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A tool for railway transport cost evaluation

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Abstract

After a compared analysis of different cost assessment methodologies with their mathematical formulations, the paper achieves a determination of cost functions (functions linking inputs with outputs) for an articulate estimation of regional railways investment and operating costs, in relation with existing and/or planned contexts, giving some example of reference points and orders of magnitude. The same methodology is then applied to compare calculated cost with some European regional operating costs (€/train-km).

Keywords: cost functions ; railway; investment costs; operating costs; €/TKM

1. Introduction

Besides its technical and infrastructural features, performance and environmental impact, the convenience of a given transportation technology must not leave out the correct assessment of its costs; this is by the way a priority when evaluating the efficiency, effectiveness and quality of an existing service, or calculating the needed resources to realize an action on system, or even when comparing different scenarios of a system's layout.

There are four characteristics of railways that make performance measurement particularly complex (Nash, 2000):

- multiplicity of outputs: an output needs to be described in terms of the provision of transport of a specific quality from a specific origin to a specific destination at a specific point in time. For a large national-scale railway, this means literally millions of products on offer and, of course, it is not possible to provide performance measures that separately identify each product;
- complexity of production process: rail technology is relatively complex, thus the production process includes multiplicity of inputs. Providing a rail service requires rolling stock, track, signalling, terminals and a variety

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of types of staff (train crew, signalling, track and rolling stock maintenance, terminals and administrations). A further problem related to this complexity is that of joint costs and economies of scale: for instance, a single track railway may carry both passenger and freight traffic, thus only some of the costs can be specifically attributed to one of the forms of traffic; the remaining costs are joint. Moreover railways are subject to economies of traffic density: putting more traffic on the same route generally reduces unit costs, unless the route is already heavily congested;
- geographic factors: gradient, climate and complexity of the network has a strong influence on railway performance through its impact on the nature of traffic carried;
- government intervention: for passenger service is not uncommon for governments to effectively control the timetable as far as the frequency of service on each route, either as part of a formal franchising agreement or via a public service obligation. In this situation the government becomes the customer, and the output the railway produces is a certain level of service, rather than transport for a number of people.

After a compared analysis of different railways cost methodologies, the paper proposes a set of cost functions for the articulate estimation of regional railways investment and operating costs in relation with existing and/or planned contexts. giving some example of reference points and orders of magnitude. The methodology is then applied to compare estimated cost with some European regional operating costs (€/train-km).

2. Literature cost models

Basically, a cost function *C* for a production level *y* (for example, the total amount of train kilometres per year, with an assumed capacity α of one train unit) can be determined as follows (Van Vuuren, 2002):

$$C(y) = c_0 + c_1 \text{ int } (y/\alpha) + c_2 y$$

where the three terms on the right-hand side correspond to sunk costs c_0, fixed costs c_1 and variable costs c_2, respectively, and for a given time horizon. Contrary to fixed costs, sunk costs cannot be eliminated, even at zero production level (examples are tracks and bridges). On the other hand, fixed costs are the kind of costs that are necessary for production, but do not vary with the output level (an example is the purchase of locomotives). In practice, it is not always clear whether costs should be categorized as sunk or fixed costs; the time horizon of the analysis is obviously crucial for this.

Knowledge of cost functions is essential for decision-making of transport companies and regulators of the public sector (Pels & Rietveld, 2000). The first ones need to achieve best results of companies objectives, whilst for the second ones, they have important implications for policies such as whether or not transport might qualify for subsidy, and whether the public sector should take special regulatory measures in markets to counter monopolistic tendencies.

Specialist literature concerning public transport systems proposes different ways to investigate costs (Tab. 1). Generally speaking, costs related with the production of a public transport service can be distinguished in *investment costs* (also known as *capital cost*), required for the realization or the purchase of components (for railways: infrastructure, rolling stock, installations, etc.) for the planned action, and *operating costs* (also known as *management costs)* including those for the operation and maintenance of transport service.

Amongst the studies particularly referred to railways and including both investment and operating costs, a paper from Baumgartner (2001) has to be mentioned. Moreover, a study about the reactivation of a railway line in central Italy (Santinelli, 2007) includes a basic indication of investment and operating cost for it. Ott (2001) compared infrastructure costs of road and rail. Mancuso and Reverberi (2003) studied operating cost and market organization in Italian railway services. A cost analysis for both investment and management costs in advanced public transport systems is proposed by Gattuso & Meduri (2006). Von Brown (2011) proposes a planning methodology for railway construction cost estimation in North America. A comparison of investment cost in urban rail is fully investigated in Flyvbjerg, Bruzelius and van Wee (2008). Moreover, some studies are specifically related to high speed rails (Levinson, Mathieu, Gillen, & Kanafani, 1997; Van Hecke, Aubry, Hakenbeck, Leveritt & Smith, 2003). More recently, a study from Garcia (2010) linked operating costs to speed. A paper from Calvo and De Oña (2012) investigated a series of national charging systems to compare track usage costs and the charges that seek to recover those costs; Olsson, Økland and Halvorsen (2012) determined the consequences of differences in cost-benefit methodology in railway infrastructure appraisal.

Table 1. Recent related literature on railways cost estimation

Paper	Year	Railway specific	Investment cost	Operating costs
Levinson, Mathieu, Gillen & Kanafani	1997	■	■	■
Baumgartner	2001	■	■	■
Ott	2001	■	■	X
Mancuso & Reverberi	2003	■	X	■
Van Hecke, Aubry, Hakenbeck, Leveritt & Smith	2003	■	■	X
Gattuso & Meduri	2006	X	■	■
Santinelli	2007	■	■	■
Flyvbjerg, Bruzelius & van Wee	2008	■	■	X
Garcia	2010	■	X	■
Van Brown	2011	■	■	X
Calvo & De Oña	2012	■	X	■
Olsson, Økland & Halvorsen	2012	■	■	X

3. A methodological approach proposed for regional railway costs estimation

The proposed estimation methodology accounts for major affecting factors, while being available in a simple and adaptable format. The proposed model considers investment cost for infrastructure, fixed equipment (such as stations) and rolling stock separately, as well as operating costs, in a fair process of allocation of them (Fig. 1). The unit cost parameters have been actualized to year 2013.

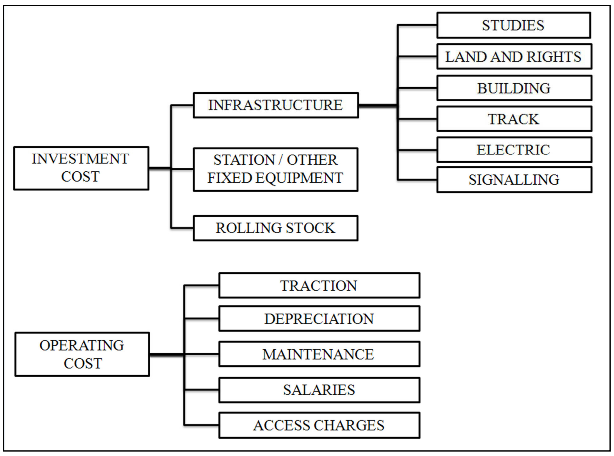

Fig. 1. Cost component of railways

3.1. Infrastructure investment cost

According to literature, the average construction cost for a new railway widely ranges between 1.5 M€ and 70 M€ per kilometer of line. It depends not only on the technology but mainly on the relief of the landscape. If there are a lot of hills and mountains, then there will be more tunnels and bridges to be built.

The infrastructure investment cost C_{INFR} can be applied to every gauge and is a sum of the following costs:

$$C_{INFR} = C_{STUD} + C_{LAND} + C_{BUILD} + C_{TRACK} + C_{ELEC} + C_{SIGN}$$

where the components are:
C_{STUD} for studies (feasability study, preliminary study and project);
C_{LAND} for land and rights;
C_{BUILD} for main infrastructure building works;
C_{TRACK} for the trackage;
C_{ELECT} for the electric traction equipment;
C_{SIGN} for the signalling systems.

The cost for studies C_{STUD} includes costs for feasability study, preliminary study and project. A range of 0.01-0.1 M€/km for both feasibility and for preliminary studies can be assumed , as well as 0.3-3% of the investment budget for project costs.

The cost for land and rights C_{LAND} can be related on the population density, widely ranging from uninhabited areas to highly-dense populated area.

Infrastructure building cost C_{BUILD} is assumed as a cost per kilometer of homogeneous portions of line, and includes: preparation of the ground, embankments, drainage, structures (walls, water ducts, bridges, tunnels, overpasses and underpasses), fences and noise-protection equipment, service access roads, interim financial charges, general expenses, initial additional maintenance. Tab. 2 reports typical infrastructure cost in case of easy topography, average topography, tunnels and bridges.

Table 2. Infrastructure costs per different topography. Source: own source, based on literature data.

Track	Easy (M€/km)	Average (M€/km)	Tunnels (M€/km)	Bridges (M€/km)
Single	1-3	3-15	10-50	10-20
Double	1-4	3-20	20-70	20-50

Track cost C_{TRACK} includes ballast, sleepers or crossters, rail fastening, rails, welds or fish-platings, laying, and initial additional maintenance. The following ranges of track cost per different rail masses can be assumed:

- 50 kg/m rail mass: 0.2 – 0.4 M€/km;
- 60 kg/m rail mass: 0.3 – 0.5 M€/km;
- 70 kg/m rail mass: 0.4 – 0.6 M€/km.

The costs of equipment for electric traction C_{ELEC} basically include the cost of substations and the cost of catenary. Furthermore, the electrification of an existing line also requires an investment cost to putting-up of the electrification gauge (for example, lowering the floor in tunnels, raising overpasses, etc) and for modification of signalling equipment along the track and in station, as well as telecommunications equipment.

The signalling cost C_{SIGN} may include cables, automatic block system, spot repetition of signal (automatic train protection or advanced train protection), cab signal (automatic train control), radio link between the dispatcher and the train, and level crossing with light and acoustic signals and automatic barriers.

Tab 3 reports typical ranges of electrification costs, as assumed from literature.

Table 3. Electrification and signalling costs. Source: own source, based on literature data.

Track	C_{ELEC} (M€/km)	C_{SIGN} (M€/km)
Single	0.5 – 0.9	0.3 – 0.5
Double	0.7 – 1.2	0.3 – 1.0

3.2. Fixed equipment investment cost

The fixed equipment cost C_{FIXED} include stations, locomotive service and repair facilities, maintenance shops for rolling stock, track, etc. Particularly, in the case of stations there is a huge variability between the cost for smallest stops (2-6 M€), that of a typical station (5-15 M€) and that of largest stations (reaching up to 100 M€).

3.3. Rolling stock investment cost

Rolling stock is the second relevant element in a railway project. The amount of trains needed for the service depends on the number of runs which have to be offered, with precautionary additional number of locomotives and railcars taking into account breakdowns and maintenance. Thus:

$$C_{ROLL} = \Sigma_i N_i \cdot c_{ROLL,i}$$

where N_i is the number of and $c_{ROLL,i}$ is the unit cost for the *i*-th rolling stock type. Tab. 4 indicates purchase prices for some different complete regional trains.

Table 4. Regional passenger services: characteristics of rolling stock. Source: own source, based on literature data.

Train model	Propulsion	N° of railcars	Capacity (*seats*)	Mass (t)	Cost (*M€*)
AnsaldoBreda TSR	Electric	3	306	158	5.44
Alstom Minuetto	Diesel	3	144	98	3.45
Alstom Minuetto	Electric	3	144	92	3.30
Bombardier Talent	Diesel	3	137	n.a.	3.80
Stadler GTW 2/6	Diesel	2	111	62	2.85
Stadler GTW 4/12	Diesel	4	237	136	5.72
Stadler Flirt	Electric	4	188	n.a.	5.80
Siemens Desiro	Diesel	2	123	n.a.	3.20
AnsaldoBreda RegioStar	Electric/diesel	8	326	250	7.62

3.4. Operating costs

Operating costs are those associated with operating a railway service. They are usually referred to one year of service and can be aggregated in many different ways. The proposed approach includes five different components: traction, capital depreciation or leasing costs of rolling stock, maintenance of rolling stock, salary for driving crew and on-board crew, and tolls for the use of infrastructures. Thus, operating costs model can be written as follows:

$$C_{OPE} = C_{TR} + C_{DEP} + C_{MAN} + C_{SAL} + C_{ACC}$$

Traction, maintenance and access charges costs are related to the number of train-km (*TKM*), defined as the product of number of runs (round-trip) and the total length of the line; depreciation cost is related to purchase price of rolling stock; salary cost is related to the amount of employees. Specification for each operating cost component is reported below.

Traction cost C_{TR} is related to the actual energy consumption, which depends on many factors, such as the mass of the train and its speed profile over full route. The total energy cost will be obtained by adding the cost of traction energy and auxiliary power forms consumed per seat-km, subtracting the cost of energy returned to the network and adding the distribution cost. The cost for running a train through a railway line (including that related to consumption for heating and air conditioning), can be determined for both electric and diesel trains as:

$$C_{TR} = c_P \cdot e \cdot TKM$$

where:
c_P is the unit cost of power source (€/kWh for electric trains, €/liters for diesel trains);
e is the unit consumption (kWh/km for electric trains, litre/km for diesel trains).

For electric trains regional services, unit consumption ranges between 3.5 and 5.5 kWh/km (Jong & Chang, 2005), with a unit cost of the electricity from 0.06 to 0.16 €/kWh. For diesel trains, assuming a consumption per mass unit of about 0.0045 l/t-km (Vaiciunas & Lingaitis, 2008), this results for regional trains in a unit consumption ranging between 0.45 and 1.10 l/km. The average unit cost of diesel is about 1.70 €/km.

The rolling stock depreciation cost C_{DEP} represents about one-third of the total cost of the service if the fleet is recent. If the fleet tends to be older, with an average age of 20 years or more (the period over which the depreciation is normally distributed), it can be already considered largely depreciated and this can reduce this cost on the order of 8 to 10% of the total cost. Assuming a straight-line depreciation over a period of *Y* years, depreciation cost of the entire fleet of rolling stock is:

$$C_{DEP} = \Sigma_i \, C_{DEP,i} = \Sigma_i \, (C_{ROLL,i} / Y)$$

where $C_{ROLL,i}$ is the investment cost associated with the *i*-th component of the fleet (€).

The rolling stock maintenance cost C_{MAN} can be calculated as:

$$C_{MAN} = c_{MAN} \cdot TKM$$

where c_{MAN} is an aggregated unit maintenance (2.5-3.5 €/train-km according with literature, with diesel's higher than electric's) taking into account different cost components, such as:

- fixed costs (including management personnel, accounting, documentation, technical office, etc.) as about 30–40% of total maintenance cost;
- variable costs for the replacement of items that wear out through use (5-10% of total maintenance cost);
- fixed and variable costs for operating the workshops (50-60% of total maintenance cost);
- cost for exterior and interior cleaning of rolling stock, representing 0.05-0.1% of total maintenance cost.

Regarding salary cost C_{SAL} , personnel providing services in the operation can be basically classified into two categories:

- personnel providing ground services, that can be operating personnel or indirect personnel;
- personnel providing services on board the train, such as drivers, conductors and ticket inspectors.

As no relationship has been appreciated in principle between their costs and the operational characteristics for ground personnel, these costs can be considered to be independent of service. On the other hand, personnel working on board the trains have a fixed working timetable (typically 36-40 hours a week), so an increase in operating hours results in an higher number of required personnel. Total salary cost can be calculated as:

$$C_{SAL} = \Sigma_i N_{GR,\,i} \cdot C_{GR} + \Sigma_k N_{ON,\,k} \cdot C_{ON}$$

where:
$N_{GR,\,i}$ is the number and C_{GR} is the salary of the *i*-th category of ground personnel (€/employee);
$N_{ON,\,k}$ is the number and C_{ON} is the salary of the *k*-th category of on-board personnel (€/employee).

When trains operate on tracks owned by another railroad company, there are access fees C_{ACC} charged by the owner of railroad, that is supposed to recover the marginal costs of track renewal and maintenance. On the other hand, if the route track is owned by the same company operating the rail service, this charging fees are replaced by infrastructure maintenance costs. Fig. 2 reports access charges for local and suburban trains in different European countries.

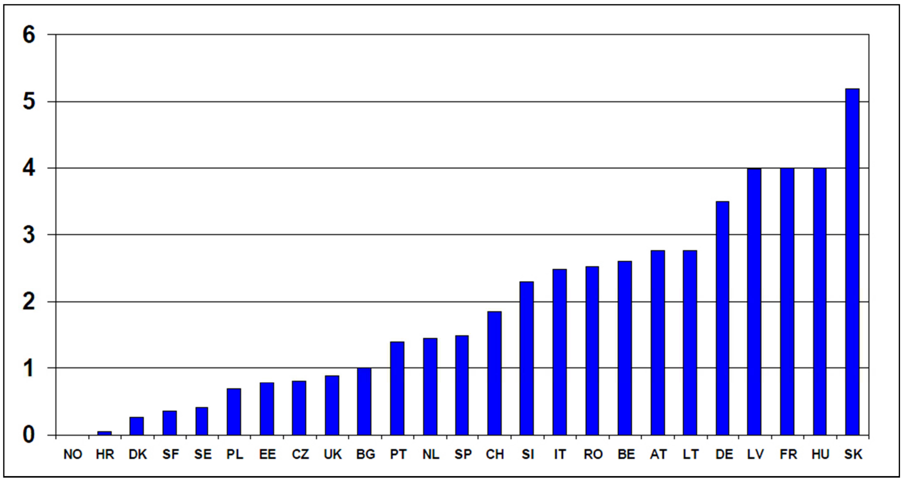

Fig. 2. Access charges for typical local and suburban trains (€/train-km). Source: Thompson (2008).

4. A methodology's comparison with European operating costs

The proposed methodology has been applied to evaluate the operating cost of a regional line and compare it with the average cost of regional railways services in three European countries (France, Germany and Italy). A sample line has been considered, whose operational characteristics of the test line are summarized in Tab. 5.

Table 5. Application – operational characteristics.

	Value		Value
Length of the line	L = 100 km	Frequency of service	q = 2 runs/h (roundtrip)
Commercial speed	v = 60 km/h	Number of Vehicles	N= int(q·T) = 7
Total travel time (roundtrip)	T = 3.33 h (roundtrip)	Number of stations	16

Assuming a 16 hours daily span *H* and no variation between working days and holidays, the total number of train-km per year results in 2,336,000 train-km.

Regarding rolling stock, in order to investigate cost in both electric and diesel railways a train existing in both versions has been considered (having a purchase price of 3.30 M€ for the electric and 3.45 M€ for the diesel one). Two further vehicles in stock have been considered, resulting in 9 trains (considered for the calculation of depreciation costs).

The model for operating cost is then applied, assuming specific values for each parameter of unit cost (Tab. 6). In particular, for the estimation of salary cost C_{SAL}, the following crew has been assumed for each train: a train drivers and a conductor (assisting passengers on and off the train when required and inspecting ticket); considering three working shift per day, this results in a total of 42 on-board personnel. Regarding the amount of ground personnel, 16 stations attendants (one per station) and further 30 (control system staff and administrative) have been considered, resulting in a total of 46. A 60,000 € year cost per employee has been assumed.

The total operating cost results in 8.34 €/km for the electric railroad and 9.66 €/km for the diesel railroad (+16% compared to electric). Average breakdown of cost is the following: 7% for traction 28% for access, 7% for depreciation, 33% for maintenance and 25% for salaries.

Table 6. Application case – Assumed unit costs

	Electric	Diesel
Unit consumption	$c_P = 0.09$ €/kWh	$c_P = 1.7$ €/l
Power/fuel unit cost	$e = 5$ kWh/TKM	$e = 0.45$ l/TKM
Maintenance unit cost	$c_{MAN} = 2.5$ €/TKM	$c_{MAN} = 3.5$ €/TKM
Access charges	$c_{ACC} = 2.49$ €/TKM	

The obtained values have been then compared with the average operating cost for regional services in the three different countries, in order to study the coherence with charging principles on which it is based.

Basically, in each analyzed country funding of regional service is done by allocating resources to the single region, which establishes the amount of train-km per year. Thus, the ratio between resources and train-km provides an average operating cost per km.

The analysis (Tab.7) shows a good consistence of model when compared with France and Germany. Regarding Italy, a further partition of the sample indicates that in southern regions the cost is 1.5 times higher than northern regions (still in coherence with the model). This result can be read as a lack of efficiency in the production of train-km.

Table 7. Comparison between model estimation and regional railways average operating costs.

	Sample data	*Source*	*Operating cost* (€/TKM)*
Model	Model estimation		9.00
Electric	"		8.34
Diesel	"		9.66
France	6 regions	www.ter-sncf.com	9.85
Germany	12 regions	ECMT, 2007	8.68
Italy	20 regions	Legambiente, 2011	12.17
Northen regions	*12 regions*	"	10.25
Southern regions	*8 regions*	"	15.06

*data actualized to 2013

5. Conclusions

This paper is meant to provide transportation planners and policy makers with a systematic process for estimating costs that are representative of the area and service in question, for analysis and decision making purposes. Although this methodology is not meant to replace the depth and detail of feasibility studies or professional railroad planning activities, it can be used as an intermediate tool to allow planners to more easily perform railroad analysis and planning activities on their own, prior to contracting out feasibility studies.

Further development of this research will be addressed to other categories of railway services, such as intercity and high-speed trains.

References

Baumgartner, J.P. (2001). Prices and costs in the railway sector. Laboratoire d'Intermodalité des Transports Et de Planification, Lausanne . Available at http://litep.epfl.ch/files/content/sites/litep/files/shared/Liens/Downloads/Divers/Baumgartner_Couts_chf_2001_e.pdf

Calvo, F., & De Oña, J. (2012). Are rail charges connected to costs? *Journal of Transport Geography* 22, pp. 28-33.

ECMT (2007). *Competitive Tendering on Rail Services.* European Conference of ministers of Transport. OECD Publishing, Paris.

Flyvbjerg, B., Bruzelius, N., van Wee, B. (2008). Comparison of Capital Costs per Route-Kilometre in Urban Rail. *European Journal of Transport and infrastructure Research* 8, n°1 (2008), pp. 17-30.

Garcia A. (2010). Relationship between rail service operating direct costs and speed. Study and Research Group for Economics and Transport Operation. International Union of Railways & Fundacìon de los Ferrocarriles Españoles.

Gattuso, D., & Meduri, G. (2006). Analisi dei costi e delle alternative di intervento (in Italian). In "*Sistemi di trasporto collettivo avanzati a media potenzialità: analisi funzionali ed economico-finanziarie*". Nuzzolo A., Festa D.C., Gattuso D., S. Gori S. (eds.). Laruffa Editore, Reggio Calabria, Italy.

ITF-OECD (2008). Charges for the use of rail infrastructure 2008. Available at http://www.internationaltransportforum.org

Jong J. C., & Chang E. F. (2005). Models for estimating energy consumption of electric trains. Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 278-291.

LEGAMBIENTE (2011). Rapporto Pendolaria 2011. La situazione e gli scenari del trasporto pendolare in Italia. Availbale at http://www.legambiente.it/sites/default/files/docs/dossier_pendolaria2011_0_2.pdf

Levinson, D., Mathieu, J. M., Gillen, D., & Kanafani, A. (1997). The full cost of high-speed rail: an engineering approach. The Annals of Regional Science. Springer-Verlag.

Mancuso, P., & Reverberi, P. 2003. Operating cost and market organization in railway services. The case of Italy, 1980-1995. *Transportation Research Part B,* Volume 37, Issue 1, January 2003, pp 43-61.

Nash, C. (2000). Modelling Performance: Rail. In: D.A. Hensher, & K. J. Button (Eds.), *Handbook of Transport Modelling* (pp. 565-575). Elsevier Science Ltd.

NTV (2012). Il pedaggio delle reti ferroviarie in Europa. Quaderno N.2. Ufficio Studi di NTV. Available at: http://www.ntvspa.it/it/ntv/pagine/992/Ufficio-studi-di-NTV---Quaderno-N2--Il-pedaggio-delle-reti-ferroviarie-in-Europa-.html

Olsson, N. O. E., Økland, A., & Halvorsen, S. B. (2012). Consequences of differences in cost-benefit methodology in railway infrastructure appraisal – A comparison between selected countries. Transport Policy, 22, pp. 29-35.

Ott, A. (2001). Comparable cost calculation for infrastructure of road and rail. Conference on Applied Infrastructure Research (InfraDay). Berlin. Available at: http://www.infraday.tu-berlin.de/

Pels, E., & Rietveld, P. (2000). Cost Functions in Transport. Rail. In: D.A. Hensher, & K. J. Button (Eds.). *Handbook of Transport Modelling* (pp. 321-333). Elsevier Science Ltd.

Santinelli M. (2007). Progetto per la riattivazione della linea ferroviaria Fano-Urbino. Relazione tecnico-illustrativa (in Italian). Available at: http://www.ferroviafvm.it/vecchio_sito/doc/progetto/Prog-Relazione%20linea.pdf

Thompson L. S. (2008). Railway access charges in the EU: current status and developments since 2004. OECD-ITF. Available at: http://www.internationaltransportforum.org

Vaiciunas G., & Lingaitis L. P. (2008). Comparing the performance of diesel locomotives for passenger transportation. *Transport Problems/Problemy Transportu 3-1.*

Van Hecke, G., Aubry, G., Hakenbeck, U., Leveritt, S., & Smith, P. (2003). High-speed railway construction projects. *The International Association of Engineering Insurers WGP,* 32 (03). Available at: http://www.imia.com/downloads/imia_papers/wgp32_2003.pdf

Van Vuuren, D. (2002). Optimal pricing in railway passenger transport: theory and practice in The Netherlands. Transport Policy 9, pp. 95-106.

Von Brown, J. T. (2011), A planning methodology for railway construction cost estimation in North America. *Graduate Theses and Dissertations.* Paper 10389. Available at: http://lib.dr.iastate.edu/etd