90219	0.33177	0.958654268	0.017773471	0	0	0	0	1.711673586	0.034802149	0.755588143
DMU1957	0.51435	0.57182	0.89956	0.34406	0.958284948	0.048893684	0	0	0	0	1.694599125	0.034454987	0.748050923
DMU1958	0.53934	0.58171	0.91828	0.35023	0.946712067	0.062128205	0	0.008381174	0	0	1.71906964	0	0.768781642
DMU1959	0.66793	0.6015	0.9439	0.36417	0.925928438	0.157184022	0	0.016978077	0	0	1.662510391	0	0.743487896
DMU1960	0.59275	0.63118	0.95737	0.36321	0.88348449	0.044398897	0	0	0	0	0.756774183	0.545598119	0.091401732
DMU1961	0.61073	0.6292	0.96788	0.38757	0.90179692	0.067996907	0	0.02247245	0	0	1.589319771	0	0.710756467
DMU1962	0.60935	0.64503	0.9889	0.45575	0.926935586	0.019466965	0	0.085655112	0	0	1.550315489	0	0.693313441
DMU1963	0.60695	0.6569	1.01221	0.5733	0.994037426	0	0	0.194329435	0	0.073152604	1.454711565	0	0.71772822
DMU1964	0.6033	0.70241	1.03882	0.61642	0.972749609	0	0	0.138444954	0	0.246460591	1.211984917	0	0.780730805
DMU1965	0.72611	0.70043	1.08742	0.64746	0.976888645	0	0	0.282314933	0	0.068236794	1.356955844	0	0.669497326
DMU1966	0.72856	0.82904	1.15869	0.71868	0.888750213	0	0	0.134924969	0	0.208098593	1.023337462	0	0.659208765
DMU1967	0.80502	0.91412	1.25952	0.76919	0.838864623	0	0	0.144472229	0	1.188608305	0.047200086	0	0.89300945
DMU1968	0.82302	0.93786	1.29992	0.82834	0.872051475	0	0	0.196964347	0	1.162435512	0.046160754	0	0.873345654
DMU1969	0.8358	0.93786	1.23916	0.84138	0.870507705	0	0	0.14971384	0	1.145419249	0.045485032	0	0.86056122
DMU1970	0.86942	0.93588	1.20073	0.85342	0.858538896	0	0	0.131486546	0	0.182759669	0.898731769	0	0.578940849
DMU1971	0.87512	0.93192	1.2142	0.87574	0.873660075	0	0	0.162995622	0	0.183220882	0.900999809	0	0.580401865
DMU1972	0.8717	0.91016	1.22011	0.87014	0.888383938	0	0	0.205039641	0	0.187004425	0.919605611	0	0.592387264
DMU1973	0.87797	0.91214	1.18431	0.85702	0.877983716	0	0	0.169505241	0	0.186446328	0.916861137	0	0.590619341
DMU1974	0.90219	0.94775	1.17807	0.87735	0.858099602	0	0	0.124354701	0	0.179765322	0.884006884	0	0.569455441
DMU1975	0.91388	0.97941	1.23554	0.89577	0.843217309	0	0	0.131729576	0	0.17451434	0.858184861	0	0.552821531
DMU1976	0.88139	0.97545	1.32488	0.87385	0.85247654	0	0	0.200221647	0	1.08680828	0.043157568	0	0.816526404
DMU1977	0.8888	1.21091	1.38498	0.9037	0.862593611	0	0.03373714	0.095274789	0	1.125112511	0	0	0.809496398
DMU1978	0.92869	1.29005	1.35739	1.00718	0.905711306	0	0.074691498	0.093609505	0	1.07678558	0	0	0.774726118
DMU1979	0.94038	1.25246	1.31075	1.05187	0.928644391	0	0.033551246	0.065709223	0	1.063399902	0	0	0.765095385
DMU1980	0.93696	1.24652	1.29203	1.09484	0.965030188	0	0.038951901	0.080224018	0	1.067281421	0	0	0.767888062
DMU1981	0.94693	1.22476	1.27298	1.07391	0.938966935	0	0.002806214	0.036023262	0	1.056044269	0	0	0.759803152
DMU1982	0.97799	1.24652	1.25919	1.0992	0.928176988	0	0	0.011370139	0	0.973245689	0.038647955	0	0.731206062
DMU1983	0.97799	1.23267	1.2674	1.17547	0.984473038	0	0	0.068233675	0	0.973766921	0.038668653	0	0.731597667
DMU1984	1.01618	1.29994	1.27233	1.20934	0.970866569	0	0.006323365	0.028369143	0	0.984077624	0	0	0.708024561
DMU1985	1.10794	1.32567	1.25985	1.26382	0.928302949	0	0	0.014193462	0	0.861636025	0.034215893	0	0.647352967
DMU1986	1.10965	1.37513	1.25656	1.29659	0.947302482	0	0.022932825	0	0	0.863423778	0	0.033346442	0.632944408
DMU1987	1.11506	1.39887	1.2697	1.38792	1	0	0	0	0	0.859034716	0	0.033176931	0.629726947

DMU1988	1.14869	1.3969	1.26543	1.38235	0.968661553	0	0	0.000479146	0	0.83045344	0.03297762	0	0.62392528
DMU1989	1.16778	1.33952	1.23949	1.33017	0.92321602	0	0	0.014116092	0	0.819019033	0.032523556	0	0.615334533
DMU1990	1.16778	1.30786	1.21551	1.33254	0.925627478	0	0	0.022838576	0	0.819863243	0.03255708	0	0.615968794
DMU1991	1.23975	1.32764	1.19613	1.38093	0.901651135	0	0	0.012983281	0	0.773711699	0.030724384	0	0.581294827
DMU1992	1.28242	1.33358	1.17577	1.426	0.898038118	0	0	0.011114381	0	0.748852215	0.029737205	0	0.562617729
DMU1993	1.29943	1.31775	1.11206	1.44687	0.899381873	0	0.021348749	0	0	0.744946063	0	0.028770693	0.546092726
DMU1994	1.29088	1.29401	1.02798	1.49905	0.936103779	0	0.060375867	0	0	0.75155094	0	0.029025781	0.55093452
DMU1995	1.2949	1.22674	0.98068	1.52894	0.952469916	0	0.02839384	0	0	0.50132483	0	0.357746133	0.380023501
DMU1996	1.2678	1.1931	0.96689	1.54507	0.980198175	0	0.011533652	0	0	0.766199901	0	0.029591542	0.561673138
DMU1997	1.28518	1.1931	0.96229	1.57231	0.982547747	0	0.004008904	0	0	0.75623243	0	0.029206586	0.554366349
DMU1998	1.27749	1.17133	0.9393	1.59209	1	0	0	0	0	0.513406097	0	0.366367343	0.389181567
DMU1999	1.3265	1.23267	0.88971	1.5272	0.967976103	0	0.054185815	0	0	0.509840337	0	0.363822811	0.386478583
DMU2000	1.33733	1.24059	0.83618	1.48429	0.964855774	0	0.079360385	0	0	0.517055256	0	0.368971388	0.391947769
DMU2001	1.3758	1.24059	0.80629	1.43637	0.937762658	0	0.069601063	0	0	0.512513077	0	0.365730083	0.388504623
DMU2002	1.41285	1.18519	0.76589	1.38989	0.915846397	0	0.014822152	0	0	0.51036286	0	0.364195685	0.386874676
DMU2003	1.40458	1.18519	0.72878	1.51093	0.989311418	0.01251263	0.052919219	0	0	0	0	1.372156206	3.690918027
DMU2004	1.40316	1.10604	0.66375	1.48965	1	0	0	0	0	0.444954074	0.130815918	0.347978311	0.47353589
DMU2005	1.41256	1.09615	0.59051	1.44193	1	0	0	0	0	0.545271493	0	0.389106536	0.413336762
DMU2006	1.41399	1.02096	0.56227	1.40175	1	0	0	0	0	0.492144817	0.104589002	0.350954102	0.424868686
DMU2007	1.53937	0.99128	0.54125	1.23392	0.956122041	0.050425819	0	0	0	0	0.997720386	0.020285885	0.440426084
DMU2008	1.54877	0.95171	0.51629	1.21909	0.989142504	0.104901516	0	0	0	0	1.039277055	0.021130825	0.458770543
DMU2009	1.56245	0.94973	0.49461	1.19414	0.980162154	0.069700406	0	0	0	0	1.041898352	0.021184122	0.459927668
DMU2010	1.57328	0.97743	0.49034	1.23683	0.975977219	0.044822472	0.004088443	0	0	0	0	2.039401232	1.035149842
DMU2011	1.50574	0.93588	0.4621	1.2044	1	0	0	0	0	0.238080213	0.471550236	0.433236668	0.312505455
DMU2012	1.39917	0.95171	0.42367	1.09382	1	0	0	0	0	0.51915499	0	0.645818473	0.315670176
DMU2013	1.38663	0.94973	0.40955	1.00539	1	0	0	0	0	0.490133464	0	0.782239617	0.194407973

Table A49: Lambdas - Efficiency Porto.

DMU Name	DMU1950	DMU1951	DMU1953	DMU1987	DMU1998	DMU2004	DMU2005	DMU2006	DMU2011	DMU2012	DMU2013
DMU1950	1	0	0	0	0	0	0	0	0	0	0
DMU1951	0	1	0	0	0	0	0	0	0	0	0
DMU1952	0	0.535623482	0.454542265	0	0	0	0	0	0	0	0.009834252
DMU1953	0	0	1	0	0	0	0	0	0	0	0
DMU1954	0	0	0.964742547	0	0	0	0	0	0	0	0.035257453
DMU1955	0	0	0.970809152	0	0	0	0	0	0	0	0.029190848
DMU1956	0	0	0.973643849	0	0	0	0	0.017900315	0.008455836	0	0
DMU1957	0	0	0.963176989	0	0	0	0	0.032448485	0.004374526	0	0
DMU1958	0	0	0.958340548	0	0	0	0	0.041659452	0	0	0
DMU1959	0	0	0.945635828	0	0	0	0	0.054364172	0	0	0
DMU1960	0	0	0.932828329	0	0	0	0	0	0.058345766	0	0.008825905
DMU1961	0	0	0.924309397	0	0	0	0	0.075690603	0	0	0

DMU1962	0	0	0.862171104	0	0	0	0	0.137828896	0	0	0
DMU1963	0.686224371	0	0.07475476	0	0	0	0	0.239020869	0	0	0
DMU1964	0.750861816	0	0	0	0.164993817	0	0	0.084144366	0	0	0
DMU1965	0.16567212	0	0.523211601	0	0	0	0	0.311116279	0	0	0
DMU1966	0.678502673	0	0	0	0.288734436	0	0	0.032762891	0	0	0
DMU1967	0.642328623	0	0	0.009595223	0.348076154	0	0	0	0	0	0
DMU1968	0.585483383	0	0	0.075727347	0.33878927	0	0	0	0	0	0
DMU1969	0.579123877	0	0	0.051668447	0.369207676	0	0	0	0	0	0
DMU1970	0.572893056	0	0	0	0.393101627	0	0	0.034005317	0	0	0
DMU1971	0.554459033	0	0	0	0.405021138	0	0	0.040519829	0	0	0
DMU1972	0.551309972	0	0	0	0.357604263	0	0	0.091085765	0	0	0
DMU1973	0.558314474	0	0	0	0.328703389	0	0	0.112982137	0	0	0
DMU1974	0.548644667	0	0	0	0.380252512	0	0	0.071102821	0	0	0
DMU1975	0.543438324	0	0	0	0.447274184	0	0	0.009287492	0	0	0
DMU1976	0.554180885	0	0	0.048773262	0.397045854	0	0	0	0	0	0
DMU1977	0.450898594	0	0	0.549101406	0	0	0	0	0	0	0
DMU1978	0.354539529	0	0	0.645460471	0	0	0	0	0	0	0
DMU1979	0.312924853	0	0	0.687075147	0	0	0	0	0	0	0
DMU1980	0.272911817	0	0	0.727088183	0	0	0	0	0	0	0
DMU1981	0.292401527	0	0	0.707598473	0	0	0	0	0	0	0
DMU1982	0.27394573	0	0	0.699261309	0.026792962	0	0	0	0	0	0
DMU1983	0.205154244	0	0	0.756323236	0.03852252	0	0	0	0	0	0
DMU1984	0.166291089	0	0	0.833708911	0	0	0	0	0	0	0
DMU1985	0.148991355	0	0	0.675165888	0.175842757	0	0	0	0	0	0
DMU1986	0.107373701	0	0	0.775181929	0.117444371	0	0	0	0	0	0
DMU1987	0	0	0	1	0	0	0	0	0	0	0
DMU1988	0.025250998	0	0	0.869214171	0.105534831	0	0	0	0	0	0
DMU1989	0.110115474	0	0	0.593548105	0.296336422	0	0	0	0	0	0
DMU1990	0.121504904	0	0	0.510644207	0.367850889	0	0	0	0	0	0
DMU1991	0.1018667	0	0	0.396567699	0.501565601	0	0	0	0	0	0
DMU1992	0.077193006	0	0	0.330273472	0.592533522	0	0	0	0	0	0
DMU1993	0.08231332	0	0	0.196002428	0.721684253	0	0	0	0	0	0
DMU1994	0.060299953	0	0	0.078231076	0.861468971	0	0	0	0	0	0
DMU1995	0.048419412	0	0	0	0.943145572	0	0.008435016	0	0	0	0
DMU1996	0.03197613	0	0	0.030133066	0.937890804	0	0	0	0	0	0
DMU1997	0.012201761	0	0	0.02049907	0.967299169	0	0	0	0	0	0
DMU1998	0	0	0	0	1	0	0	0	0	0	0
DMU1999	0.024866117	0	0	0	0.754639997	0	0.220493887	0	0	0	0
DMU2000	0.040353899	0	0	0	0.585212879	0	0.374433222	0	0	0	0
DMU2001	0.061105479	0	0	0	0.42195978	0	0.516934742	0	0	0	0
DMU2002	0.079347497	0	0	0	0.249446162	0	0.671206341	0	0	0	0
DMU2003	0	0	0	0	0.207731355	0.792268645	0	0	0	0	0
DMU2004	0	0	0	0	0	1	0	0	0	0	0

DMU2005	0	0	0	0	0	0	1	0	0	0	0
DMU2006	0	0	0	0	0	0	0	1	0	0	0
DMU2007	0	0	0.046531323	0	0	0	0	0.361756306	0.591712371	0	0
DMU2008	0	0	0.047349497	0	0	0	0	0.29034135	0.662309153	0	0
DMU2009	0	0	0.03212699	0	0	0	0	0.094504363	0.873368646	0	0
DMU2010	0	0	0	0	0	0	0	0.164327337	0.835672663	0	0
DMU2011	0	0	0	0	0	0	0	0	1	0	0
DMU2012	0	0	0	0	0	0	0	0	0	1	0
DMU2013	0	0	0	0	0	0	0	0	0	0	1

MIXED PERFORMANCE

Table A50: DEA modelling results - Mixed Performance Porto.

			Variables			Theta			Slacks					Weights		
DMU Name	net length	vehicles	staff	seatkm	paxkm	Objective Value	net length	vehicles	staff	seatkm	paxkm	net length	vehicles	staff	seatkm	paxkm
DMU1950	0.34241	0.53818	0.89201	0.57219	0.31402	1	0	0	0	0	0	0.94548806	0	0.758125395	0.324262359	0.573035464
DMU1951	0.34563	0.54807	0.88741	0.58315	0.29187	1	0	0	0	0	0	0.702477968	0	0.85327249	0.418040614	0.281932259
DMU1952	0.38367	0.54412	0.8769	0.59332	0.30132	1	0	0	0	0	0	0.421180061	0.34808286	0.740115179	0.502694612	0.185793385
DMU1953	0.4065	0.53027	0.87395	0.59143	0.30452	1	0	0	0	0	0	0.369253667	0.515260456	0.659844639	0.515311873	0.235961826
DMU1954	0.45654	0.55797	0.87789	0.59694	0.30755	0.978055633	0	0	0	0	0.029252451	0.115765305	0.574649766	0.713655672	0.46790037	0
DMU1955	0.46842	0.5639	0.89431	0.62596	0.31615	0.982416792	0.023458374	0	0	0	0.021394032	0	0.88767949	0.558461311	0.684614126	0
DMU1956	0.47108	0.56588	0.90219	0.63778	0.33177	0.984446434	0.035417303	0	0	0	0.003403743	0	0.88224637	0.5550432	0.680423885	0
DMU1957	0.51435	0.57182	0.89956	0.66416	0.34406	0.999084329	0.076994571	0	0.00083891	0	0.005729089	0	1.748802071	0	0.986485015	0
DMU1958	0.53934	0.58171	0.91828	0.67002	0.35023	0.987780818	0.093417117	0	0.007232491	0	0.00320651	0	1.71906964	0	0.969713193	0
DMU1959	0.66793	0.6015	0.9439	0.59316	0.36417	0.925928438	0.157184022	0	0.016978077	0.015179976	0	0	1.662510391	0	0	0.743487896
DMU1960	0.59275	0.63118	0.95737	0.56155	0.36321	0.88348449	0.044398897	0	0	0.037917351	0	0	0.756774183	0.545598119	0	0.091401732
DMU1961	0.61073	0.6292	0.96788	0.60474	0.38757	0.90179692	0.067996907	0	0.02247245	0.010233562	0	0	1.589319771	0	0	0.710756467
DMU1962	0.60935	0.64503	0.9889	0.6253	0.45575	0.926935586	0.019466965	0	0.085655112	0.009001678	0	0	1.550315489	0	0	0.693313441
DMU1963	0.60695	0.6569	1.01221	0.70336	0.5733	1	0	0	0	0	0	0.197609213	1.339718508	0	0.127340662	0.750631163
DMU1964	0.6033	0.70241	1.03882	0.74956	0.61642	0.990225973	0	0	0.063202762	0	0	0.237041299	1.220075147	0	0.425199931	0.585393211
DMU1965	0.72611	0.70043	1.08742	0.77845	0.64746	1	0	0	0	0	0	0.157774793	1.264135096	0	0.44180817	0.548177853
DMU1966	0.72856	0.82904	1.15869	0.82042	0.71868	0.912199928	0	0	0.089587387	0	0	0.200171693	1.030303618	0	0.359063971	0.494340651
DMU1967	0.80502	0.91412	1.25952	0.80525	0.76919	0.844744357	0	0	0.138840508	0	0	0.181485352	0.934123159	0	0.325544786	0.448193176
DMU1968	0.82302	0.93786	1.29992	0.84314	0.82834	0.872051475	0	0	0.196964347	0.003191012	0	1.162435512	0.046160754	0	0	0.873345654
DMU1969	0.8358	0.93786	1.23916	0.84449	0.84138	0.870848451	0	0	0.148534487	0	0	1.032678246	0.145957309	0	0.063174453	0.799255508
DMU1970	0.86942	0.93588	1.20073	0.80673	0.85342	0.858538896	0	0	0.131486546	0.004093045	0	0.182759669	0.898731769	0	0	0.578940849
DMU1971	0.87512	0.93192	1.2142	0.75454	0.87574	0.873660075	0	0	0.162995622	0.065329922	0	0.183220882	0.900999809	0	0	0.580401865
DMU1972	0.8717	0.91016	1.22011	0.76532	0.87014	0.888383938	0	0	0.205039641	0.043821632	0	0.187004425	0.919605611	0	0	0.592387264
DMU1973	0.87797	0.91214	1.18431	0.78591	0.85702	0.877983716	0	0	0.169505241	0.013745206	0	0.186446328	0.916861137	0	0	0.590619341
DMU1974	0.90219	0.94775	1.17807	0.84931	0.87735	0.865130234	0	0	0.061703647	0	0	0.172999799	0.890447176	0	0.310323572	0.427237398
DMU1975	0.91388	0.97941	1.23554	0.9503	0.89577	0.877817221	0	0	0.081299697	0	0	0.167926093	0.864332305	0	0.301222459	0.414707458
DMU1976	0.88139	0.97545	1.32488	0.98888	0.87385	0.88823434	0	0	0.161457652	0	0	0.16943041	0.872075176	0	0.303920874	0.418422495
DMU1977	0.8888	1.21091	1.38498	1.07192	0.9037	0.862593611	0	0.03373714	0.095274789	0.066997561	0	1.125112511	0	0	0	0.809496398
DMU1978	0.92869	1.29005	1.35739	1.353	1.00718	0.912996751	0	0.082345155	0.072455226	0	0	1.07678558	0	0	0.063556039	0.713643906
DMU1979	0.94038	1.25246	1.31075	1.64105	1.05187	0.951682027	0	0.02412417	0.007505853	0	0	1.063399902	0	0	0.066277045	0.700308171

Appendix

DMU1980	0.93696	1.24652	1.29203	1.86117	1.09484	1	0	0	0	0	0	1.067281421	0	0	0.066518963	0.702864367
DMU1981	0.94693	1.22476	1.27298	1.64125	1.07391	0.963605889	0	0	0	0	0	0.821529276	0.029385849	0.146175644	0.088523547	0.580957843
DMU1982	0.97799	1.24652	1.25919	1.65165	1.0992	0.957783496	0	0.017683232	0	0	0	0.50310603	0	0.403408011	0.17254406	0.304919343
DMU1983	0.97799	1.23267	1.2674	1.66752	1.17547	1	0	0	0	0	0	1.022505343	0	0	0.06035221	0.677669464
DMU1984	1.01618	1.29994	1.27233	1.55369	1.20934	0.977896427	0	0.013619423	0.004537094	0	0	0.984077624	0	0	0.058084058	0.652201341
DMU1985	1.10794	1.32567	1.25985	1.57313	1.26382	0.942417566	0	0.005300106	0	0	0	0.722293019	0	0.158544805	0.080862415	0.497720821
DMU1986	1.10965	1.37513	1.25656	1.51804	1.29659	0.95359277	0	0.031532382	0	0	0	0.721778024	0	0.158431763	0.08080476	0.497365946
DMU1987	1.11506	1.39887	1.2697	1.60429	1.38792	1	0	0	0	0	0	0.896812728	0	0	0	0.645239179
DMU1988	1.14869	1.3969	1.26543	1.45785	1.38235	0.968661553	0	0	0.000479146	0.072505735	0	0.83045344	0.03297762	0	0	0.62392528
DMU1989	1.16778	1.33952	1.23949	1.45188	1.33017	0.92864449	0	0	0	0	0	0.696263389	0.024905127	0.123886941	0.075025573	0.492374025
DMU1990	1.16778	1.30786	1.21551	1.39548	1.33254	0.929402105	0	0	0.002649387	0	0	0.739299864	0.104491616	0	0.045226928	0.572191281
DMU1991	1.23975	1.32764	1.19613	1.32016	1.38093	0.903730897	0	0	0.001129242	0	0	0.700576045	0.099018445	0	0.042857985	0.542220449
DMU1992	1.28242	1.33358	1.17577	1.2763	1.426	0.898889303	0	0	0.006084068	0	0	0.679852938	0.09608947	0	0.041590242	0.526181516
DMU1993	1.29943	1.31775	1.11206	1.20691	1.44687	0.900465907	0	0.02313021	0	0	0	0.647865833	0	0.142207885	0.072530115	0.446434212
DMU1994	1.29088	1.29401	1.02798	1.14427	1.49905	0.936103779	0	0.060375867	0	0.007004864	0	0.75155094	0	0.029025781	0	0.55093452
DMU1995	1.2949	1.22674	0.98068	1.14853	1.52894	0.956950057	0	0.023933252	0	0	0	0.480481976	0	0.385267253	0.164784967	0.291207498
DMU1996	1.2678	1.1931	0.96689	1.14327	1.54507	0.980198175	0	0.011533652	0	0.00257141	0	0.766199901	0	0.029591542	0	0.561673138
DMU1997	1.28518	1.1931	0.96229	1.14475	1.57231	0.982547747	0	0.004008904	0	0.008160313	0	0.75623243	0	0.029206586	0	0.554366349
DMU1998	1.27749	1.17133	0.9393	1.15067	1.59209	1	0	0	0	0	0	0.755284751	0.029992643	0	0	0.567450537
DMU1999	1.3265	1.23267	0.88971	1.14862	1.5272	0.975882756	0	0.047090071	0	0	0	0.467162082	0	0.427453326	0.225127039	0.3383808
DMU2000	1.33733	1.24059	0.83618	1.1355	1.48429	0.976246642	0	0.068950161	0	0	0	0.498055499	0	0.399358319	0.170811941	0.301858348
DMU2001	1.3758	1.24059	0.80629	1.11299	1.43637	0.951066701	0	0.057189482	0	0	0	0.494483659	0	0.396494292	0.169586951	0.29969355
DMU2002	1.41285	1.18519	0.76589	1.09371	1.38989	0.931825254	0	0	0	0	0	0.430147674	0.101780467	0.354667989	0.18637319	0.293899298
DMU2003	1.40458	1.18519	0.72878	1.05547	1.51093	0.989311418	0.01251263	0.052919219	0	0.009286388	0	0	0	1.372156206	0	3.690918027
DMU2004	1.40316	1.10604	0.66375	1.04223	1.48965	1	0	0	0	0	0	0.501275685	0	0.446900202	0	0.587153801
DMU2005	1.41256	1.09615	0.59051	0.9944	1.44193	1	0	0	0	0	0	0.545271493	0	0.389106536	0	0.413336762
DMU2006	1.41399	1.02096	0.56227	0.90248	1.40175	1	0	0	0	0	0	0.492144817	0.104589002	0.350954102	0	0.424868686
DMU2007	1.53937	0.99128	0.54125	0.82973	1.23392	0.964341278	0	0	0	0	0	0.165744319	0.431602614	0.585716635	0.396749297	0.066352361
DMU2008	1.54877	0.95171	0.51629	0.84612	1.21909	1	0	0	0	0	0	0.19370271	0.372308541	0.669525445	0.502046856	0.011850074
DMU2009	1.56245	0.94973	0.49461	0.78666	1.19414	0.991156973	0.028057175	0	0	0	0.01256413	0	0.742345695	0.596372947	0.390888614	0
DMU2010	1.57328	0.97743	0.49034	0.74499	1.23683	0.975977219	0.044822472	0.004088443	0	0.016177753	0	0	0	2.039401232	0	1.035149842
DMU2011	1.50574	0.93588	0.4621	0.73338	1.2044	1	0	0	0	0	0	0.177597451	0	1.585337403	0	0.722111383
DMU2012	1.39917	0.95171	0.42367	0.66784	1.09382	1	0	0	0	0	0	0.51915499	0	0.645818473	0	0.315670176
DMU2013	1.38663	0.94973	0.40955	0.56369	1.00539	1	0	0	0	0	0	0.490133464	0	0.782239617	0	0.194407973

Table A51: Lambdas - Mixed Performance Porto.

DMU Name	DMU1950	**DMU1951**	**DMU1952**	**DMU1953**	**DMU1963**	**DMU1965**	**DMU1980**	**DMU1983**	**DMU1987**	**DMU1998**	**DMU2004**	**DMU2005**	**DMU2006**	**DMU2008**	**DMU2011**	**DMU2012**	**DMU2013**
DMU1950	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1951	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1952	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1953	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1954	0	0	0	0.962742237	0	0	0	0	0	0	0	0	0	0.00922014	0.015553369	0.012484254	0
DMU1955	0	0	0	0.960612288	0	0	0.02413511	0	0	0	0	0	0	0.015252602	0	0	0
DMU1956	0	0	0	0.961588691	0	0	0.03602485	0	0	0	0	0	0	0.002386459	0	0	0
DMU1957	0	0	0	0.942720557	0	0	0.057279443	0	0	0	0	0	0	0	0	0	0
DMU1958	0	0	0	0.938105439	0	0	0.061894561	0	0	0	0	0	0	0	0	0	0
DMU1959	0	0	0	0.945635828	0	0	0	0	0	0	0	0	0.054364172	0	0	0	0
DMU1960	0	0	0	0.932828329	0	0	0	0	0	0	0	0	0	0	0.058345766	0	0.008825905
DMU1961	0	0	0	0.924309397	0	0	0	0	0	0	0	0	0.075690603	0	0	0	0
DMU1962	0	0	0	0.862171104	0	0	0	0	0	0	0	0	0.137828896	0	0	0	0
DMU1963	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DMU1964	0.398762584	0	0	0	0.439468265	0	0.036797648	0	0	0.124971503	0	0	0	0	0	0	0
DMU1965	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
DMU1966	0.396056527	0	0	0	0.328871279	0	0.06469837	0	0	0.210373825	0	0	0	0	0	0	0

DMU1967	0.590811554	0	0	0	0.052824576	0	0.028123334	0	0	0.328240537	0	0	0	0	0	0	0
DMU1968	0.585483383	0	0	0	0	0	0	0	0.075727347	0.33878927	0	0	0	0	0	0	0
DMU1969	0.575314601	0	0	0	0	0	0	0.018656729	0.037443808	0.368584863	0	0	0	0	0	0	0
DMU1970	0.572893056	0	0	0	0	0	0	0	0	0.393101627	0	0	0.034005317	0	0	0	0
DMU1971	0.554459033	0	0	0	0	0	0	0	0	0.405021138	0	0	0.040519829	0	0	0	0
DMU1972	0.551309972	0	0	0	0	0	0	0	0	0.357604263	0	0	0.091085765	0	0	0	0
DMU1973	0.558314474	0	0	0	0	0	0	0	0	0.328703389	0	0	0.112982137	0	0	0	0
DMU1974	0.28021021	0	0	0	0.340938518	0	0.018636468	0	0	0.360214803	0	0	0	0	0	0	0
DMU1975	0.164315914	0	0	0	0.420484299	0	0.11649585	0	0	0.298703938	0	0	0	0	0	0	0
DMU1976	0.209184445	0	0	0	0.359973517	0	0.169231206	0	0	0.261610832	0	0	0	0	0	0	0
DMU1977	0.450898594	0	0	0	0	0	0	0	0.549101406	0	0	0	0	0	0	0	0
DMU1978	0.269736111	0	0	0	0	0	0	0.428667406	0.301596483	0	0	0	0	0	0	0	0
DMU1979	0.102178409	0	0	0	0	0	0.441255236	0.456566355	0	0	0	0	0	0	0	0	0
DMU1980	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
DMU1981	0.106580913	0	0	0	0	0	0.632976636	0.11455994	0.095442709	0.050439802	0	0	0	0	0	0	0
DMU1982	0.083407868	0	0	0	0	0	0.774633448	0	0	0.134617022	0	0.007341662	0	0	0	0	0
DMU1983	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
DMU1984	0.076753852	0	0	0	0	0	0	0.452596086	0.470650062	0	0	0	0	0	0	0	0
DMU1985	0.038030234	0	0	0	0	0	0.448649256	0	0.277091913	0.236228597	0	0	0	0	0	0	0
DMU1986	0.06225393	0	0	0	0	0	0.19371303	0	0.585841775	0.158191265	0	0	0	0	0	0	0
DMU1987	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
DMU1988	0.025250998	0	0	0	0	0	0	0	0.869214171	0.105534831	0	0	0	0	0	0	0
DMU1989	0.052854291	0	0	0	0	0	0.13187882	0.11757052	0.390897503	0.306798866	0	0	0	0	0	0	0
DMU1990	0.062556023	0	0	0	0	0	0	0.288736159	0.290472476	0.358235343	0	0	0	0	0	0	0
DMU1991	0.067508229	0	0	0	0	0	0	0.168578752	0.267651851	0.496261169	0	0	0	0	0	0	0
DMU1992	0.062680077	0	0	0	0	0	0	0.071284633	0.275661806	0.590373485	0	0	0	0	0	0	0
DMU1993	0.073477408	0	0	0	0	0	0.038692828	0	0.157078516	0.730751248	0	0	0	0	0	0	0
DMU1994	0.060299953	0	0	0	0	0	0	0	0.078231076	0.861468971	0	0	0	0	0	0	0
DMU1995	0.033915083	0	0	0	0	0	0.031017672	0	0	0.905894281	0	0.029172963	0	0	0	0	0
DMU1996	0.03197613	0	0	0	0	0	0	0	0.030133066	0.937890804	0	0	0	0	0	0	0
DMU1997	0.012201761	0	0	0	0	0	0	0	0.02049907	0.967299169	0	0	0	0	0	0	0
DMU1998	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
DMU1999	0	0	0	0	0	0	0.053353864	0	0	0.684720174	0.020348101	0.241577861	0	0	0	0	0
DMU2000	0.004151128	0	0	0	0	0	0.076463929	0	0	0.49002373	0	0.429361214	0	0	0	0	0
DMU2001	0.018277595	0	0	0	0	0	0.090098062	0	0	0.308521699	0	0.583102644	0	0	0	0	0
DMU2002	0.028749818	0	0	0	0	0	0.107456599	0	0	0.101185897	0.052184484	0.710423202	0	0	0	0	0
DMU2003	0	0	0	0	0	0	0	0	0	0.207731355	0.792268645	0	0	0	0	0	0
DMU2004	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
DMU2005	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
DMU2006	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
DMU2007	0	0	0	0.020113633	0	0	0	0	0	0	0	0	0.218428859	0.572835918	0.153334571	0.035287018	0
DMU2008	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DMU2009	0	0	0	0.005262455	0	0	0	0	0	0	0	0	0	0.479217718	0.515519826	0	0
DMU2010	0	0	0	0	0	0	0	0	0	0	0	0	0.164327337	0	0.835672663	0	0
DMU2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DMU2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
DMU2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Dresden

EFFECTIVENESS

Table A52: DEA modelling results - Effectiveness Dresden.

DMU Name	Variables				Theta	Slacks				Weights			
	net length	vehicles	staff	paxkm	Objective Value	net length	vehicles	staff	paxkm	net length	vehicles	staff	paxkm
DMU1957	0.85803	0.80999	1.66176	1.53717	1	0	0	0	0	0.340206	0.516885	0.174166	0.26043
DMU1958	0.87855	0.82321	1.60577	1.55277	1	0	0	0	0	0.338829	0.514793	0.173461	0.259376
DMU1959	0.8993	0.83974	1.73217	1.56623	0.99344	0	0	0.072736	0	0.590288	0.55869	0	1.184519
DMU1960	0.92029	0.83809	1.67089	1.58145	1	0	0	2E-12	0	0	1.140725	0.026315	0.729328
DMU1961	0.99214	0.84635	1.44697	1.58629	1	0	0	0	0	0.201267	0.652872	0.171224	0.321569
DMU1962	0.86309	0.85627	1.56217	1.56152	1	0	0	0	0	0.346462	0.481866	0.184593	0.288678
DMU1963	0.9011	0.88272	1.38156	1.50586	0.998168	0	0	0	0	0.336906	0.396059	0.251024	0.42918
DMU1964	0.88165	0.90256	1.40041	1.50605	0.998086	0	0.014802	0	0	0.527519	0	0.381969	0.971879
DMU1965	0.93761	0.86454	1.35975	1.48535	0.989736	0	0	0	0	0.337032	0.396207	0.251119	0.429341
DMU1966	0.94544	0.83148	1.2746	1.43509	1	0	0	0	0	0.349497	0.531001	0.178922	0.267543
DMU1967	0.96711	0.81991	1.23807	1.40014	1	0	0	0	0	0.110167	0.577866	0.338962	0.477278
DMU1968	0.976	0.80007	1.1977	1.3495	1	0	0	0	0	0.343728	0.571201	0.173266	0.242566
DMU1969	0.84656	0.87611	1.15233	1.31273	1	0	0	0	0	0.361326	0.548973	0.184978	0.276598
DMU1970	0.88145	0.94884	1.12169	1.27312	0.957714	0	0	0	0	0.545185	0.337141	0.177905	0.105909
DMU1971	0.87326	0.94388	1.10489	1.24085	0.963086	0	0	0	0	0.550206	0.340246	0.179544	0.106884
DMU1972	0.80758	0.94388	1.08633	1.21694	1	0	0	0	2.12E-10	0.74331	0.330167	0.08108	0.124753
DMU1973	0.81991	0.96703	1.08397	1.35014	1	0	0	0	0	0.379096	0.446422	0.237527	0.380873
DMU1974	0.82688	1.01827	1.08073	1.20166	0.985162	0	0.04906	0	0	0.804161	0	0.310027	0.068946
DMU1975	0.89969	1.11911	1.09782	1.20543	0.92628	0	0.053791	0	0	0.755898	0	0.29142	0.064808
DMU1976	0.90009	1.14721	1.18268	1.18053	0.902236	0	0.085403	0	0.00239	0.849571	0	0.198963	0
DMU1977	0.96461	1.18853	1.15616	1.21019	0.872118	0	0.075373	0	0	0.511222	0	0.438408	0.159053
DMU1978	0.99017	1.26788	1.15645	1.20721	0.860293	0	0.159473	0	0	0.504565	0	0.432699	0.156982
DMU1979	0.99329	1.2811	1.15999	1.19327	0.855448	0	0.152719	0	0	0.503003	0	0.431359	0.156496
DMU1980	1.04247	1.27945	1.13671	1.16567	0.842098	0	0.184872	0	0	0.000251	0	0.879502	0.604224
DMU1981	1.06615	1.30259	1.16382	1.14924	0.817256	0	0.16697	0	0	0.484448	0	0.415447	0.150723
DMU1982	1.09884	1.29929	1.13141	1.13813	0.829316	0.016595	0.194043	0	0	0	0	0.883853	0.607302
DMU1983	1.11517	1.29929	1.15969	1.12426	0.800876	0	0.164178	0	0	0.000246	0	0.862063	0.592243
DMU1984	1.1409	1.35549	1.19859	1.23213	0.83672	0.093079	0.213642	0	0	0	0	0.834314	0.573263
DMU1985	1.15624	1.36871	1.20742	1.30786	0.873697	0.17538	0.24547	0	0	0	0	0.828212	0.569071

DMU1986	1.17328	1.3869	1.19682	1.30694	0.880907	0.198403	0.271724	0	0	0	0	0.835548	0.574111
DMU1987	1.18117	1.39516	1.21833	1.29604	0.859207	0.175877	0.253021	0	0	0	0	0.820796	0.563975
DMU1988	1.18917	1.40839	1.21509	1.29165	0.859015	0.180975	0.265849	0	0	0	0	0.822984	0.565479
DMU1989	1.21629	1.42988	1.17266	1.25697	0.869777	0.205127	0.313363	0	0	0	0	0.852762	0.585939
DMU1990	1.14662	1.40177	1.09841	1.08162	0.818882	0.024323	0.286675	0	0	0	0	0.910407	0.625547
DMU1991	1.07695	1.37367	1.02416	0.90626	0.824139	0	0.183519	0	0	0.511447	0	0.438601	0.159123
DMU1992	1.00728	1.34557	0.94991	0.7309	0.863588	0	0.138491	0	0.01652	0.813179	0	0.19044	0
DMU1993	0.93761	1.31416	0.87507	0.55555	0.929495	0	0.195896	0	0.17959	0.875239	0	0.204974	0
DMU1994	0.93483	1.23151	0.76753	0.56312	0.952817	0	0.123223	0	0.027178	0.897199	0	0.210117	0
DMU1995	0.91225	1.16539	0.69358	0.56892	0.999596	0	0.150772	0	0	0.663551	0	0.569041	0.206446
DMU1996	0.90584	1.14555	0.6706	0.47564	0.999154	0	0.076051	0	0.006487	0.940832	0	0.220335	0
DMU1997	0.90584	1.06951	0.66676	0.47635	1	0	0	0	0	0.744675	0.164805	0.223744	0
DMU1998	0.9365	0.98852	0.65498	0.4544	0.993198	0	0	0	0.051434	0.73961	0.163684	0.222222	0
DMU1999	0.98945	0.93231	0.62581	0.46077	0.970413	0	0	0	0.02529	0.722642	0.159929	0.217124	0
DMU2000	1.01454	0.82156	0.57042	0.46566	0.983387	0	0.009746	0	0.014226	0.662408	0	0.574947	0
DMU2001	1.03126	0.81991	0.56718	0.46863	0.97441	0	0.02199	0	0.011533	0.656361	0	0.569698	0
DMU2002	1.05635	0.78354	0.5442	0.467	0.971131	0	0.045977	0	0.013971	0.654152	0	0.567781	0
DMU2003	1.05077	0.77527	0.52887	0.4687	0.983279	0	0.069065	0	0.012553	0.662335	0	0.574883	0
DMU2004	1.05635	0.75874	0.51296	0.46927	0.988667	0	0.089927	0	0.012414	0.665965	0	0.578034	0
DMU2005	1.05746	0.72734	0.50471	0.47026	0.992667	0	0.077531	0	0.011629	0.668659	0	0.580373	0
DMU2006	1.06527	0.7356	0.49823	0.47585	0.992719	0	0.10525	0	0.008517	0.319924	0	1.323074	0
DMU2007	1.05467	0.62981	0.49529	0.48208	1	0	0	0	0	0.679214	0.390091	0.076663	0
DMU2008	1.06443	0.61328	0.49293	0.48993	1	0	0	0	0	0.664146	0.443603	0.042623	0
DMU2009	1.11432	0.66948	0.49764	0.4939	0.996006	0.028701	0.047419	0	0	0	0	2.009485	1.378111
DMU2010	1.11878	0.63311	0.50177	0.50282	1	0	0	0	0	0	0.002269	1.990082	1.368295
DMU2011	1.11878	0.56864	0.51002	0.51414	1	0	0	0	0	0.51211	0.585996	0.183994	0.19904
DMU2012	1.11878	0.56534	0.51709	0.51096	1	0	0	0	0	0.528748	0.597855	0.136255	0.160163
DMU2013	1.12157	0.58848	0.5165	0.51888	0.993532	0.012679	0	0	0	0	0.016004	1.917874	1.32433

Table A53: Lambdas - Effectiveness Dresden.

DMU Name	DMU1957	DMU1958	DMU1960	DMU1961	DMU1962	DMU1966	DMU1967	DMU1968	DMU1969	DMU1972	DMU1973	DMU1997	DMU2007	DMU2008	DMU2010	DMU2011	DMU2012
DMU1957	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1958	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1959	0.259042839	0	0.552819525	0	0.188137636	0	0	0	0	0	0	0	0	0	0	0	0
DMU1960	0	0	1	3.24108E-11	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1961	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1962	0	0	0	-1.22618E-12	1	0	0	0	0	0	0	0	0	0	0	0	0
DMU1963	0	0	0	0.333642346	0.340312903	0.058799514	0	0	0	0	0.267245238	0	0	0	0	0	0
DMU1964	0	0	0	0.227470786	0.483455264	0	0	0	0	0	0.289073949	0	0	0	0	0	0

DMU1965	0	0	0	0.253189657	0.17452134	0.453548459	0	0	0	0	0.118740544	0	0	0	0	0	0
DMU1966	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
DMU1967	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
DMU1968	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
DMU1969	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
DMU1970	0	0	0	0	0	0	0	0	0.384195261	0.075298816	0.479337774	0	0	0.061168149	0	0	0
DMU1971	0	0	0	0	0	0	0	0	0.295205594	0.292473563	0.343397115	0	0	0.068923728	0	0	0
DMU1972	0	0	0	0	0	0	0	0	2.60038E-10	0.999999998	1.46292E-09	0	0	0	0	0	0
DMU1973	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
DMU1974	0	0	0	0	0	0	0	0	0	0.782596869	0.166775295	0.050627836	0	0	0	0	0
DMU1975	0	0	0	0	0	0	0	0	0	0.030526805	0.808514807	0.160958388	0	0	0	0	0
DMU1976	0	0	0	0	0	0	0	0	0	0.954063876	0	0.045936124	0	0	0	0	0
DMU1977	0	0	0	0	0	0	0	0	0	0	0.839502898	0.109753155	0.050743948	0	0	0	0
DMU1978	0	0	0	0	0	0	0	0	0	0	0.835640794	0.044737803	0.119621403	0	0	0	0
DMU1979	0	0	0	0	0	0	0	0	0	0	0.819840919	0.08396307	0.096196011	0	0	0	0
DMU1980	0	0	0	0	0	0	0	0	0	0	0.78412781	0	0	0.120804938	0.095067253	0	0
DMU1981	0	0	0	0	0	0	0	0	0	0	0.768692756	0.019447443	0.211859801	0	0	0	0
DMU1982	0	0	0	0	0	0	0	0	0	0	0.749787566	0	0	0	0.250212434	0	0
DMU1983	0	0	0	0	0	0	0	0	0	0	0.735089547	0	0	0.109858408	0.155052045	0	0
DMU1984	0	0	0	0	0	0	0	0	0	0	0.860725582	0	0	0	0.139274418	0	0
DMU1985	0	0	0	0	0	0	0	0	0	0	0.950101496	0	0	0	0.049898504	0	0
DMU1986	0	0	0	0	0	0	0	0	0	0	0.94901572	0	0	0	0.05098428	0	0
DMU1987	0	0	0	0	0	0	0	0	0	0	0.936151631	0	0	0	0.063848369	0	0
DMU1988	0	0	0	0	0	0	0	0	0	0	0.93097059	0	0	0	0.06902941	0	0
DMU1989	0	0	0	0	0	0	0	0	0	0	0.890041543	0	0	0	0.109958457	0	0
DMU1990	0	0	0	0	0	0	0	0	0	0	0.683094935	0	0	0	0.316905065	0	0
DMU1991	0	0	0	0	0	0	0	0	0	0	0.490952847	0.348434258	0.160612895	0	0	0	0
DMU1992	0	0	0	0	0	0	0	0	0	0.366019653	0	0.633980347	0	0	0	0	0
DMU1993	0	0	0	0	0	0	0	0	0	0.349437756	0	0.650562244	0	0	0	0	0
DMU1994	0	0	0	0	0	0	0	0	0	0.153860855	0	0.846139145	0	0	0	0	0
DMU1995	0	0	0	0	0	0	0	0	0	0	0.105276011	0.793349781	0.101374208	0	0	0	0
DMU1996	0	0	0	0	0	0	0	0	0	0.007799922	0	0.992200078	0	0	0	0	0
DMU1997	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
DMU1998	0	0	0	0	0	0	0	0	0	0.038352837	0	0.773119614	0.188527549	0	0	0	0
DMU1999	0	0	0	0	0	0	0	0	0	0.010233922	0	0.617925537	0.371840541	0	0	0	0
DMU2000	0	0	0	0	0	0	0	0	0	0	0	0.382885772	0.617114228	0	0	0	0
DMU2001	0	0	0	0	0	0	0	0	0	0	0	0.334610997	0.665389003	0	0	0	0
DMU2002	0	0	0	0	0	0	0	0	0	0	0	0.193616413	0.806383587	0	0	0	0
DMU2003	0	0	0	0	0	0	0	0	0	0	0	0.144261446	0.855738554	0	0	0	0
DMU2004	0	0	0	0	0	0	0	0	0	0	0	0.069147881	0.930852119	0	0	0	0
DMU2005	0	0	0	0	0	0	0	0	0	0	0	0.033353522	0.966646478	0	0	0	0
DMU2006	0	0	0	0	0	0	0	0	0	0	0	0	0.70863311	0.29136689	0	0	0
DMU2007	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
DMU2008	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DMU2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0.69200931	0.30799069	0	0
DMU2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DMU2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
DMU2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DMU2013	0	0	0	0	0	0	0	0	0	0	0.012770815	0	0	0.245204532	0	0.742024652	0

EFFICIENCY

Table A54: DEA modelling results - Efficiency Dresden.

DMU Name	**Variables**				**Theta**	**Slacks**				**Weights**			
	net length	vehicles	staff	seatkm	Objective Value	net length	vehicles	staff	seatkm	net length	vehicles	staff	seatkm
DMU1957	0.85803	0.80999	1.66176	0.73743	1	0	0	0	0	0.601361826	0.597554923	0	0.11780817
DMU1958	0.87855	0.82321	1.60577	0.74491	0.983181434	0	0	0	0.010632775	0.652976274	0.436142158	0.04190582	0
DMU1959	0.8993	0.83974	1.73217	0.75137	0.960719937	0	0	0.060437773	0	0.57679306	0.573141688	0	0.112995092
DMU1960	0.92029	0.83809	1.67089	0.75867	0.950931265	0	0	0.056864068	0	0.570426415	0.566815347	0	0.111747852
DMU1961	0.99214	0.84635	1.44697	0.76099	0.912372852	0	0	0	0.01362661	0.605949019	0.404731264	0.038887769	0
DMU1962	0.86309	0.85627	1.56217	0.74911	0.981031983	0	0	0	0.082893556	0.667287671	0.422596329	0.039825451	0
DMU1963	0.9011	0.88272	1.38156	0.72241	0.953356874	0	0	0	0.12644953	0.633168404	0.422911896	0.040634617	0
DMU1964	0.88165	0.90256	1.40041	0.7225	0.956633357	0	0	0	0.173794865	0.650691982	0.412086203	0.038834978	0
DMU1965	0.93761	0.86454	1.35975	0.71257	0.939691691	0	0	0	0.114289551	0.624092724	0.416849981	0.04005217	0
DMU1966	0.94544	0.83148	1.2746	0.79385	0.951398513	0	0	0	0.025113923	0.631867766	0.422043162	0.040551147	0
DMU1967	0.96711	0.81991	1.23807	0.87025	0.947852781	0	0	0.075269279	0	0.561220898	0.557668106	0	0.10994447
DMU1968	0.976	0.80007	1.1977	0.92433	0.959628206	0	0	0.26024758	0	0.564651087	0.56107658	0	0.110616451
DMU1969	0.84656	0.87611	1.15233	0.92279	1	0	0	0	0	0.668176602	0.43173539	0.048684598	0
DMU1970	0.88145	0.94884	1.12169	0.93905	0.949468255	0	0	0	0.124433601	0.634412473	0.409919048	0.04622448	0
DMU1971	0.87326	0.94388	1.10489	1.04427	0.957130667	0	0	0	0.032329545	0.639532317	0.413227182	0.046597521	0
DMU1972	0.80758	0.94388	1.08633	1.15903	1	0	0	0	0	0.717707765	0.117441826	0.284943408	0.073808756
DMU1973	0.81991	0.96703	1.08397	1.30665	1	0	0	0	0	0.179740324	0.425451499	0.407026715	0.733518674
DMU1974	0.82688	1.01827	1.08073	1.33628	1	0	0	0	0	0.303495539	0.107636868	0.591676196	0.58796707
DMU1975	0.89969	1.11911	1.09782	1.36139	0.977443038	0	0.040538196	0	0	0.34484941	0	0.628283721	0.529227103
DMU1976	0.90009	1.14721	1.18268	1.44513	1	0	0	0	0	0.431742418	0.532939015	0	0.943400193
DMU1977	0.96461	1.18853	1.15616	1.39786	0.941175361	0	0.026662446	0	0	0.325624016	0	0.593256831	0.499722631
DMU1978	0.99017	1.26788	1.15645	1.3857	0.927221988	0	0.091456852	0	0	0.322881142	0	0.58825957	0.495513249
DMU1979	0.99329	1.2811	1.15999	1.33075	0.897221276	0	0.119364376	0	0	0.321886568	0	0.586447548	0.493986915
DMU1980	1.04247	1.27945	1.13671	1.28583	0.87312981	0	0.120725835	0	0	0.32118706	0	0.585173109	0.492913407
DMU1981	1.06615	1.30259	1.16382	1.31203	0.865725771	0	0.105510843	0	0	0.313821742	0	0.57175418	0.481610136
DMU1982	1.09884	1.29929	1.13141	1.2659	0.850544562	0	0.119534457	0	0	0.316439239	0	0.576523017	0.485627108
DMU1983	1.11517	1.29929	1.15969	1.29903	0.848416591	0	0.085372262	0	0	0.309787626	0	0.564404395	0.475419135
DMU1984	1.1409	1.35549	1.19859	1.35174	0.848095681	0	0.081857122	0	0	0.300786247	0	0.548004715	0.461605065
DMU1985	1.15624	1.36871	1.20742	1.34935	0.839060851	0	0.082094976	0	0	0.297969558	0	0.542872968	0.4572824
DMU1986	1.17328	1.3869	1.19682	1.69939	1	0	0	0	0	0.108543336	0.388340002	0.279122613	0.593031681
DMU1987	1.18117	1.39516	1.21833	1.7086	0.997103115	0.003028435	0	0.004841721	0	0	0.716763669	0	0.756241186
DMU1988	1.18917	1.40839	1.21509	1.72497	1	0	0	0	0	0	0.586013526	0.143746068	0.663346037

DMU1989	1.21629	1.42988	1.17266	1.69916	1	0	0	0	0	0.104272537	0.184555629	0.519572556	0.590914061
DMU1990	1.14662	1.40177	1.09841	1.4552	0.946169315	0	0.13961515	0	0	0.317680031	0	0.578783626	0.487531304
DMU1991	1.07695	1.37367	1.02416	1.21124	0.884840916	0	0.272113795	0	0	0.33980379	0	0.619091068	0.521483785
DMU1992	1.00728	1.34557	0.94991	0.96729	0.871556733	0	0.097727893	0	0	0.711955842	0	0.297776757	0.103029387
DMU1993	0.93761	1.31416	0.87507	0.72333	0.929495468	0	0.19589563	0	0.133572388	0.875239414	0	0.204974199	0
DMU1994	0.93483	1.23151	0.76753	0.80114	0.955629776	0	0.11299368	0	0	0.796272968	0	0.333042541	0.115231185
DMU1995	0.91225	1.16539	0.69358	0.81643	1	0	0	0	0	0.6827123	0	0.543838785	0.292899946
DMU1996	0.90584	1.14555	0.6706	0.68819	0.999153912	0	0.076050668	0	0.010052362	0.940831789	0	0.220335419	0
DMU1997	0.90584	1.06951	0.66676	0.69462	1	0	0	0	0	0.734933021	0.05281109	0.416621098	0.171974598
DMU1998	0.9365	0.98852	0.65498	0.66758	0.993198084	0	0	0	0.060989399	0.739609709	0.16368371	0.222221881	0
DMU1999	0.98945	0.93231	0.62581	0.68176	0.970413303	0	0	0	0.049442286	0.722642454	0.159928671	0.217123928	0
DMU2000	1.01454	0.82156	0.57042	0.69367	0.983386668	0	0.009746277	0	0.053774978	0.662407504	0	0.57494669	0
DMU2001	1.03126	0.81991	0.56718	0.70263	0.974409795	0	0.02198988	0	0.048947299	0.656360698	0	0.569698272	0
DMU2002	1.05635	0.78354	0.5442	0.70454	0.971130846	0	0.045976726	0	0.059106435	0.654152004	0	0.567781202	0
DMU2003	1.05077	0.77527	0.52887	0.70857	0.983278519	0	0.069064579	0	0.05930122	0.662334655	0	0.574883459	0
DMU2004	1.05635	0.75874	0.51296	0.73739	0.988667318	0	0.089927117	0	0.036910941	0.66596454	0	0.578034073	0
DMU2005	1.05746	0.72734	0.50471	0.74996	0.992667331	0	0.077531113	0	0.027404939	0.668658942	0	0.58037272	0
DMU2006	1.06527	0.7356	0.49823	0.76001	0.992718973	0	0.105250372	0	0.024006511	0.319923565	0	1.323073728	0
DMU2007	1.05467	0.62981	0.49529	0.78022	1	0	0	0	0	0.658003162	0	0.617867926	0.380962591
DMU2008	1.06443	0.61328	0.49293	0.79325	1	0	0	0	0	0.505103136	0.010344883	0.925098409	0.788124356
DMU2009	1.11432	0.66948	0.49764	0.79792	0.993468748	0.033637042	0.048552843	0	0	0	0	2.009484768	0.628141632
DMU2010	1.11878	0.63311	0.50177	0.82153	1	0	0	0	0	0.316668574	0.02218687	1.258885155	1.017660798
DMU2011	1.11878	0.56864	0.51002	0.83033	1	0	0	0	0	0.4040535	0.119796502	0.94081005	0.881635266
DMU2012	1.11878	0.56534	0.51709	0.8225	1	0	0	0	0	0.577751755	0.571013606	0.059575818	0.18686384
DMU2013	1.12157	0.58848	0.5165	0.81743	0.984491933	0	0	0	0	0.569331326	0.562691383	0.058707532	0.184140398

Table A55: Lambdas - Efficiency Dresden.

DMU Name	DMU1957	DMU1969	DMU1972	DMU1973	DMU1974	DMU1976	DMU1986	DMU1988	DMU1989	DMU1995	DMU1997	DMU2007	DMU2008	DMU2010	DMU2011	DMU2012
DMU1957	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1958	0.879421898	0.087865567	0	0	0	0	0	0	0	0	0	0	0.032712535	0	0	0
DMU1959	0.935935295	0	0.02833372	0	0	0	0	0	0	0	0	0	0.035730985	0	0	0
DMU1960	0.869634973	0	0.038173285	0	0	0	0	0	0	0	0	0	0.092191742	0	0	0
DMU1961	0.634627705	0.129624272	0	0	0	0	0	0	0	0	0	0	0.235748023	0	0	0
DMU1962	0.775372466	0.000547801	0.224079733	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1963	0.372422579	0.589764998	0	0	0	0	0	0	0	0	0	0	0.037812422	0	0	0
DMU1964	0.393201958	0.410435107	0.196362936	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1965	0.422398072	0.441468361	0	0	0	0	0	0	0	0	0	0	0.136133567	0	0	0
DMU1966	0.405259431	0.373131883	0	0	0	0	0	0	0	0	0	0	0.221608686	0	0	0
DMU1967	0.381449952	0	0.268720368	0	0	0	0	0	0	0	0	0	0.349829679	0	0	0
DMU1968	0.145721634	0	0.38059539	0	0	0	0	0	0	0	0	0	0.473682976	0	0	0

DMU1969	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1970	0	0.297569265	0.633403898	0	0	0	0	0	0	0	0	0	0.069026837	0	0	0
DMU1971	0	0.23354516	0.691935329	0	0	0	0	0	0	0	0	0	0.07451951	0	0	0
DMU1972	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1973	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DMU1974	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
DMU1975	0	0	0	0	0.852983909	0	0	0	0.1158439	0	0	0	0.03117219	0	0	0
DMU1976	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
DMU1977	0	0	0	0	0.784939862	0	0	0	0.196889433	0	0	0	0.018170704	0	0	0
DMU1978	0	0	0	0	0.747570997	0	0	0	0.2058665	0	0	0	0.046562502	0	0	0
DMU1979	0	0	0	0	0.801424225	0	0	0	0.112927998	0	0	0	0.085647776	0	0	0
DMU1980	0	0	0	0	0.720649967	0	0	0	0.111761045	0	0	0	0.167588988	0	0	0
DMU1981	0	0	0	0	0.695116038	0	0	0	0.155988054	0	0	0	0.148895908	0	0	0
DMU1982	0	0	0	0	0.636220869	0	0	0	0.140370436	0	0	0	0.223408695	0	0	0
DMU1983	0	0	0	0	0.618074037	0	0	0	0.187819161	0	0	0	0.194106803	0	0	0
DMU1984	0	0	0	0	0.579642787	0	0	0	0.269040608	0	0	0	0.151316605	0	0	0
DMU1985	0	0	0	0	0.570622146	0	0	0	0.271809623	0	0	0	0.15756823	0	0	0
DMU1986	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
DMU1987	0	0	0	0.039132721	0	0	0	0.960867279	0	0	0	0	0	0	0	0
DMU1988	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
DMU1989	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
DMU1990	0	0	0	0	0.275421028	0	0	0	0.565605987	0	0	0	0.158972986	0	0	0
DMU1991	0	0	0	0	0.552588653	0	0	0	0.13016501	0	0	0	0.317246338	0	0	0
DMU1992	0	0	0	0.357949632	0	0	0	0	0	0.43998101	0.202069358	0	0	0	0	0
DMU1993	0	0	0.349437756	0	0	0	0	0	0	0	0.650562244	0	0	0	0	0
DMU1994	0	0	0	0.153161501	0	0	0	0	0	0.104922146	0.741916353	0	0	0	0	0
DMU1995	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
DMU1996	0	0	0.007799922	0	0	0	0	0	0	0	0.992200078	0	0	0	0	0
DMU1997	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
DMU1998	0	0	0.038352837	0	0	0	0	0	0	0	0.773119614	0.188527549	0	0	0	0
DMU1999	0	0	0.010233922	0	0	0	0	0	0	0	0.617925537	0.371840541	0	0	0	0
DMU2000	0	0	0	0	0	0	0	0	0	0	0.382885772	0.617114228	0	0	0	0
DMU2001	0	0	0	0	0	0	0	0	0	0	0.334610997	0.665389003	0	0	0	0
DMU2002	0	0	0	0	0	0	0	0	0	0	0.193616413	0.806383587	0	0	0	0
DMU2003	0	0	0	0	0	0	0	0	0	0	0.144261446	0.855738554	0	0	0	0
DMU2004	0	0	0	0	0	0	0	0	0	0	0.069147881	0.930852119	0	0	0	0
DMU2005	0	0	0	0	0	0	0	0	0	0	0.033353522	0.966646478	0	0	0	0
DMU2006	0	0	0	0	0	0	0	0	0	0	0	0.70863311	0.29136689	0	0	0
DMU2007	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
DMU2008	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DMU2009	0	0	0	0	0	0	0	0	0	0	0	0	0.834865629	0.165134371	0	0
DMU2010	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DMU2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
DMU2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-2.14225E-12	1
DMU2013	0	0	0	0.000319911	0	0	0	0	0	0	0	0	0.266932312	0	0.329870372	0.402877404

MIXED PERFORMANCE

Table A56: DEA modelling results - Mixed Performance Dresden.

	Variables					Theta	Slacks					Weights				
DMU Name	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**	**Objective Value**	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**	**net length**	**vehicles**	**staff**	**seatkm**	**paxkm**
DMU1957	0.85803	0.80999	1.66176	0.73743	1.5372	1	0	0	0	0	0	0.141411096	0.781392365	0.147882387	0	0.318036473
DMU1958	0.87855	0.82321	1.60577	0.74491	1.55277	1	0	0	0	0	0	0.292479157	0.504534531	0.204079392	0	0.372608267
DMU1959	0.8993	0.83974	1.73217	0.75137	1.56623	0.993432621	0	0	0.072718476	0	0	0.590500097	0.558462456	0	0.43542104	0.976474309
DMU1960	0.92029	0.83809	1.67089	0.75867	1.58145	1	0	0	0	0	0	0.051722305	1.057926944	0.03935776	0.428258574	0.54714355

Appendix

DMU1961	0.99214	0.84635	1.44697	0.76099	1.58629	1	0	0	0	0	0	0.132065658	0.781690365	0.143326218	0	0.312661414
DMU1962	0.86309	0.85627	1.56217	0.74911	1.56152	1	0	0	0	0	0	0.34646216	0.481865532	0.18459257	0	0.288678107
DMU1963	0.9011	0.88272	1.38156	0.72241	1.50586	0.998167834	0	0	0	0.182294271	0	0.336905804	0.396058668	0.251024402	0	0.429179693
DMU1964	0.88165	0.90256	1.40041	0.7225	1.50605	0.99808642	0	0.014801558	0	0.190482643	0	0.527518617	0	0.381969003	0	0.971879227
DMU1965	0.93761	0.86454	1.35975	0.71257	1.48535	0.98973627	0	0	0	0.126042254	0	0.33703211	0.396207149	0.25111851	0	0.429340592
DMU1966	0.94544	0.83148	1.2746	0.79385	1.43509	1	0	0	0	0	0	0.254023417	0.446488555	0.304871958	0	0.347072128
DMU1967	0.96711	0.81991	1.23807	0.87025	1.40014	1	0	0	0	0	0	0	0.380718935	0.555578229	0	0.592064707
DMU1968	0.976	0.80007	1.1977	0.92433	1.3495	1	0	0	0	0	0	0	0.392407199	0.572803517	0	0.580253209
DMU1969	0.84656	0.87611	1.15233	0.92279	1.31273	1	0	0	0	0	0	0.372880477	0.420489666	0.274174153	0	0.255309025
DMU1970	0.88145	0.94884	1.12169	0.93905	1.27312	0.957714227	0	0	0	0.177603468	0	0.545184745	0.337140605	0.177905138	0	0.105908985
DMU1971	0.87326	0.94388	1.10489	1.04427	1.24085	0.963085748	0	0	0	0.070501991	0	0.550205973	0.340245717	0.179543669	0	0.106884421
DMU1972	0.80758	0.94388	1.08633	1.15903	1.21694	1	0	0	0	0	0	0.864862563	0	0.277589951	0.067800048	0
DMU1973	0.81991	0.96703	1.08397	1.30665	1.35014	1	0	0	0	0	0	0.306923356	0	0.690379319	0.485253536	0.097492157
DMU1974	0.82688	1.01827	1.08073	1.33628	1.20166	1	0	0	0	0	0	0.350066153	0	0.657460513	0.540070332	0.014082141
DMU1975	0.89969	1.11911	1.09782	1.36139	1.20543	0.979117596	0	0.048872225	0	0	0	0.296817292	0	0.667647202	0.469275594	0.094282033
DMU1976	0.90009	1.14721	1.18268	1.44513	1.18053	1	0	0	0	0	0	0.704498237	0	0.309372088	0.763590265	0
DMU1977	0.96461	1.18853	1.15616	1.39786	1.21019	0.941846627	0	0.035288275	0	0	0	0.280487342	0	0.630915362	0.443457534	0.089094933
DMU1978	0.99017	1.26788	1.15645	1.3857	1.20721	0.92935585	0	0.104602326	0	0	0	0.278440188	0	0.626310587	0.440220932	0.088444669
DMU1979	0.99329	1.2811	1.15999	1.33075	1.19327	0.901151951	0	0.134479102	0	0	0	0.2775836	0	0.624383818	0.438866645	0.088172579
DMU1980	1.04247	1.27945	1.13671	1.28583	1.16567	0.879782308	0	0.143524619	0	0	0	0.277829228	0	0.624936321	0.439254988	0.088250601
DMU1981	1.06615	1.30259	1.16382	1.31203	1.14924	0.869391849	0	0.121546305	0	0	0	0.271444574	0	0.610574975	0.429160691	0.086222559
DMU1982	1.09884	1.29929	1.13141	1.2659	1.13813	0.858002007	0	0.14587593	0	0	0	0.274440147	0	0.617313078	0.433896766	0.087174082
DMU1983	1.11517	1.29929	1.15969	1.29903	1.12426	0.852465474	0	0.103661084	0	0	0	0.268548404	0	0.604060461	0.424581772	0.085302609
DMU1984	1.1409	1.35549	1.19859	1.35174	1.23213	0.86877593	0.038137749	0.148278475	0	0	0	0	0	0.834313652	0.284882896	0.410477152
DMU1985	1.15624	1.36871	1.20742	1.34935	1.30786	0.892604685	0.142961538	0.204348521	0	0	0	0	0	0.828212221	0.282799515	0.407475286
DMU1986	1.17328	1.3869	1.19682	1.69939	1.30694	1	0	0	0	0	0	0	0.524371558	0.227894827	0.631215091	0.046703647
DMU1987	1.18117	1.39516	1.21833	1.7086	1.29604	0.997810117	0.002663481	0	0.007542088	0	0	0	0.716763669	0	0.803289201	0.336487019
DMU1988	1.18917	1.40839	1.21509	1.72497	1.29165	1	0	0	0	0	0	0	0.586013526	0.143746068	0.663346037	0
DMU1989	1.21629	1.42988	1.17266	1.69916	1.25697	1	0	0	0	0	0	0	0.25927753	0.536612697	0.666276737	0
DMU1990	1.14662	1.40177	1.09841	1.4552	1.08162	0.946169315	0	0.13961515	0	0	0.038177824	0.317680031	0	0.578783626	0.487531304	0
DMU1991	1.07695	1.37367	1.02416	1.21124	0.90626	0.884840916	0	0.272113795	0	0	0.076805691	0.33980379	0	0.619091068	0.521483785	0
DMU1992	1.00728	1.34557	0.94991	0.96729	0.7309	0.871556733	0	0.097727893	0	0	0.098951851	0.711955842	0	0.297776757	0.103029387	0
DMU1993	0.93761	1.31416	0.87507	0.72333	0.55555	0.929495468	0	0.19589563	0	0.133572388	0.179590108	0.875239414	0	0.204974199	0	0
DMU1994	0.93483	1.23151	0.76753	0.80114	0.56312	0.955629776	0	0.11299368	0	0	0.056773631	0.796272968	0	0.333042541	0.115231185	0
DMU1995	0.91225	1.16539	0.69358	0.81643	0.56892	1	0	0	0	0	0	0.6827123	0	0.543838785	0.292899946	0
DMU1996	0.90584	1.14555	0.6706	0.68819	0.47564	0.999153912	0	0.076050668	0	0.010052362	0.006486544	0.940831789	0	0.220335419	0	0
DMU1997	0.90584	1.06951	0.66676	0.69462	0.47635	1	0	0	0	0	0	0.708480415	0	0.537269933	0.15557786	0
DMU1998	0.9365	0.98852	0.65498	0.66758	0.4544	0.993198084	0	0	0	0.060989399	0.05143399	0.739609709	0.16368371	0.222221881	0	0
DMU1999	0.98945	0.93231	0.62581	0.68176	0.46077	0.970413303	0	0	0	0.049442286	0.025289787	0.722642454	0.159928671	0.217123928	0	0
DMU2000	1.01454	0.82156	0.57042	0.69367	0.46566	0.983386668	0	0.009746277	0	0.053774978	0.014226065	0.662407504	0	0.57494669	0	0
DMU2001	1.03126	0.81991	0.56718	0.70263	0.46863	0.974409795	0	0.02198988	0	0.048947299	0.011532679	0.656360698	0	0.569698272	0	0
DMU2002	1.05635	0.78354	0.5442	0.70454	0.467	0.971130846	0	0.045976726	0	0.059106435	0.013970578	0.654152004	0	0.567781202	0	0
DMU2003	1.05077	0.77527	0.52887	0.70857	0.4687	0.983278519	0	0.069064579	0	0.05930122	0.012553382	0.662334655	0	0.574883459	0	0
DMU2004	1.05635	0.75874	0.51296	0.73739	0.46927	0.988667318	0	0.089927117	0	0.036910941	0.012413783	0.66596454	0	0.578034073	0	0
DMU2005	1.05746	0.72734	0.50471	0.74996	0.47026	0.992667331	0	0.077531113	0	0.027404939	0.011628884	0.668658942	0	0.58037272	0	0
DMU2006	1.06527	0.7356	0.49823	0.76001	0.47585	0.992718973	0	0.105250372	0	0.024006511	0.00851723	0.319923565	0	1.323073728	0	0
DMU2007	1.05467	0.62981	0.49529	0.78022	0.48208	1	0	0	0	0	0	0.658003162	0	0.617867926	0.380962591	0
DMU2008	1.06443	0.61328	0.49293	0.79325	0.48993	1	0	0	0	0	0	0.502461149	0	0.943674109	0.775180228	0.020212548
DMU2009	1.11432	0.66948	0.49764	0.79792	0.4939	0.996006426	0.028700586	0.047418927	0	0.004039977	0	0	0	2.009484768	0	1.378110578
DMU2010	1.11878	0.63311	0.50177	0.82153	0.50282	1	0	6.96691E-12	0	0	0	0.251988903	0	1.431093638	0.716614652	0.471730202
DMU2011	1.11878	0.56864	0.51002	0.83033	0.51414	1	0	0	0	0	0	0.249356527	0.002313558	1.411139412	0.711200756	0.462383252
DMU2012	1.11878	0.56534	0.51709	0.8225	0.51096	1	0	0	0	0	0	0.577751755	0.571013606	0.059575818	0.18686384	0
DMU2013	1.12157	0.58848	0.5165	0.81743	0.51888	0.993531973	0.012679335	0	0	0.009890811	0	0	0.016004467	1.917873555	0	1.324329601

Table A57: Lambdas - Mixed Performance Dresden.

#	DMU1957	DMU1960	DMU1961	DMU1962	DMU1966	DMU1969	DMU1972	DMU1973	DMU1974	DMU1986	DMU1988	DMU1989	DMU1995	DMU1997	DMU2007	DMU2008	DMU2010	DMU2011
DMU1957	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1958	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1959	0.259227904	0.552726184	0	0.188039241	0	0	0	6.67146E-06	0	0	0	0	0	0	0	0	0	0
DMU1960	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1961	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1962	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1963	0	0	0.333642346	0.340312903	0.058799514	0	0	0.267245238	0	0	0	0	0	0	0	0	0	0
DMU1964	0	0	0.227470786	0.483455264	0	0	0	0.289073949	0	0	0	0	0	0	0	0	0	0
DMU1965	0	0	0.253189657	0.17452134	0.453548459	0	0	0.118740544	0	0	0	0	0	0	0	0	0	0
DMU1966	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1967	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1968	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1969	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DMU1970	0	0	0	0	0	0.384195261	0.075298816	0.479337774	0	0	0	0	0	0	0	0.061168149	0	0
DMU1971	0	0	0	0	0	0.295205594	0.292473563	0.343397115	0	0	0	0	0	0	0	0.068923728	0	0
DMU1972	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
DMU1973	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
DMU1974	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
DMU1975	0	0	0	0	0	0	0	0.107396706	0.722935461	0.132900973	0	0	0	0	0	0.03676686	0	0
DMU1976	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU1977	0	0	0	0	0	0	0	0.043232821	0.71109546	0.216597989	0	0	0	0	0	0.02907373	0	0
DMU1978	0	0	0	0	0	0	0	0.145393208	0.564299693	0.233267999	0	0	0	0	0	0.0570391	0	0
DMU1979	0	0	0	0	0	0	0	0.272921991	0.49648142	0.141013027	0	0	0	0	0	0.089583562	0	0
DMU1980	0	0	0	0	0	0	0	0.464180282	0.212450674	0.153290611	0	0	0	0	0	0.170078434	0	0
DMU1981	0	0	0	0	0	0	0	0.260320321	0.396782097	0.187241447	0	0	0	0	0	0.155656135	0	0
DMU1982	0	0	0	0	0	0	0	0.527933013	0.05532434	0.189337646	0	0	0	0	0	0.227405001	0	0
DMU1983	0	0	0	0	0	0	0	0.291029734	0.282156815	0.224188005	0	0	0	0	0	0.202625445	0	0
DMU1984	0	0	0	0	0	0	0	0.603605375	0	0.269142162	0	0	0	0	0	0	0	0.127252464

Appendix

DMU1985	0	0	0	0	0	0	0	0.797664471	0	0.160030906	0	0	0	0	0	0	0	0.042304625
DMU1986	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
DMU1987	0	0	0	0	0	0	0	0.028163843	0	0.179378472	0.792457685	0	0	0	0	0	0	0
DMU1988	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
DMU1989	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
DMU1990	0	0	0	0	0	0	0	0	0.275421028	0	0	0.565605987	0	0	0	0.158972986	0	0
DMU1991	0	0	0	0	0	0	0	0	0.552588653	0	0	0.13016501	0	0	0	0.317246338	0	0
DMU1992	0	0	0	0	0	0	0	0.357949632	0	0	0	0	0.43998101	0.202069358	0	0	0	0
DMU1993	0	0	0	0	0	0	0.349437756	0	0	0	0	0	0	0.650562244	0	0	0	0
DMU1994	0	0	0	0	0	0	0	0.153161501	0	0	0	0	0.104922146	0.741916353	0	0	0	0
DMU1995	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
DMU1996	0	0	0	0	0	0	0.007799922	0	0	0	0	0	0	0.992200078	0	0	0	0
DMU1997	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
DMU1998	0	0	0	0	0	0	0.038352837	0	0	0	0	0	0	0.773119614	0.188527549	0	0	0
DMU1999	0	0	0	0	0	0	0.010233922	0	0	0	0	0	0	0.617925537	0.371840541	0	0	0
DMU2000	0	0	0	0	0	0	0	0	0	0	0	0	0	0.382885772	0.617114228	0	0	0
DMU2001	0	0	0	0	0	0	0	0	0	0	0	0	0	0.334610997	0.665389003	0	0	0
DMU2002	0	0	0	0	0	0	0	0	0	0	0	0	0	0.193616413	0.806383587	0	0	0
DMU2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0.144261446	0.855738554	0	0	0
DMU2004	0	0	0	0	0	0	0	0	0	0	0	0	0	0.069147881	0.930852119	0	0	0
DMU2005	0	0	0	0	0	0	0	0	0	0	0	0	0	0.033353522	0.966646478	0	0	0
DMU2006	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.70863311	0.29136689	0	0
DMU2007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
DMU2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
DMU2009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.69200931	0.30799069	0
DMU2010	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5.90724E-11
DMU2011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
DMU2012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU2013	0	0	0	0	0	0	0	0.012770816	0	0	0	0	0	0	0	0.245204539	0	0.742024651

(DMUs 1960, 1967, 1968, 1976, 2012 deleted due to self-referencing)

14 Plots Lambdas over time

Hamburg

EFFECTIVENESS

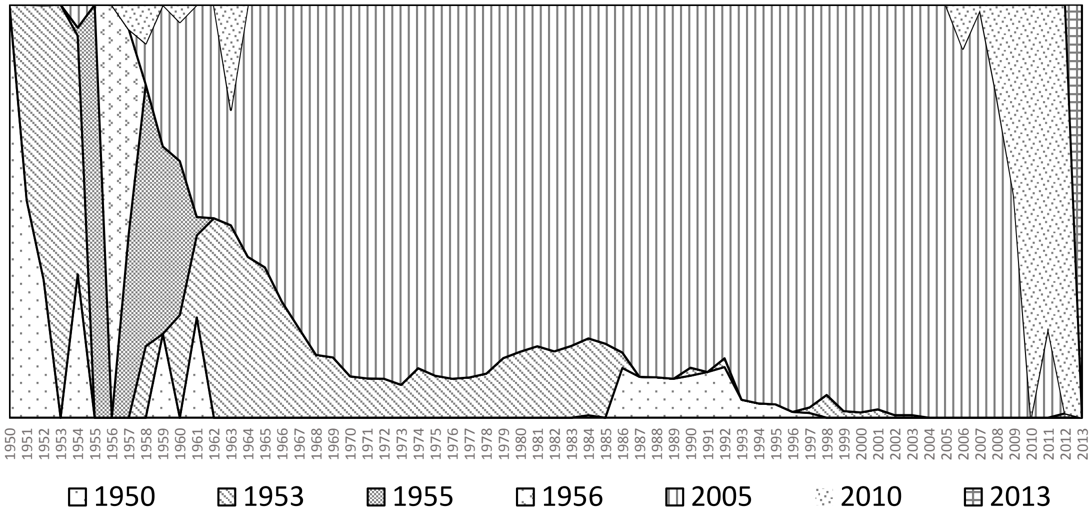


Figure A7: Lambdas over time, Hamburg, Effectiveness

EFFICIENCY

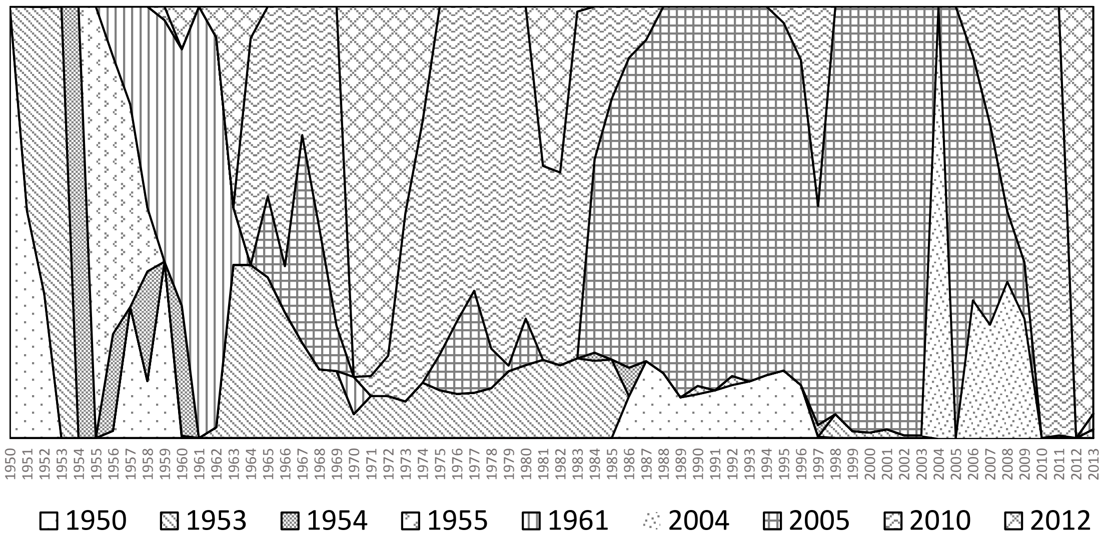


Figure A8: Lambdas over time, Hamburg, Efficiency

Porto

EFFECTIVENESS

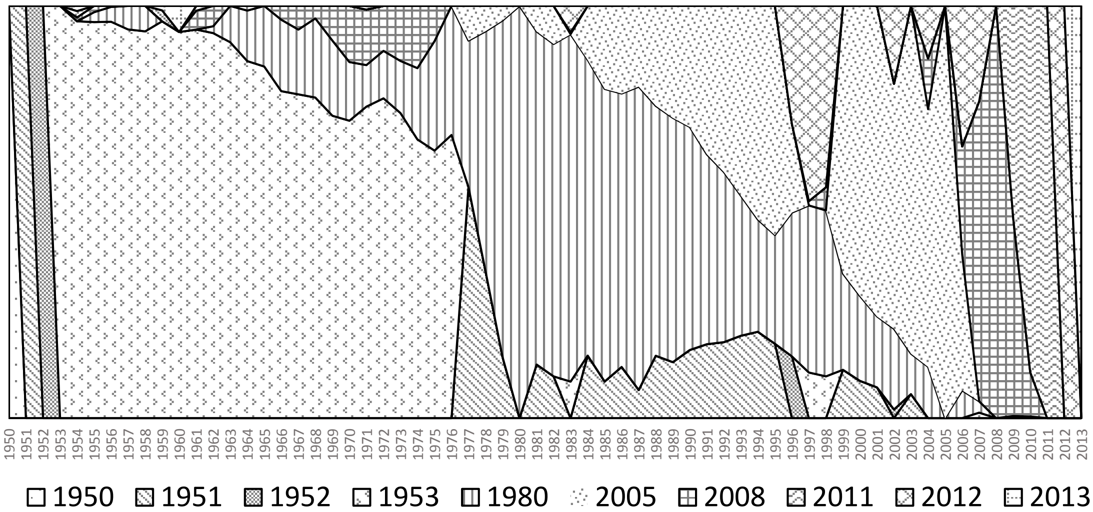


Figure A9: Lambdas over time, Porto, Effectiveness

EFFICIENCY

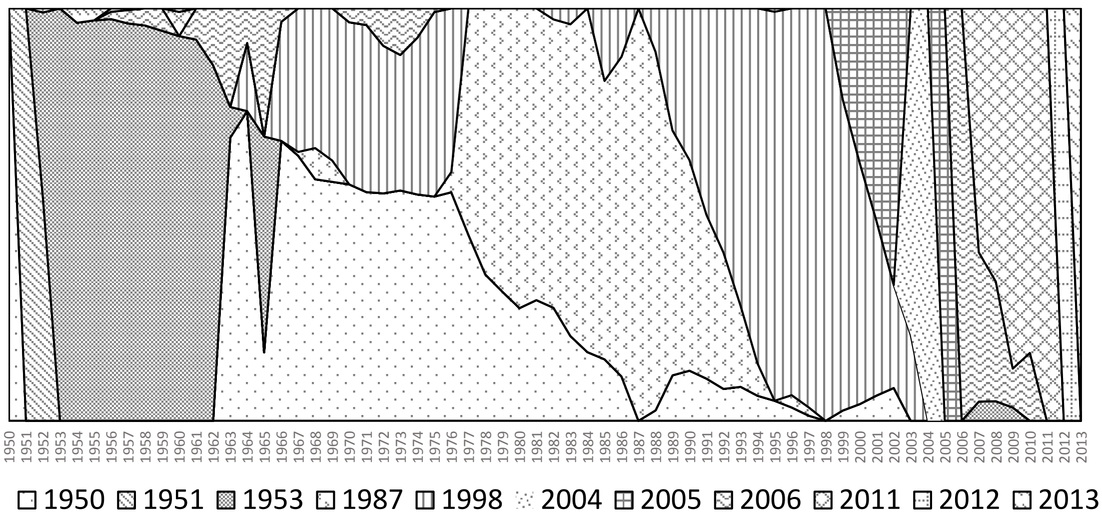


Figure A10: Lambdas over time, Porto, Efficiency

Dresden

EFFECTIVENESS

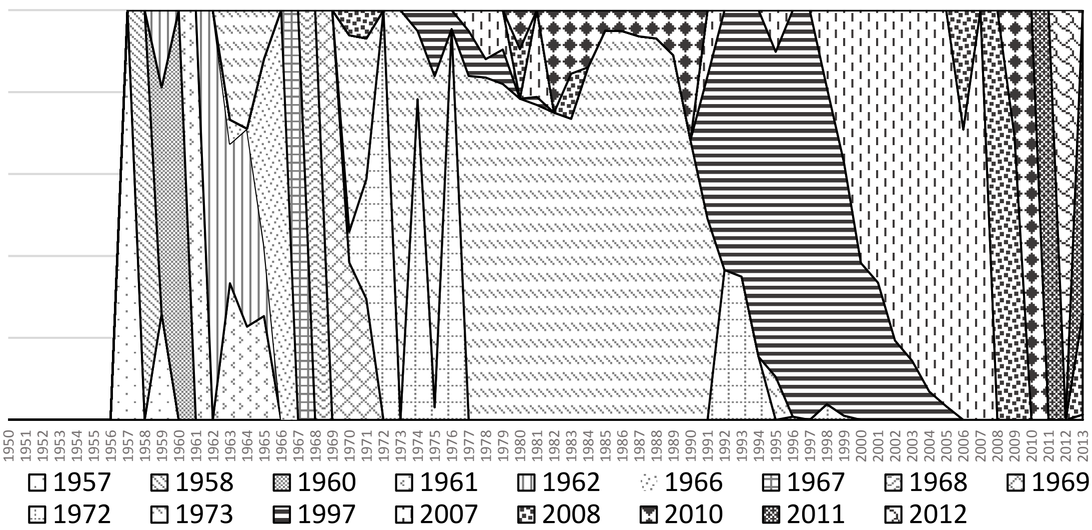


Figure A11: Lambdas over time, Dresden, Effectiveness

EFFICIENCY

Figure A12: Lambdas over time, Dresden, Efficiency

15 Plots Outputs Shortfalls

Hamburg

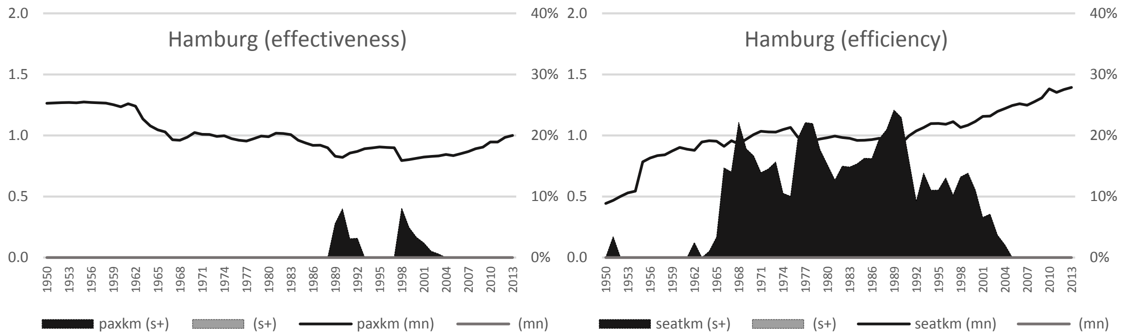


Figure A13: Output Shortfall over time, Hamburg

Porto

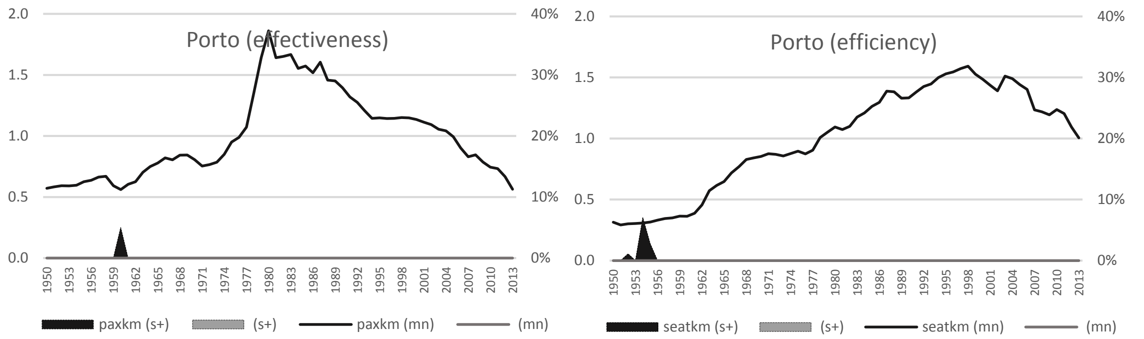


Figure A14: Output Shortfall over time, Porto

Dresden

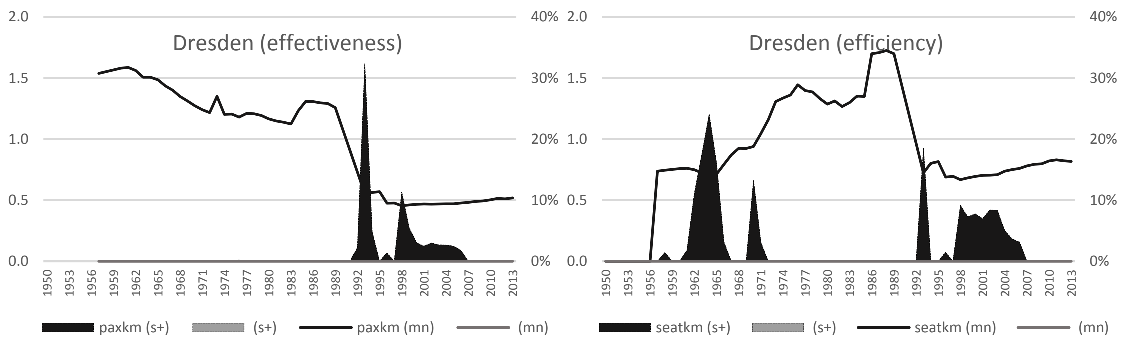


Figure A15: Output Shortfall over time, Dresden

16 Calculation Scale Efficiency

SE=CRS/VRS

Table 58: Thetas from BCC and CCR Model and Scale Efficiency.

	Effectiveness Hamburg			Efficiency			Effectiveness Porto			Efficiency			Effectiveness Dresden			Efficiency		
year	VRS	CRS	SE	VRS	CRS	SE	VRS	CRS	SE	VRS	CRS	SE	VRS	CRS	SE	VRS	CRS	SE
1950	1.00	1.00	1.00	1.00	0.71	0.71	1	0.841257	0.84	1	0.735869	0.74						
1951	0.99	0.99	1.00	0.99	0.73	0.73	1	0.849384	0.85	1	0.677591	0.68						
1952	0.99	0.99	1.00	0.99	0.77	0.77	1	0.778514	0.78	0.999649	0.630173	0.63						
1953	1.00	1.00	1.00	1.00	0.80	0.80	1	0.746998	0.75	1	0.601098	0.60						
1954	1.00	1.00	1.00	1.00	0.78	0.78	0.978056	0.716528	0.73	0.976861	0.540539	0.55						
1955	1.00	1.00	1.00	1.00	1.00	1.00	0.982417	0.74346	0.76	0.962076	0.541561	0.56						
1956	0.99	0.99	1.00	1.00	1.00	1.00	0.984446	0.754848	0.77	0.958654	0.565109	0.59						
1957	0.94	0.94	1.00	0.95	0.95	1.00	0.999084	0.777905	0.78	0.958285	0.536742	0.56	1	1	1.00	1	0.663674	0.66
1958	0.90	0.90	1.00	0.89	0.85	0.96	0.987781	0.771426	0.78	0.946712	0.521051	0.55	1	1	1.00	0.983181	0.65927	0.67
1959	0.95	0.94	1.00	0.91	0.84	0.92	0.907831	0.660464	0.73	0.925928	0.445128	0.48	0.99344	0.982807	0.99	0.96072	0.651726	0.68
1960	0.96	0.95	0.99	0.92	0.86	0.93	0.882173	0.595866	0.68	0.883484	0.491673	0.56	1	0.9964	1.00	0.950931	0.658086	0.69
1961	1.00	1.00	1.00	0.93	0.81	0.87	0.881016	0.643714	0.73	0.901797	0.509203	0.56	1	1	1.00	0.912373	0.650242	0.71
1962	0.99	0.99	1.00	0.91	0.78	0.86	0.87298	0.649265	0.74	0.926936	0.600136	0.65	1	1	1.00	0.981032	0.64008	0.65
1963	0.94	0.91	0.97	0.92	0.83	0.91	0.903347	0.71712	0.79	0.994037	0.757912	0.76	0.998168	0.99674	1.00	0.953357	0.598222	0.63
1964	0.95	0.91	0.96	0.93	0.82	0.89	0.886495	0.714708	0.81	0.97275	0.819848	0.84	0.998086	0.994759	1.00	0.956633	0.586983	0.61
1965	0.95	0.90	0.95	0.94	0.82	0.87	0.90768	0.744353	0.82	0.976889	0.715485	0.73	0.989736	0.978775	0.99	0.939692	0.599763	0.64
1966	0.99	0.94	0.96	0.97	0.77	0.79	0.806611	0.662787	0.82	0.88875	0.791517	0.89	1	0.997223	1.00	0.951399	0.692167	0.73
1967	0.97	0.90	0.93	0.97	0.77	0.80	0.729557	0.589985	0.81	0.838865	0.766685	0.91	1	0.997394	1.00	0.947853	0.767188	0.81
1968	0.96	0.90	0.94	0.94	0.71	0.75	0.725775	0.602109	0.83	0.872051	0.807585	0.93	1	0.991277	0.99	0.959628	0.832705	0.87

1969	0.97	0.93	0.96	0.95	0.74	0.78	0.742535	0.603073	0.81	0.870508	0.807755	0.93	1	0.964195	0.96	1	0.772921	0.77
1970	0.98	0.97	1.00	0.93	0.74	0.79	0.7368	0.577326	0.78	0.858539	0.787632	0.92	0.957714	0.927975	0.97	0.949468	0.728191	0.77
1971	0.96	0.96	0.99	0.93	0.75	0.81	0.711536	0.542272	0.76	0.87366	0.802967	0.92	0.963086	0.915162	0.95	0.957131	0.814262	0.85
1972	0.96	0.95	0.99	0.93	0.75	0.81	0.723705	0.563169	0.78	0.888384	0.800962	0.90	1	0.911182	0.91	1	0.908274	0.91
1973	0.95	0.94	0.98	0.92	0.74	0.80	0.742258	0.577065	0.78	0.877984	0.783251	0.89	1	1	1.00	1	1	1.00
1974	0.93	0.91	0.98	0.90	0.75	0.84	0.757285	0.600186	0.79	0.8581	0.780306	0.91	0.985162	0.892694	0.91	1	1	1.00
1975	0.91	0.88	0.97	0.89	0.75	0.84	0.772388	0.649844	0.84	0.843217	0.786497	0.93	0.92628	0.881555	0.95	0.977443	0.966454	0.99
1976	0.92	0.88	0.96	0.90	0.69	0.77	0.773457	0.678972	0.88	0.852477	0.795534	0.93	0.902236	0.801398	0.89	1	0.993496	0.99
1977	0.90	0.86	0.95	0.88	0.67	0.76	0.72647	0.607146	0.84	0.862594	0.81585	0.95	0.872118	0.840377	0.96	0.941175	0.933041	0.99
1978	0.91	0.88	0.97	0.88	0.67	0.76	0.813923	0.733436	0.90	0.905711	0.870214	0.96	0.860293	0.838097	0.97	0.927222	0.911485	0.98
1979	0.91	0.89	0.97	0.89	0.70	0.78	0.921027	0.878524	0.95	0.928644	0.897529	0.97	0.855448	0.825891	0.97	0.897221	0.872625	0.97
1980	0.90	0.87	0.96	0.88	0.70	0.80	1	1	1.00	0.96503	0.937604	0.97	0.842098	0.823312	0.98	0.87313	0.827609	0.95
1981	0.90	0.88	0.98	0.87	0.71	0.82	0.939453	0.897505	0.96	0.938967	0.909997	0.97	0.817256	0.7928	0.97	0.865726	0.825327	0.95
1982	0.90	0.88	0.98	0.88	0.70	0.80	0.941974	0.906247	0.96	0.928177	0.901846	0.97	0.829316	0.807626	0.97	0.850545	0.79272	0.93
1983	0.90	0.87	0.97	0.88	0.70	0.80	0.943393	0.912012	0.97	0.984473	0.964422	0.98	0.800876	0.778329	0.97	0.848417	0.804914	0.95
1984	0.89	0.83	0.93	0.88	0.70	0.79	0.895012	0.841447	0.94	0.970867	0.954921	0.98	0.83672	0.825324	0.99	0.848096	0.807811	0.95
1985	0.88	0.81	0.92	0.87	0.69	0.79	0.884841	0.853479	0.96	0.928303	0.91529	0.99	0.873697	0.869644	1.00	0.839061	0.798699	0.95
1986	0.88	0.79	0.91	0.87	0.69	0.79	0.869435	0.825446	0.95	0.947302	0.937576	0.99	0.880907	0.876729	1.00	1	1	1.00
1987	0.89	0.80	0.90	0.88	0.68	0.77	0.887656	0.863737	0.97	1	0.998748	1.00	0.859207	0.854067	0.99	0.997103	0.995291	1.00
1988	0.92	0.81	0.88	0.92	0.70	0.76	0.838273	0.785228	0.94	0.968662	0.965617	1.00	0.859015	0.853444	0.99	1	1	1.00
1989	0.93	0.76	0.82	0.93	0.69	0.74	0.844197	0.79567	0.94	0.923216	0.913979	0.99	0.869777	0.86058	0.99	1	1	1.00
1990	0.91	0.75	0.83	0.91	0.68	0.75	0.83841	0.780533	0.93	0.925627	0.915607	0.99	0.818882	0.790585	0.97	0.946169	0.91365	0.97
1991	0.90	0.78	0.86	0.90	0.71	0.79	0.808426	0.745665	0.92	0.901651	0.893773	0.99	0.824139	0.710434	0.86	0.884841	0.814934	0.92
1992	0.87	0.76	0.87	0.87	0.73	0.84	0.795031	0.730105	0.92	0.898038	0.892235	0.99	0.863588	0.617752	0.72	0.871557	0.700997	0.80
1993	0.93	0.80	0.86	0.92	0.75	0.82	0.798728	0.723223	0.91	0.899382	0.893442	0.99	0.929495	0.509705	0.55	0.929495	0.568346	0.61
1994	0.93	0.82	0.88	0.92	0.77	0.84	0.820776	0.733287	0.89	0.936104	0.931794	1.00	0.952817	0.589039	0.62	0.95563	0.706446	0.74
1995	0.94	0.84	0.90	0.93	0.78	0.84	0.845302	0.771187	0.91	0.95247	0.947423	0.99	0.999596	0.658557	0.66	1	0.788489	0.79
1996	0.96	0.87	0.90	0.95	0.78	0.82	0.858796	0.780984	0.91	0.980198	0.977884	1.00	0.999154	0.569447	0.57	0.999154	0.684842	0.69
1997	0.94	0.88	0.94	0.92	0.78	0.84	0.858696	0.784898	0.91	0.982548	0.981667	1.00	1	0.573581	0.57	1	0.694652	0.69
1998	0.99	0.82	0.83	0.99	0.81	0.82	0.877423	0.807224	0.92	1	1	1.00	0.993198	0.556992	0.56	0.993198	0.674558	0.68
1999	1.00	0.85	0.85	1.00	0.82	0.82	0.886925	0.831648	0.94	0.967976	0.958764	0.99	0.970413	0.591126	0.61	0.970413	0.709777	0.73
2000	1.00	0.86	0.86	1.00	0.84	0.84	0.910912	0.865949	0.95	0.964856	0.949589	0.98	0.983387	0.655409	0.67	0.983387	0.776525	0.79
2001	0.99	0.86	0.87	0.99	0.87	0.87	0.909526	0.871562	0.96	0.937763	0.914844	0.98	0.97441	0.663357	0.68	0.97441	0.787899	0.81

2002	0.99	0.87	0.88	0.99	0.86	0.87	0.916827	0.89272	0.97	0.915846	0.886058	0.97	0.971131	0.688964	0.71	0.971131	0.813365	0.84
2003	0.99	0.88	0.88	0.99	0.89	0.90	0.928327	0.896162	0.97	0.989311	0.983378	0.99	0.983279	0.711516	0.72	0.983279	0.837929	0.85
2004	1.00	0.90	0.90	1.00	0.90	0.90	0.975233	0.962083	0.99	1	1	1.00	0.988667	0.734476	0.74	0.988667	0.892666	0.90
2005	1.00	0.89	0.89	1.00	0.93	0.93	1	1	1.00	1	1	1.00	0.992667	0.748057	0.75	0.992667	0.91949	0.93
2006	0.99	0.90	0.90	0.99	0.93	0.93	0.998322	0.959446	0.96	1	1	1.00	0.992719	0.766794	0.77	0.992719	0.939988	0.95
2007	0.99	0.91	0.92	0.99	0.91	0.92	0.962793	0.914021	0.95	0.956122	0.911356	0.95	1	0.781444	0.78	1	0.971536	0.97
2008	0.99	0.93	0.94	0.99	0.93	0.94	1	0.975248	0.98	0.989143	0.941509	0.95	1	0.797971	0.80	1	0.989823	0.99
2009	1.00	0.95	0.95	0.99	0.95	0.96	0.991157	0.944475	0.95	0.980162	0.946976	0.97	0.996006	0.796824	0.80	0.993469	0.979322	0.99
2010	1.00	0.98	0.98	1.00	1.00	1.00	0.957616	0.902234	0.94	0.975977	0.974235	1.00	1	0.804538	0.80	1	1	1.00
2011	1.00	0.98	0.98	0.99	0.98	0.98	1	0.942452	0.94	1	1	1.00	1	0.809343	0.81	1	1	1.00
2012	1.00	1.00	1.00	0.99	0.99	1.00	1	0.936075	0.94	1	0.990566	0.99	1	0.79334	0.79	1	0.996352	1.00
2013	0.98	0.97	1.00	1.00	0.99	0.99	1	0.817334	0.82	1	0.941874	0.94	0.993532	0.806557	0.81	0.984492	0.973836	0.99
mean	0.95	0.90	0.94	0.94	0.80	0.85	0.89	0.78	0.87	0.94	0.83	0.88	0.95	0.82	0.87	0.96	0.82	0.86
SD	0.04	0.07	0.05	0.05	0.10	0.08	0.09	0.12	0.09	0.05	0.15	0.16	0.07	0.14	0.14	0.05	0.13	0.13
min	0.87	0.75	0.82	0.87	0.67	0.71	0.71	0.54	0.68	0.84	0.45	0.48	0.80	0.51	0.55	0.84	0.57	0.61
max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

17 Literature Review on Time-Lags

Table A59: Time-Lags reported or considered in different empirical works. Adapted from Costa et al. (2014).

Study Identification	Relationship Under Analysis	Units Under Analysis	Model or Method Used	Time-Lags
Co and Chew (1997)	Impact of R&D expenditures on firms performance	American and Japanese firms	Data Envelopment Analysis	6 years
Kim and McMillin (2003)	Impact of monetary policy actions on economic performance	USA	Vector Autoregressive Model/Monte Carlo Simulations	12 months (for the symmetric lag structure) 4 to 28 months (for the asymmetric lag structure)
Devaraj and Kohli (2003)	Impact of IT usage on firm performance	Hospitals	Conceptual framework based on 9 hypothesis for the relationship	2 months
Czarnitzki and Kraft (2010)	Impact of innovative activities on firms profitability	German manufacturing firms	Econometric Model	1 to 2 years
Matteucci and Sterlacchini (2004)	Impact of R&D and ICT investment policy on firms productivity	Italian R&D- and ICT-intensive manufacturing firms	Econometric Model	2 years
Nicholson-Crotty (2005)	Multidirectional relationships between management practices and organizational performance	Law enforcement organizations	Dual feedback model of performance and management	3 years (in both directions)
Wright et al. (2005)	Dual relationships between HR management practices and organizational performance	Self-contained business units (equivalent to a plant) of a large food corporation	Conceptual framework that tests the relationships between HR practices and multiple performance measures at 4 different times: past, concurrent, early post and late post	3 to 9 months prior to measures of operational and financial performance 9 to 15 months following measure of operational and financial performance
Wu and Chen (2006)	Impact of e-business investments on corporate strategic performance	High-tech manufacturing firms	Hybrid performance measure system for e-business investments with time-lag effects.	1 to 3 years
Sels et al. (2006)	Impact of HR management on firms performance	Small Belgian businesses	Conceptual framework based on 4 hypothesis for the relationship	1 year
Hashimoto and Kodama (1996)	Impact of R&D expenditures on firm performance	Japanese Pharmaceutical Industry	DEA/Malmquist index analysis	7 to 9 years
Carree and Thurik (2007)	Impact of entrepreneurship policy on economic performance	OECD countries	Econometric model	5 years
Leverty and Grace (2012)	Influence of CEOs on efficiency	unsurance companies USA	DEA/Regression	3 years

18 Presentation of Beta Coefficients - Issues

The plot of beta coefficients over time requires adjusting the past-oriented perspective of regression modelling to a future-oriented presentation perspective, as demonstrated in the following example: In *modelling* the interpretation of coefficients focuses on how the *explained* variable is affected by current or past *explanatory* variables. For instance a β_1 for lag -5, describes the effect from decisions five *past* lags apart on current performance. As Table A60 shows, the decision column *KSUM* is essentially "shifted" five periods to estimate the $\beta_1$for lag -5. Hence, the series to be correlated are all observation of X10 at time $t = 0$ and KSUM at time $t - 5$.

Table A60: The difference between backwards and forward perspective: none.

	Modelling *(retrospective)*												**Presentation** *(prospective)*			
	β_1 for lag 0				β_1 for lag -1				$\beta_1$for lag -5				$\beta_1$for lag +5			
#	lag	X10	KSUM	lag	lag	X10	KSUM	lag	lag	X10	KSUM	lag	lag	X10	KSUM	lag
1	0	4.61	3.43	0	0	4.61	3.98	-1	0	4.61	2.96	-5	+5	4.61	2.96	0
2	-1	4.61	3.98	-1	-1	4.61	3.56	-2	-1	4.61	3.44	-6	+4	4.61	3.44	-1
3	-2	4.61	3.56	-2	-2	4.61	3.89	-3	-2	4.61	1.94	-7	+3	4.61	1.94	-2
4	-3	4.61	3.89	-3	-3	4.61	2.84	-4	-3	4.61	1.42	-8	+2	4.61	1.42	-3
4	-4	4.58	2.84	-4	-4	4.58	2.96	-5	-4	4.58	3.95	-9	+1	4.58	3.95	-4
5	-5	4.59	2.96	-5	-5	4.59	3.44	-6	-5	4.59	4.13	-10	0	4.59	4.13	-5
6	-6	4.59	3.44	-6	-6	4.59	1.94	-7	-6	4.59	4.11	-11	-1	4.59	4.11	-6
7	-7	4.60	1.94	-7	-7	4.60	1.42	-8	-7	4.60	3.65	-12	-2	4.60	3.65	-7
8	-8	4.59	1.42	-8	-8	4.59	3.95	-9	-8	4.59	3.56	-13	-3	4.59	3.56	-8
9	-9	4.51	3.95	-9	-9	4.51	4.13	-10	-9	4.51	3.49	-14	-4	4.51	3.49	-9
10	-10	4.48	4.13	-10	-10	4.48	4.11	-11	-10	4.48	3.27	-15	-5	4.48	3.27	-10

Now for presentation purposes, one might simply alter the interpretation to how *current explanatory variables* affect *current or future explained* variables. This can be done by adjusting the lag column of KSUM to $t = 0$, while keeping the gap between cause and effect by 5 time periods as illustrated in Table X under "Forwards" (adding "+5" for either lags). Hence, the series to be correlated are e.g. X10 at time $t = 5$ and KSUM at time 0. Obviously, the numerical values that would enter the regression are identical for both cases, and so is the corresponding beta-coefficient β_1. However, as intended the interpretation would change, as β_1 for lag +5, describes the effect from current decisions on performance five future periods apart.

19 Preliminary Collection of Operator Data

Annual reports from multiple public transport operators in Germany, Spain and Portugal was collected, since the original scope of the thesis was much broader. The files might be used for future research and the author is happy to share them.

Table A61: Gathered operator data sets for future research.

City/Operator	Period	Number of years
Köln	1990-2012	23
Hamburg Verbund	1992-2012	21
Chemnitz	1993-2012	20
Leipzig	1996-2012	17
Dortmund	2000-2012	13
Stuttgart	2000-2012	13
Düsseldorf	2000-2012	13
Berlin	2001-2012	12
Essen	2001-2012	12
Frankfurt am Main	2001-2012	12
Bremen	2005-2012	8
München	2007-2012	6
Barcelona	1995-2012	18
EMT Madrid	2004-2011	8
Metro Madrid	2007-2011	6
Lisbon (Metro)	2003-2012	10
Porto (Metro)	2003-2012	10
Lisbon (Carris)	2005-2012	8

20 Annual Reports - Examples

Annual reports were available as borrowed hardcopies until the year 2000; later version were downloaded from the web pages indicated or provided by the operators as digital copies.

Figure A16: Examples Annual Reports from Hochbahn, STCP, and DVB.

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