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# THE PROBLEM OF ROUTE ALIGNMENT IN BUS TRANSPORT NETWORK SYSTEM

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To my family and friends.

"An advanced city is not one where even the poor use cars, but rather one where even the rich use public transport"

Enrique Peñalosa

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## ABSTRACT

Nowadays, public transport is in constant competition with the dominant car usage in cities worldwide. Therefore, it is very important to encourage people to change their mode of private transport to public transport, which is an essential element in cities at contributing assertively to the environment and health of citizens. Hence, it is essential to provide optimum and attractive quality service of public transport. This leads to seek solutions to the problems that public transport networks present in every city where their quality depends greatly on the capacity of public transport to compete with private transport for daily trips in environments where car is dominant. In addition, it is known that bus system is the most common mode of transport around the world. Generally, the biggest problem of bus networks is the low quality of service that arise because of lack of planning strategies that can be noticed when new routes are added and existing service are expanded without any specific goals. One major requirement of passengers is traveling the shortest possible time to reach their destinations, so, it is essential to have a reliable and organized public transport service in order to satisfy users.

This work analyses the public transport network design with an emphasis on bus system through a literature review and a focus on route alignment. This study also presents a performance of the terminology route alignment by establishing the necessary elements that should be considered. In addition, this document analyses real implementation cases of public transport network optimization made by changes of the alignment of routes in four specific cities: Santiago de Chile, Berlin, Malta, and Porto. Finally, it is presented a simple numerical analysis of public transport of Viseu, where a specific bus route is taken and compared in different scenarios.

This research shows the importance of bus network design taking into account small practices such as route alignment. Also, this document expresses the importance of attending new implementations in public transport network of cities taking into consideration the citizen reactions generated, both positive and negative. This work creates a contrast on the public transport network planning between the scientific perspective on this issue and the traditional practical aspects that are performed in the real world knowing that the goal is not only to obtain a high quality public transport system, but also achieve a better quality of life of people living in cities. Finally, this study provides some final recommendations to take into consideration for future works.


KEYWORDS: public transportation, transit network design, bus network, route alignment, network implementation.

## RESUMEN

En nuestros días, el transporte público está en constante competencia con el dominante uso del automóvil en las ciudades en todo el mundo. Por lo tanto, es cada vez más importante alentar a las personas a cambiar su modo de transporte privado al sistema de transporte público, que es un elemento esencial en las ciudades contribuyendo de manera asertiva con el medio ambiente y con la salud de los ciudadanos. Para ello, es indispensable proveer una calidad de servicio de transporte público óptimo y atractivo. Esto conlleva a buscar soluciones a los problemas que las redes de transporte publico presentan en cada ciudad, donde su calidad depende de gran manera en la capacidad que tiene el sistema de transporte público de competir con el transporte privado para los viajes diarios en ambientes donde el coche es dominante. Además, se conoce que el sistema de autobuses es el modo de transporte más utilizado en el mundo. Generalmente, el mayor problema de las redes de autobuses es la baja calidad de servicio que presentan debido a falta de estrategias de planificación, que se puede notar cuando se van añadiendo nuevas rutas de servicio y se amplían las existentes, sin ninguna meta específica. Uno de los mayores requerimientos de los pasajeros es viajar el menor tiempo posible para llegar a sus destinos, por lo que es fundamental contar con un servicio de transporte público fiable y organizado para satisfacer a los usuarios.

Este estudio presenta un análisis sobre el diseño de redes de transporte público con un énfasis en los sistemas de autobuses a través de una revisión de la literatura disponible, buscando un enfoque en el alineamiento de los recorridos de las rutas. Este trabajo también presenta una caracterización del término de “route alignment” o ”recorrido de la línea” estableciendo los factores necesarios a tener en cuenta. Además, en este documento se analizan casos reales de implementación de optimización de redes de transporte público a través de cambios, como el alineamiento de rutas, en cuatro ciudades específicas: Santiago de Chile, Berlín, Malta, y Porto. Finalmente se presenta un simple análisis numérico de la red de transporte público de Viseu, donde se toma una ruta de autobús específica y se realizan comparaciones en diferentes escenarios.

Esta investigación muestra la importancia del diseño de las redes de sistema de autobuses teniendo en cuenta pequeñas prácticas como la linealidad de las rutas. Además, muestra la relevancia del cuidado al implementar cambios en las redes de transporte público de las ciudades teniendo en cuenta las reacciones que genera en la ciudadanía, tanto positivas como negativas. Este trabajo crea un contraste sobre el planeamiento de redes de transporte público entre la perspectiva científica de este tema y los tradicionales aspectos prácticos que se realizan en el mundo real, conociendo que el objetivo no sólo es obtener una alta calidad del sistema de transporte público, sino también lograr una mejor calidad de vida de las personas que viven en las ciudades. Por último, el presente estudio provee algunas recomendaciones finales para considerar en trabajos futuros.


PALABRAS CLAVE: transporte público, diseño de redes, redes de autobuses, recorrido de ruta, implementación de redes.

## RESUMO

Hoje em dia, o transporte público está em constante competição com o uso dominante do carro nas cidades em todo o mundo. Por isso, é cada vez mais importante incentivar às pessoas de mudar o seu modo de transporte privado para o sistema de transporte público, que é um elemento essencial nas cidades para contribuir ao meio ambiente e a saúde dos cidadãos. Portanto, é essencial proporcionar qualidade de serviço de transporte público óptima e atraente. Isto leva à procura de soluções para os problemas que as redes de transportes públicos apressentam em cada uma das cidades, onde a sua qualidade depende muito da capacidade do transporte público de competir com o transporte privado para viagens diárias em ambientes onde carro é dominante. Além disso, sabe-se que o sistema de autocarros é o modo de transporte mais usado no mundo. Geralmente, o maior problema das redes de autocarros é a baixa qualidade do serviço que surgem devido à falta de estratégias de planeamento que pode ser notado quando novas rotas são adicionadas ao serviço e expandem-se as existentes, sem qualquer objetivo específico. Uma das principais necessidades dos passageiros é viajar o menor tempo possível para chegar até os seus destinos, portanto é essencial ter um serviço de transporte público confiável e organizado para satisfazer aos usuários.

Esse estudo apresenta uma análise sobre o desenho de redes de transportes públicos com ênfase nos sistemas de autocarros através de uma revisão da literatura disponível, à procura de um foco nos percursos das rotas. O trabalho também apresenta uma caracterização do termo "route alignment" ou "percurso da linha" estabelecendo os fatores necessários a considerar. Além disso, aqui analizam-se casos reais de implementação de redes de transportes públicos optimizadas através de alterações, tais como o alinhamento de percursos de rotas, em quatro cidades específicas: Santiago de Chile, Berlim, Malta e Porto. Finalmente, apressenta-se uma análise numérica simples do transporte público de Viseu, onde uma rota de autocarro é tomada e comparada em diferentes cenários.

A pesquisa amostra a importância do desenho de redes de autocarros, tendo em conta pequenas práticas como a linearidade de rotas. Também amostra a importância do cuidado na implementação de mudanças nas redes de transportes públicos das cidades tendo em conta as reações geradas pela cidadania, seja positivas como negativas. Esse trabalho cria um contraste sobre o planeamento das redes públicas de transporte entre as perspectiva científica sobre a questão e os aspectos práticos tradicionais que são realizados no mundo real, sabendo que o objetivo não é apenas obter um sistema de transporte público de alta qualidade, mas também alcançar uma melhor qualidade de vida para as pessoas que vivem nas cidades. Finalmente, este estudo fornece algumas recomendações finais para considerar em trabalhos futuros.


PALAVRAS-CHAVE: transporte público, desenho de redes, redes de autocarros, percurso de rota, implementação de redes.

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## ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ACO | Ant Colony Optimization |
| ADT | Malta Transport Authority |
| AI | Artificial Intelligence |
| AMP | Area Metropolitana do Porto |
| ATP | Public Transport Association |
| BRT | Bus Rapid Transit |
| BTNDP | Bus Transport Network Design Problem |
| BVG | Berliner Verkehrsbetriebe |
| CBD | Central Business District |
| CCTV | Closed-Circuit Television |
| COMV | Centro de Operações de Mobilidade de Viseu |
| ES | Exhaustive Search |
| GA | Genetic Algorithm |
| GIS | Geographical Information System |
| GPS | Global Position System |
| HSP | Heuristic Search Procedure |
| IGEB | Berliner's Passenger Association |
| MPT | Malta Public Transport |
| MUV | Mobilidade Urbana de Viseu |
| PTUS | Plan de Transporte Urbano de Santiago |
| RGA | Route Genetic Algorithm |
| RIA | Route improvement Algorithm |
| SA | Simulated Annealing |
| SS | Stochastic Simulation |
| STCP | Sociedade de Transportes Coletivos do Porto |
| STUV | Serviços de Transportes de Viseu |
| TNDP | Transport Network Design Problem |
| TNP | Transport Network Planning |
| TRUST | Transit Route Analyst |

# 1
# INTRODUCTION

## 1.1 FRAMEWORK

Nowadays, private car usage is dominant in most cities from urban regions all over the world, generating congestion, pollution, and it is increasing. Public transport has to compete with this reality every day. It is known that public transport is an essential part of the urban structure of a sustainable city, as it allows people to achieve their daily activities (work, study, leisure, etc.) and at the same time contributes to the quality of the environment and citizen's health. Encouraging travellers to shift their mode of transport away from private transport is being increasingly important.

Transport planning in many cities has been focused on supply-side measures further promoting private car usage. Some solutions, such as additional road construction or inadequate traffic management schemes, have been adopted taking into account rather private vehicles movement than the real need and comfort of all.

The tendency of small and medium-sized cities is to develop bus network as the leading public transport system because smaller populations and consequently lower passenger demand mean that expensive infrastructure such metro system or heavy railway cannot be justified. Nevertheless, very often public transport is based on relatively low quality bus service. One common problem about bus transport network is the evolution of the system without any planning strategy, as can be seen when new line services are constantly added and existing ones are extended.

Public transport service quality depends not only on comfortable vehicles, bus lanes or a costly light rail system, but also depends on the capacity to compete with private transport for everyday travel in environments where the car and motorcycle ownership is dominant. In addition, travel time is one of the major key aspects when people choose to go by public transport or not. Routes with high frequency means reliable and attractive service, but in smaller urban areas the route network design is precarious and it is more difficult to create high frequency service.

Extra travel time causes dissatisfaction to public transport users. This aspect is not always well understood in practice, and it is probably one important reason for the decline in public transport market. Transport network design is a key element of urban mobility planning, therefore, it has to be studied in order to improve the service with a sustainable vision of a reliable and efficient public transport system. The purpose is not just to obtain high quality of public transport system; the purpose is to achieve high quality of people life in cities.

## 1.2 OBJECTIVES

In this study, the objective is to explore the potentiality of bus transit network design in terms of route alignment in order to benefit both requirements of passengers and operators and contribute at improving the bus system making it more attractive and competitive with the private car.

## 1.3 METHODOLOGY

In order to facilitate the reader a first approach to the subject of this study, this section serves to present the methodology used. The research problem was identified through an investigation of real world problem about bus network design. To solve the problem were defined objectives and appropriately questions.

With the purpose to analyse the bus network design and specifically the route alignment of the networks, it has been essential to direct this dissertation in two main stages. First, it is presented a literature review with the current state of art of the transport network design in order to define key aspects. Therefore, by collecting and organizing the information available, the literature review figures a support able to illustrate the diverse issues that have been analysed by different researchers about transport network design problems, as well as bus route network design problems. Additionally, for a better understanding, this document starts with an introduction about important considerations taken in the transport planning process.

Then, on the second stage it is presented an analysis of different case studies about real situations of bus network implementations by optimizing route alignment, mainly by collecting information using annual reports, state policies, statistical summaries and newspapers. Also, a numerical case study was analysed in depth through simple GIS-technique measurements with the purpose to break them down into parameters. This is used as validation of the analysis reliability.

In sum, it was used qualitative method in order to examine the importance of decision making in a transport planning process, including and understanding the social behaviour in urban areas.

## 1.4 STRUCTURE

The study is basically composed of seven chapters in total. The first one briefly presents the background of the work, identifies the research problem and defines the objectives and questions.

Chapter two defines important considerations about public transport system and identifies some key elements for the transport planning process focusing on the daily life of the people and the structure of the city, considering health, environment and economics.

Then, chapter three performs the literature review of the principal topic Transit Network Design Problem (TNDP) highlighting the Bus Network Design Problem (BNDP) and considerations that take into account the bus route alignment. It is organized in three main sections: (i) conventional analytical models, (ii) heuristics and metaheuristics approaches, and (iii) practical guidelines and ad hoc procedures. Finally, a summary of the literature and a discussion complete this chapter.

Chapter four summarizes the available information about route alignment existing in the literature review and presents a characterization that can be used in order to define the concept of bus route alignment.

The fifth chapter describes four real examples of optimized network implementations of public transport systems, specifically the cases of Transantiago (Santiago de Chile), BVG (Berlin), MPT (Malta) and STCP (Porto). This is mainly based on journal information, publications, statistical summaries, and blogs.

Chapter six presents a case study on STUV (Viseu Urban Transport Services) describing the process of optimizing the route alignment of the bus network system. The case study has been divided in two main parts. Firstly, it defines the characteristics of the city and the region that plays an important role to the movement of the city. Secondly, through collected data it is measured parameters defined by simple GIS-techniques and summarized some performance qualities.

In the last chapter is found the conclusions of the dissertation and the most relevant impacts of the route alignment in bus transport network system.

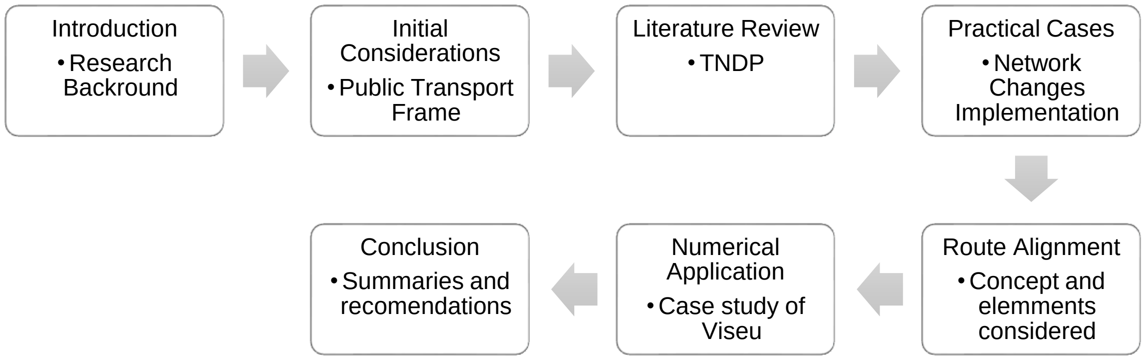



Figure 1: Structure of the work.

# 2
# INITIAL CONSIDERATIONS

## 2.1 INTRODUCTION

This chapter aims to clarify some elements that are fundamental to comprehend urban transport planning in a first interaction. So, it will be presented some concepts and the current situation in order to introduce the topic of this study.

## 2.2 URBAN MOBILITY

Conceptually, urban transport is involved with urban form and structure and has been increasing the importance with the urbanization process in cities in the last decades. People have more necessity to access to work places, health establishments, institutions and other activities that current society perform regularly. Very often this tendency is an obstacle to a well-planned urban development. Additionally, other considerations such as economical or cultural aspects are linked to the planning philosophy adopted by cities.

It is known that transportation infrastructure represents clearly an economic growth and welfare for current urbanization. Despite the advantages of transportation, they end up being one of the most responsible of excessive energy consumption, air pollution, roads accidents and congestion that our cities suffer. There are several factors to transport problem, most of them are related with the domain of private vehicle traffic that have been the predominant mode of transport in many cities. Therefore, cities have been developing public transport systems to meet the travel needs and contribute to the environment.

Beirão and Sarsfield Cabral (2007) in their work stated that generally “the car is the most attractive mode of transport, convenience, speed, comfort and individual freedom are well-known arguments”. So, this signify that public transport systems need service adjustments in order to satisfy the users requirements and become more attractive for them and influence a modal shift.

It is perceived that public transport competes directly with private car. Not only is it the travel from place to place important, but also the time consuming traveling with any mode of transport system. There are several aspects that must be taken into account when analysing the best choice of urban transport for a city, consequently, several researchers are aiming at improvement of public transport as the best practice to attract more travellers and motivate other users to shift their transport mode.

## 2.3 MARKET AND USERS

Transport market is the expression that deals with the distribution of resources within the transport area involving basically demand and supply. So, transport demand refers to the transport needs, how many and which type of people would choose, under specific conditions, the transport option available. Transport supply is related with the infrastructures, services and networks of the offered transport system.

There are several combined factors that influences the people choice to use one or another type of transport system and generally are reduced to quality, prices and travel behaviour. As Tirachini *et al*. (2014) described “demand is sensitive to the overall quality of service, which in turn depends on the design of the system, hence understanding the economic nature of urban public transport operations is crucial as a means to ensure the efficiency of a public transport network”.

In transport planning and network design for a particular urban area it is elementary understand the market, users and non-user’s requirements. Each urban agglomeration presents specific travel markets and behaviour of their customers and potential users. A good public transport system serves the different requirements that are made every day in a city. However, it is very difficult to design one whole system that fit to everyone.

Therefore, professionals and academics recommend to analyse individual markets integrating diversified services and considering origins and destinations, time travel and trip purpose (Anable, 2005; Beirão and Sarsfield Cabral, 2007; Stradling *et al.*, 2007). Understanding that different customer segment evaluates the same service provided by different attributes is very important to consider in the market analysis. Naturally, each urban market evaluates the services according to some properties and manners.

Beirão and Sarsfield Cabral (2007) made an important quality study of car and public transport users about their attitudes towards transportation, results are shown in Table 1, where is possible to find motivations and barriers that public transport generates. The principal motivations resulted to use public transport were good service, timetables reliability and direct travel from home to work. On the other hand, the main barriers were not having a car, the lack of direct routes and lack of number of buses or frequencies.

Another important concern that users commonly take into account is the cost of the service that is influenced by the cost-efficiency of the operations, which turns in other factors cost, such road network design, vehicles speed, etc. It is not about adapting the service to all different market demands, but it is important to improve the approach that the system presents to the current and potential users. Many researches confirm that the development of a transport network that present robustness, attractiveness, open to all the public and designed for universal accessibility, reduce the need for special and difficult solutions (Beirão and Sarsfield Cabral, 2007; Pternea *et al.*, 2015).

Another typical concern about demand for public transport is the weaker demand. The smaller the city and less density, the harder it is to provide high frequency services that can be competitive to the private car. It is essential to identify the potential strengths and weaknesses of public transport systems in order to manage the service aimed to increase the market.

Besides, practical experiences demonstrate that political ambitions for public transportation are a key that supports the market, otherwise the supply of service can be totally left to the operators working in a free market. Therefore, the market is also conditioned by local institutions, coordinating and integrating services that involves efficient use of resources, in order to secure a just and efficient competition between the operators.

Table 1: Motivations and barriers to public transport use. Adapted from Beirão and Sarsfield Cabral (2007).

| Motivations | Barriers |
|---|---|
| Better service | Not having alternative to car |
| Reliability | Lack of direct transport |
| Direct transport from home to work | Lack of availability of buses |
| More information available and easy to understand | Long travel time |
| Save money | Buses unreliability |
| Not having a parking space | Do not known what to expect |
| More comfort and air conditioning on vehicles | Need for multiple journeys |
| Contribute to a better environment | Poor information |
| | Not frequent enough |
| | Bus stops too far |
| | Buses are smelly and crowded |
| | Feeling of personal insecurity |
| | Having to use more than one transport |
| | Bad waiting conditions |
| | Negative feelings towards public transport |
| | Habit of driving |

Finally, the challenge for planner's perspective related to serve travellers with different needs and motivations, involves attractive services and operations in a wide range of characteristics, and lays in the innumerable compensations that need to be considered in order to establish the best service design. Tirachini *et al*. (2014) explained this with clear examples: increasing bus frequency reduces waiting time for users but increases the cost of operation; increasing the number of bus stops reduces users access time but increases bus riding time for all-stop services; and investing in a better fare collection technology and road infrastructure for buses reduces bus travel time (and consequently may reduce operating cost) but increases investment costs.

There are so many different considerations for public transport that finally the point is to have the capability to combine user's behaviour and service offered to obtain a suitable transport market. So, the challenge depends on the set of strategies that each city considers the best.

## 2.4 RELIABILITY

A fundamental issue in transport service is reliability commonly defined as the probability that a transport system has the ability to perform a desired service to a satisfactory level in a defined period of time. In other words, reliability is the "on time" performance of a service. Recently, the transit reliability has been included by many researchers and practitioners of transportation due to its importance in the improvement of transport service quality.

Reliability on the bus service is one of the key factors in the choice of transport, because "arriving on time" is a desire of almost all passengers. Some authors recommend some specific treatments for bus services in order to improve reliability and reduce travel time, such as implementing exclusive bus lanes and transit signal priority on routes, among others (Beirão and Sarsfield Cabral, 2007; Chen *et al.*, 2009).

The total travel time of a transport is directly related with the speed of travel, which in turns it is affected by route directness and alignments. Creating lines that go as straight and direct as possible between the points of travel demand can impact the service positively and be more reliable. "Reliability involves routes, stops, punctuality, deviation, and evenness" (Chen *et al.*, 2009).

Travel time and reliability are factors that several researchers and professionals confirmed again and again that are determinants of transport decisions, especially for those trip purpose related to school and work activities. This issue affects strongly the attractiveness of the service, the demand, and the costs of operation.

## 2.5 PLANNING IN DIFFERENT INSTITUTIONAL SETTINGS

Transport service is an important component of contemporary society to produce significant benefits, however, it need to adopt appropriate planning (policies, design, etc.) to ensure high quality of service, both by public and private sector. Public transport system is considered as one fundamental support of urban structure and development and the success of public transport planning involves understanding the organisational structure and the interaction between institutions that are part, as well as the dynamics of the public transport sector.

In the last decades, owing to the increasing urban mobility demand, many cities have been given significant importance to an efficient public transportation agency or organisation. The institutional setting defines and commands the public transport system to the citizen as a basic service for the community and has the right to determine or change the offered services. Consequently and as Ceder (2004) described, government and community decisions influences the individual choice between public and private transport.

In practice, local government commonly are constrained by limited budgets which does not always allow implementation of the identified optimal transport service. Therefore, studies look for an optimal balanced solution in an effort to be both practical and optimal. In this way it is essential to take into account other stakeholders that support transportation strategies: local authorities, neighbourhoods, social activist, environmentalists and others. Any intervention in public transport is focused on particular objectives and there are opportunities to develop cooperation between all participants.

The good management methods between the different entities (local, regional or central organisation) can have an impact on the success of transport planning improving liveability of the cities. However, practitioners based on their experiences recommend the establishment of a single organisational entity with the responsibility for all public transport within an urban region. Ideally, this regional body should not only ensure coordination between different levels of public transport, but also with other agencies concerned with traffic (e.g. parking and pedestrians) and urban planning more generally.

There are some guidelines, for example the European Union's HiTrans Nielsen *et al.* (2005) that recommend a regional public transport agency for an effective transit network in the city. The public transport government and their regulation, management and distribution plays the fundamental role when there are conflicts between public needs and private sector. For instance, low demand areas and off peak hours would be inadequately served by a private sector that is guided by profits, and consequently the service would be unreliable and uncompetitive. So, an effective market regulation performed by a proper governance is an important key.

The political authorities can also be players in transport projects through the legislative environment they create in order to restrict variables such as transport fares, operator subsidies, and so on. Many decisions related to the operation and development of a transport system are politically motivated. In a way, the satisfaction of the customers, voters and politicians is an essential condition that conduct support for public transport developments.

Transport planning is taken to be all those activities involving the analysis and evaluation of past, present and prospective problems associated with the demand for the movement of people, goods and information at a local, national or international level and the identification of solutions in the context of current and future identification of economic, social, environmental, land use and technical developments and in the light of the aspirations and concerns of the society which it serves (Transport Planning Society, UK). Transport planning deals with the preparation and implementation of actions designed to address specific problems.

### 2.6 THE ROLE OF MULTIMODAL TRANSPORT

Public transport system is essentially based on the movement of passengers through a specific line. It is very difficult that one individual line of bus or rail services can serve all combinations of passenger needs. In practice, public transport concentrate travellers in selected routes and some journeys cannot be directly connected and transfers becomes necessary to provide connection within a city. In the last decades, several modes of public transport have been developed in urban areas (bus, metro, tram, etc.) in order to improve travel service taking into consideration the diverse demand.

Van Nes (2002) named as multimodal transport when two or more transport modes are used for a trip between which a transfer is necessary. This is already an interesting approach to improve the transport problems of our times, considering the expanded origin-destination demand pattern.

So, one common examples of multimodal travel are making a long trip by train and integrate it with other mode such as bus system or bicycle. In general, the multimodal transport is used to combine private and public transport service to access to the city centre or the destination required. A big number of analysis shows that the main factors that determine multimodal transport use are the following: travel distance, destination area type and trip purpose (Van Nes, 2002). Therefore, long distance commuting is most likely to be multimodal travel.

One major topic for academics in multimodal service is how to improve integration between all other options (Ceder, 2004; Song *et al.*, 2012). Bus transit system is generally an important piece of a multimodal transport system. Several studies confirmed that bus transport may be part of the overall multimodal transport system (Wang and Qu, 2015).

Transfers are important variable decisions when analysing multimodal transport system. The lines of different modes of transport concur to the same interchange point and they are usually very recurring by passengers that wait for their best route and as easier the transfer, the better the service.

Moreover, Song *et al*. (2012) states that “there are almost an infinite number of ways that bus networks can be adjusted or integrated with another type of transportation”. The project presented by these investigators developed a method for multimodal transport corridor that provides a way to quantify interest of government, public transport travellers and the bus company in order to achieve the best optimization based on a mix of variables such as bus level service, bus route structure, operational cost as well as total travel time and number of transfers.

Furthermore, Van Nes (2002) described that multimodal transport requires good arrangements between all organisational and financial actors involved. The multimodal network is the most important component of a multimodal transport system, due to the diversification of actors, such as private transport, public transport and other services.

## 2.7 BUS TRANSPORT SYSTEM

Buses are an essential part of transport in almost every urban environment and it is the most common mode of transportation in many cities. It is a flexible type of transport that serves different travel purposes providing basic mobility and accessibility.

Most cities have been commonly adopted bus network as the best public transport system. Firstly, because of the economic and financial aspects. Bus system are less expensive than other type of transportation such metro or train system and smaller cities have usually lower income to invest on heavy transport system. Considering the finances of different levels of government (central, regional and local) and the investment that other type of transport requires, a bus transport system is also a major choice in urban areas. Moreover, because of the flexibility that signify these scheme, creating more possibilities to change and redesign according to the needs.

But, bus transit system is not as simple solution to urban mobility as it seems, especially because of the competence with private car and other private transport choices such as motorbike or taxi. The number of customers on buses depends on many characteristics that the service offers, such as travel time, fares, comfort, and others.

The bus network design is the one that manages the first step of the whole system and plays a very important role considering demand changes and a set of circumstances that make a dynamic city development. The components of a bus system are essentially a series of routes where passenger load and unload, and the frequency which consist in a specific bus schedule operation that in real life strongly depends on the route network structure and the traffic congestion.

In many cities around the world, the mobility planners continue to design their bus networks under his practical concepts with or without the assistance of other computational tools. However, different approaches have been conducted by several researchers to solve bus network design problems, but in general the solutions resulted by mathematical models and computational optimizations are usually considered by planners as recommendations and often they finish modifying the solutions using their own experience, because of the complexity and difficulty to implement such approaches on real situations.

# 3
# LITERATURE REVIEW ON TNDP

## 3.1 INTRODUCTION

It is pinpointed that public transport is a basic and complex issue for urban development and transport network directly influences the morphology (structure and form) of a city generating particular characteristics. Also, it is known that public transport service performance depends on many factors such as planning and design, market and costumers, institutions and authorities, policies implemented, among others; the continuous interaction between all those elements need multiple fundamental decisions.

First and very important to understand is that transport planning has the fundamental and cumbersome purpose to carry people with different travel origins and destinations in the same vehicle and this issue implicates many other considerations that should be taken into account by transport planners. In the context of this work, as said before, bus transport system is the most common mode of public transport in many cities worldwide owing to the flexible characteristic that serves different travel purposes providing basic mobility.

In the last 50 years, transport planning has been extensively studied by researchers and practitioners. Generally speaking, the design of a transport network addresses finding the optimal set of route configuration and the associated service frequencies in order to reach the desired goals with the given constraints of the city. But this is not a simple activity. In the review of Kepaptsoglou and Karlaftis (2009) it is expressed that "the design of a public transportation network is driven by different (often contradicting) objectives and affected by a multi-attribute design environment". The design of a transport network structure helps to meet dilemmas and satisfaction of the different user's requirements.

In this order and taking into consideration the objectives of this study, the analysis of the literature review will be focused on Transport Network Design with an emphasis on Bus Transport System. To clarify typical denominations of this subject in the literature, it is adopted the terminology Transit Network Design (TND) as it is better known in the investigation fields. Then, to simplify the literature analysis, it is presented in three sub-divisions and then it is shown a table that summarizes all the works studied.

## 3.2 TRANSIT NETWORK DESIGN PROBLEM (TNDP)

The last decades have been important for transport planning development based on new strategies and technologies solving design concerns (algorithms, large data sets). Since the 1960s until nowadays, transit network design has attracted the attention of many researchers all around the world (Lampkin and Saalmans, 1967; Dubois *et al*., 1979; Ceder and Wilson, 1986; Baaj and Mahmassani, 1991; Gao *et al*., 2004; Yao *et al*., 2014).

The researchers have identified Transit Network Design Problem (TNDP) as one category of the whole Transit Network Planning (TNP), which in turn is presented as a group of sub-problems that span tactical, strategic and operational decisions (Ibarra-Rojas *et al.*, 2015). TNDP defines the geometric characteristics of the routes and the associated operational activities, such as route length, deviations, spaces between stops, etc. More specifically, Bus Transit Network Design Problem (BTNDP) is the field that studies the bus system in the context of public transport planning.

Several authors reviewed publications on this topic. For instance, Guihaire and Hao (2008) presented a review on the design and scheduling problems of the network that they set as "the crucial strategic and tactical steps of transit planning". Kepaptsoglou and Karlaftis (2009) also confirmed that different approaches have been explored on Transit Route Network Design Problem (TRNDP) and showed a variety of methodologies at representing and solving problems. Moreover, Ibarra-Rojas *et al.* (2015) presented a literature review about optimization approaches of bus transport systems dividing the problems into strategic, tactical and operational levels. In Table 2 are presented the aforementioned works with information about each one.

Table 2: Summary of the principal literature review analysed.

| Year | Author | Title | Number of papers | Focus point |
|---|---|---|---|---|
| 2008 | Guihaire and Hao | Transit network design and scheduling: A global review | 69 (TNDSP: Transit Network Design System problem) | Design and scheduling problems of transit network |
| 2009 | Kepaptsoglou and Karlaftis | Transit route network design problem: Review | 62 (TRNDP: Transit Route Network Design problem) | Design, operation and solutions of transit route network problem |
| 2015 | Ibarra-Rojas et al. | Ibarra-Rojas et al. | 45 (TNDP)<br>22 (TNFSP)<br>27 (TNTP)<br>18 (Vehicle Scheduling)<br>21 (Driver Scheduling)<br>6 (Driver Rostering)<br>17 (Real-time control process)<br>Total: 156 | Transit network planning problems (design, frequency setting, timetabling) and real-time control strategies for bus transport systems |

As mentioned before, Guihaire and Hao (2008) presented a global review of the design and scheduling on strategic and tactical steps of transit network planning. They affirmed that "these steps influence directly the quality of service through coverage and directness concerns but also the economic profitability of the system since operational costs are highly dependent on the network structure". After a descriptive analysis of 69 different works, the authors classified them into the following features (both theoretical and practical): design, frequency setting, timetabling and their combinations. They highlighted the main characteristics of each paper, the various problems tackled and the solution methods used. They concluded that the global problem of Transit Network Design problem (TNDP) “is computationally intractable and can hardly be tackled at once […] and there are two ways to undertake this problem: innovative solutions methods and pertinent problem subdivision”. The authors affirmed that the benchmark studied are basic data and can be used for algorithm comparison purpose, but for real-world applications it would be necessary more detailed data. Finally, they stated that “interaction between researchers and transport companies will continue to improve the efficiency of the methods and thereby the profits of the companies as well as the quality of service to the users”.

The literature review of Kepaptsoglou and Karlaftis (2009) presented a structured analysis (for both researchers and practitioners) of the three main layers of Transit Route Network Design problems (TRNDP): design objectives, operation parameters and solution methods. The authors said that “design of a public transport network is driven by different often contradicting objectives and affected by a multiattribute design environment”. The review composed by 62 studies presented different approaches, from analytical methods to advanced metaheuristics. The study stated TRNDP as a potential field for future investigations, specially to more useful solutions for real world models. In this sense, the authors recommended to investigate TRNDP design parameters in a more detailed and realistically way, in accordance with the computational advances. The authors also concluded that in conjunction with the researches methods, “it would be useful for researchers to investigate the opinion, needs and requirements of practitioners with respect to the outputs of existing models”.

More recently, the work of Ibarra-Rojas *et al.* (2015) presented an extensive literature review on Transit Network Planning problem (TNP) in terms of planning, operation and control of bus transport systems. The authors divided the different problems into strategic, tactical and operational decision levels. Now, Transit Network Design Problem (TNDP) represent the strategic stage, Frequency Setting and Timetabling problems (TNFSP and TNTP) were part of the tactical stage. For the operational level, the authors presented also a review of Vehicle and Driver Scheduling problems. All these decision levels are important factors on transit systems optimization. The authors concluded that despite the current “development of models and solutions techniques to address relevant decision problems in bus transport systems, there are still many open research questions”. One interesting opportunity is the integration of problems and the amount of data that can be generated through tools such GPS that allow us to consider more robust transit planning and operation.

One remarkable work is from Ceder and Wilson (1986), which presented for the first time a framework for bus network planning as a sequential system process, which consists of the following levels: network design, frequency setting, timetable development, bus scheduling and driver scheduling, as can be seen in Table 3. The first two stages are usually performed by regulator organisms, i.e. Government, Municipal Authorities, Public Agencies, etc., while the last three stages are usually performed by operator services, transport companies and so on. the authors said that a comprehensive solution depends on the individual solution of each stage. And it is also reasonable to think that feasible solution of the three last stages are conditioned by the decisions made in the first two.

Table 3: Sub-problems of the bus network planning process (Ceder and Wilson, 1986).

| Independent inputs | Planning activity | Outputs |
|---|---|---|
| Demand data<br>Supply data<br>Route performance indices | Level 1:<br>Network Design | Route changes<br>New routes<br>Operating strategies |
| Subsidy available<br>Buses available<br>Service policies<br>Current patronage | Level 2:<br>Setting Frequencies | Service frequencies |
| Demand by time of day<br>Times for first and last trips Running times | Level 3:<br>Timetable Development | Trip departure times<br>Trip arrival times |
| Deadhead times<br>Recovery times Schedule constraints Cost structure | Level 4:<br>Bus Scheduling | Bus schedules |
| Driver work rules<br>Run cost structure | Level 5:<br>Driver Scheduling | Driver schedules |

Those sub-problems are strongly interdependent and involve activities and decisions that influence other characteristics of the whole system. The review of Ibarra-Rojas *et al.* (2015) illustrated this interaction (see Figure 2), where the output of each level affects the following level. It is fundamental to have a comprehensive approach taking into account all factors towards solving TNP, however, each sub-problem can be difficult to solve individually.

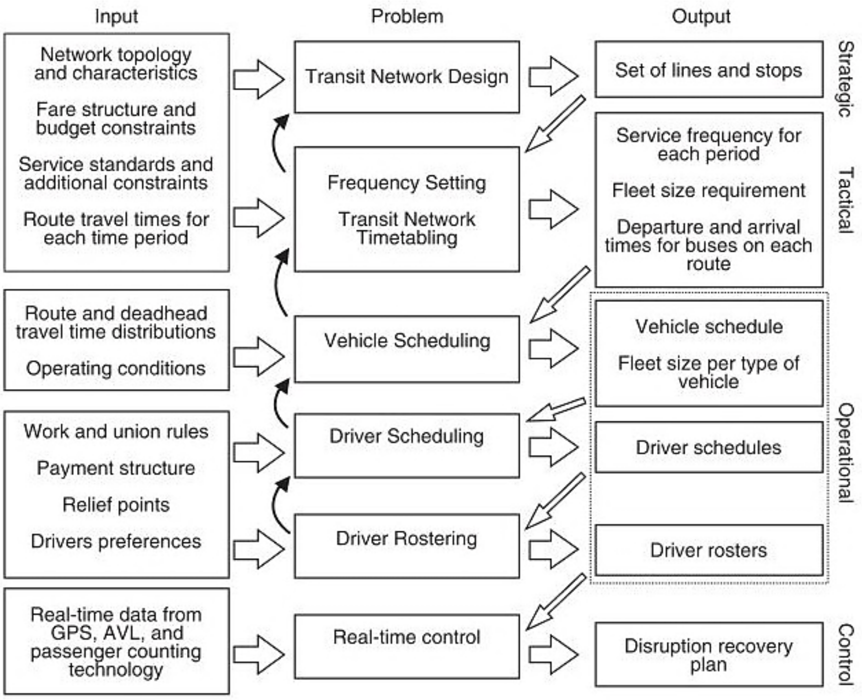



Figure 2: Interaction between stages of the planning process (Ibarra-Rojas *et al.*, 2015).

After analysing the above-mentioned works and following the framework of this study, there were selected a set of papers related to Transit Network Design Problem (TNDP) in order to analyse the current state of the art in this field.

## 3.3 LITERATURE REVIEW ON TNDP

Basically, as Guihaire and Hao (2008) expressed "TNDP consists in determining a set of routes, each being formed of two terminals and a sequence of intermediate stops, given a trip demand distribution, an area's topologic characteristics and a set of objectives and constraints". So, routes are the basis of any public transport planning. The papers studied herein were also selected in terms of parameters and objectives, which were connected with routes characteristics (route length, route directness, overlapping routes and so on).

Several studies analysed have solved TNDP through different approaches, taken into account different study focus points, namely objective problems, varied parameters, constraints and decision variables, as well as the diverse methodology adopted and the data set used for their method applications.

Guihaire and Hao (2008) divided their review depending on the method of solution of the papers: mathematical, heuristics, neighbourhood search, evolutionary and others. Kepaptsoglou and Karlaftis (2009) classified the studies in two main categories: conventional (analytical) models; and heuristics and metaheuristics approaches. Finally, Ibarra-Rojas *et al.* (2015) presented a different classifications of their literature review: continuous approximations for TND and discrete optimization approaches (sequential and simplified cases, metaheuristic algorithms, bi-level approaches, robust and stochastic, and multi-objective).

This review will be presented from a methodology point of view including the different objectives considered and the parameters adopted, as well as the applications.

### 3.3.1 CONVENTIONAL ANALYTICAL MODEL

Conventional methods include analytical approaches and mathematical programming formulations, generally based on the selection of the best element of an objective with some criteria. This models have centred the attention on one or few parameters – lines, stop spacing, route length, service frequency, fleet size, and others – usually on a predetermined simple or idealized network structure.

One important work is from Newell (1979), who performed a theoretical analysis of bus route network design and pointed out the non-convexity characteristic of the objective designed to minimize total cost. He stated that it is needed powerful computer and large data to determine an optimal geometry. Other authors presented analytical models solving TNDP at determining routes in order to achieve the total welfare of users and operators (Van Nes, 2003) and other parameters, such as minimum passenger transfers (Aldaihani *et al.*, 2004). More recently, Wirasinghe and Vandebona (2011) through a computational method presented a regular grid network for expresses buses in order to optimize operation costs and passenger total travel time.

Guan *et al.* (2003) presented a model that optimize simultaneous transit line configuration and passenger line assignment in a general network by using a linear binary integer program formulation. The proposed method could be solved by standard branch and bound method and was illustrated in numerical experiences and a simplified version of the mass transit railway network of Hong Kong. The authors described that the basic line configuration problem is finding the minimum cost by linking all nodes and stations needed. They said that line configuration from mass transit system has a direct impact on the operation cost, the passenger travel time and the transfers. This operation cost depends on the length of the transit route and the frequency, for a given frequency it can take more vehicles to serve a longer route. So, they concluded that the operation cost of any transit line can be linearly proportional to the length of the transit line.

The analytical work of Tirachini *et al.* (2014) introduced a social welfare maximisation model with multiple travel alternatives in order to improve the design of urban bus routes, as well as the pricing decisions for both bus and car users. The authors inserted the number of seats as a decision variable and the model was applied in Sydney.

Also, Ouyang *et al.* (2014) presented an analytical method, a continuum approximation approach for a bus network design proposing a hierarchical system complemented by more lines travelling high density neighbourhoods in order to minimize the total cost based on travel time and distances, walking time for passengers, waiting time at stops, and penalties for transfers. Figure 3 shows the hierarchical route geometry, where main bus routes are placed at relatively big spaces in low-demand neighbourhoods, along with local routes are more closely-spaced and cover high demand neighbourhoods. The numerical results show that the heterogeneous network configurations produce lower generalized costs than homogeneous grids and recognizes that the optimal spacing between the bus routes and stops depend also on the passengers from other neighbourhoods that travel through them.

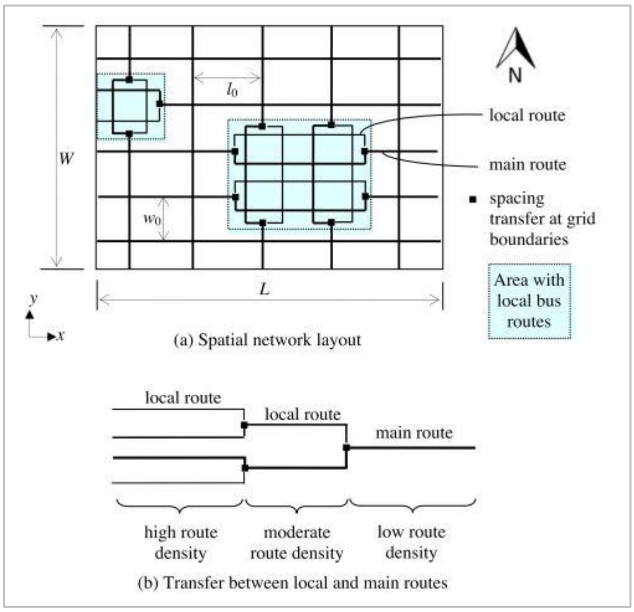



Figure 3: General scheme of a heterogeneous transit network (Ouyang, Nourbakhsh and Cassidy, 2014).

Moreover, Tribby and Zandbergen (2012) created a high-resolution spatio-temporal, GIS-based public transit network model that generates new routes and measures the changes highlighting individual travel time savings. The authors mentioned that this method can also be used to analyze various scenarios such as future route alignment and stop placement.

Also recently, Cancela *et al.* (2015) and Wang and Qu (2015) introduced mathematical programming approaches so as to achieve optimal routes and their frequencies with the purpose of benefit both users and operators. The first author proposed a mixed integer linear programming (MILP) formulation that incorporates waiting time and multiple lines. This mathematical formulation contributes towards a more realistic modelling effort taking into account important aspects of a real system which were not included in previous studies.

Nevertheless, in many cases, the mathematical programming models were solved using heuristics.

As Kepaptsoglou and Karlaftis (2009) identified, analytical methods are effective for public transportation network in cases with idealized structures. Predominantly these analytical approaches are very competent for small networks and a couple of decision variables, however, for a realistic network in which are involved many parameters, this model does not work effectively.

### 3.3.2 HEURISTICS AND METAHEURISTICS APPROACHES

Heuristic and metaheuristic approaches are the most common alternative solution to the analytical methods improving TNDP results and at the same time reducing the computational power requirement. Basically, a heuristic approach is a strategy used to solve a problem by employing practical methodologies and it is not guaranteed to be perfect, but sufficient for the objectives. In other words, it can be said that it is a trial and error method. Similarly, metaheuristic is a procedure that is defined to find or select a heuristic in order to give solutions to an optimization problem.

Several researches have implemented heuristic approaches, for example Lampkin and Saalmans (1967) proposed an heuristic algorithm for the optimization model of the design of transport routes by first determining routes and then assigning frequencies to them and presented on a Municipal Bus Company transit network; Mandl (1980) presented an algorithm that improves public transport network throughout developing initial routes assuming a constant frequency, and then improve them, and applied to a Swiss network structure. Also, Ceder and Wilson (1986) developed a heuristic algorithm in order to design new bus routes taking account of both passenger and operator benefit and by considering minimum frequency and fleet size as constraints.

Moreover, Baaj and Mahmassani (1991) used an Artificial Intelligent (AI) heuristic algorithm seeking a better design of public transport network and discussed the difficulty to solve TNDP by empirical knowledge, so, the authors proposed a method that include a module for analysing route characteristics and an algorithm for route improvement. Recently, Bagloee and Ceder (2011) developed an algorithm for a real road network, including two components: route-generation and route-selection.

As Kepaptsoglou and Karlaftis (2009) stated heuristic techniques can be categorized in two main groups. A typical heuristic approach involves a heuristic for the candidate route generation and another heuristic or metaheuristic to determine the optimal route configuration through different algorithms. Another common heuristic approach involves the direct route construction and the route improvement if it is necessary.

#### 3.3.2.1 Route Generation and Configuration

Route generation and configuration is the process that selects the optimal set of routes of a transit network and at the same time determines the optimal frequency for them. This is an iterative process guided by different algorithms and supported by external programs. So, those algorithms usually are traditional heuristics, metaheuristics, mathematical programming, and other approaches in fewer cases.

Generally speaking, this is a process in the tactical level of public transport planning when it is needed a reorganization of the routes of transit network. Ouyang *et al.* (2014) illustrated four different results of route generation that depend on the demand density.

Usually, TNDP cannot be treated by exact approaches, however, it is possible to present solutions that take some considerations such as simplifications that reduce the size of the network, single-line design cases, and determine only some variables decisions, such as stop locations or fleet size.

For instance, Pattnaik *et al.* (1998) presented the urban bus route network design using shortest path algorithm for generating candidate routes as an optimization problem of minimizing the overall cost. The method was based on network nodes and links, and generated routes under constraints, such as number of routes, travel time, among others. Then, the model was applied to a real network of a city in South India Also, Baaj and Mahmassani (1991) developed a heuristic model that generates transit routes based on demand and creating shorter paths in order to satisfy the demand and minimize the number of transfers.

Advanced metaheuristics are commonly used to solve TNDP, typically combining them with other heuristics. Baaj and Mahmassani (1995) proposed a procedure to solve TNDP through a hybrid solution, in other words, heuristic and metaheuristic approaches with the objective of maximizing direct trips and minimizing transfer times; they applied this to a real network of Austin, Texas.

An important approach for the route configuration take significantly consideration to Genetic Algorithms (GA) that usually involve the line design and after that, the frequency assignment (Bielli *et al.*,1998; Chien *et al.*, 2001; Cipriani *et al.*, 2012; Sun *et al.*, 2013). This is one of the most common approach in solving transport network problems and usually it is called a bi-level optimization or bi-objective model generating lines at first step and then assigning frequency to them at subsequent steps.

The research of Szeto and Wu (2011) investigated a bus network design problem for a suburban area in Hong Kong and solved route generation and frequency setting simultaneously in two main stages: (i) a genetic algorithm confronts the route design problem, and (ii) a neighbourhood search heuristic that tackles the frequency setting problem. The main goal was to reduce the number of transfers and the total user travel time.

Also, Gao *et al.* (2004) presented a bi-level programming model, in which the upper-level define lines minimizing the average of travel time, mean waiting time and operational cost, and the lower-level is a transit equilibrium assignment model. The authors used a heuristic solution based on sensitivity analysis for the model and finally they applied it to a numerical example and illustrated the efficiency of the algorithm.

Similarly, Fernández *et al.* (2008) presented a heuristic approach to solve the problems for the public transport of the city of Santiago, Chile. In this study, the authors aimed to minimize the total cost based on passengers and vehicles travel time through a bi-level solution approach. Other similar case was analysed by Pacheco *et al.*, (2009), they studied the real bus transport network of Burgos – Spain in order to satisfy passenger requirements and optimize quality services and applied two algorithms to solve the problem, local and tabu search strategies.

One more similar case is the work of Cipriani *et al.* (2012), which presented a solution for TNDP with the purpose to maximize the total welfare from both user and operators. This consisted of a set of heuristics presented in two main stages. First a heuristic for an optimal route generation and their frequencies, and then, a GA in order to find a sub-optimal set of routes. This model was tested on the transport network of Rome – Italy and has proved to be effective in terms of waiting time by reducing the number of lines and consequently the operation costs while still guaranteeing the same service coverage.

Heuristics and metaheuristics present different variations or combinations in the studies analysed. As revealed by Nayeem *et al.* (2014), who developed a population based model for solving TNDP through GA with elitism with the aim to maximize the passenger satisfaction, minimize the number of transfers and the total travel time. The authors presented two different versions of GA based metaheuristic, which the first was competitive with other approaches in the literature and could generate high-quality solutions with reasonable CPU times; however, the second version of GA with increasing population showed that beats the other approach.

Arbex and da Cunha (2015) proposed an Alternating Objective Genetic Algorithm (AOGA) in order to solve a TNDFSP problem applied to the city of São Paulo, Brazil. The main objectives were to minimize both users (number of transfers, waiting and in-vehicle time) and operators (required fleet) costs. The authors concluded that this procedure was efficient when compared to previous work published and they said that "our proposed heuristic can be helpful in establishing an intercity suburban bus network that connects the municipalities of metropolitan regions, as is the case of São Paulo. On the other hand, designing efficient transit network for urban transport, especially in larger cities, requires considering many aspects that have not yet been fully addressed in the literature on the TNDFSP".

The model proposed by Zhao and Zeng (2006) combined Simulated Annealing (SA) and GA, from which the first one searched for optimal transit routes and then frequencies, while the GA intervened to improve the first stage. The results indicated that SA provided good results compared to GA alone.

Other studies are focused on the analysis between different evaluation criteria. For example, Fan and Machemehl (2004) studied an optimal transit route network design by using hybrid heuristic algorithms. The authors tackled the topic as a multi-objective model minimizing operator and user cost through three main components: (i) an initial candidate route set generation procedure that generates all feasible routes, employing different heuristic algorithms (Genetic Algorithm, Local Search, Simulated Annealing, Random Search and Tabu Search); (ii) a network analysis procedure (NAP) that assigns transit trips, determines line frequencies and computes performance measures; and (iii) a heuristic search procedures (HSP) that guides the search techniques. This methodology examined and compared the quality of the solutions obtained by using those different heuristic algorithms by testing numerical examples.

Zhao and Gan (2003) developed a systematic mathematical model in order to optimize route network in terms of minimum transfers. They include diverse objectives and constraints, and various solution methods, using heuristics and metaheuristics. They applied his method to the typical Mandl's benchmark and also to a real transit network of Miami. The authors concluded that "the methodology may also be used as a useful computational tool to evaluate existing transit route networks […] various parameters such as less transfers, trip coverage, network directness, and others, may serve as indicators on the qualities of transit networks".

Now, regarding on sustainable transit planning, Pternea *et al.* (2015) developed a solution model for TNDP incorporating environmental aspects (minimization of emissions and low carbon footprint vehicles). The authors presented a direct route design approach with directness control by using a metaheuristic technique and applied to a Greece network case. They concluded that particularly, average speed has a strong impact on air pollution and passenger travel time at the same level.

Furthermore, Kuo (2013) presented a method based on Simulated Annealing (SA) for optimizing TNDP and described the type of routes that compose a transit network. In a line-type route, buses start from a first node, follow the route to the last node and then, in reverse order, buses move back to the first node again. In a circular-type route, buses start from the first node and move back to the first node passing only once to each node. Figure 4 shows two examples from both types of routes.

This research expressed that the passenger waiting time of a line-type route design would be shorter than for a circular-type route design. On the other hand, considering that the stops are located on both sides of a road and in a circular-type route design, passengers can go to their destination by waiting on both sides and it can be confused. The author also took into consideration the characteristics of both types of routes, line and circular, and defined a hybrid route type increasing the flexibility of the transit network. For example, in the Figure 4 (C) can be noticed that line-type route is the route A-B and a circular-type route is the route among B, C and D nodes.

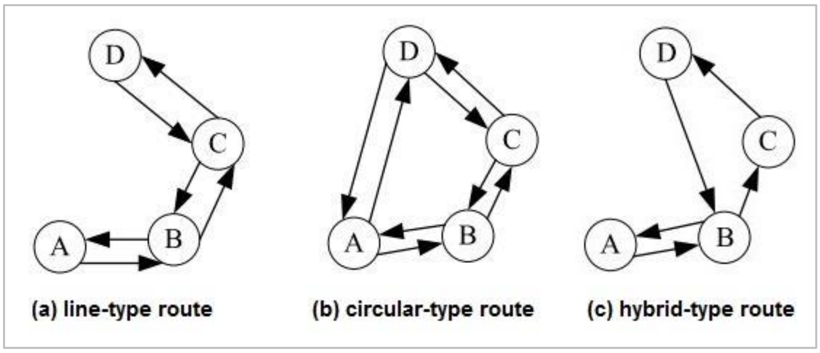



Figure 4: Types of routes in transit network (Kuo, 2013).

#### 3.3.2.2 Route Improvement

Following the division that Kepaptsoglou and Karlaftis (2009) made in their review, an alternative to routes generation and configuration method is the direct construction and improvement of routes and their frequencies. So, for example, Mandl (1980) implemented a method improving the transit routes in order to benefit the transportation cost. The author examined a set or routes so as to consider possible reductions in the average cost and the new set was compared with the older one, and so on until no new improvement could be necessary.

Fusco *et al.* (2002) also proposed an algorithm in order to produce the best solution with different design criteria. They said that the procedure used can provide general and flexible framework for transit network design. In order to improve the route network, they verified the impact of the route generated before in terms of route extension, shortening and expansion. The model used a heuristic algorithm and was illustrated to a numerical example network.

One modern metaheuristic approach implemented by some researchers is the Ant Colony Optimization (ACO) with the aim to construct optimal routes, because they are suitable for constructing optimal routes.

For example, Yu *et al.* (2012) presented a direct traveller density model to design a transit network in order to maximize the number of direct travellers and transfers. The methodology used was divided into three stages: (i) an empty network building and a skeleton route design including constraints such as directness, line length limits and passenger demand satisfaction; (ii) a main route design according to the traveller density including direct passenger and transfers; and (iii) a branch route design together with the skeleton lines according to the maximum traveller density. This model (Figure 5) was solved by using an ACO algorithm that determine the skeleton, main or branch routes according to searching process and was tested using data from the city of Dalian – China and the results showed that the optimized transit network improved regarding transfers.

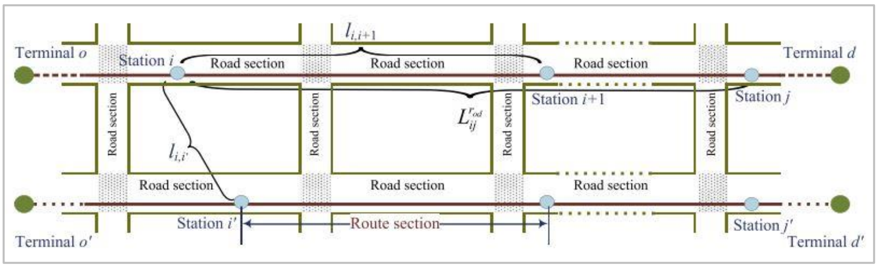



Figure 5: Model example of transit network (Yu *et al.*, 2012)

There is not much information about this methodology, particularly because the first approach is more used. And because for this work was more important to analyse route configuration regarding transit design.

In the following section are presented the whole literature review studied. Table of Literature Review

Table 4 summarizes the list of literature analysis for TNDP with objectives, parameters (decision variables and constraints), solution methodology adopted and other important characteristics considered in each paper such data set used as application example.

## 3.4 TABLE OF LITERATURE REVIEW

Table 4: Summary of Transport Network Design Problem (TNDP) review.

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | Simple or Multiple | Constraints and Decision Variables | Type of Solution | | |
| 1967 | Lampkin and Saalmans | TNDFSP | Capacity, travel time, number of direct passengers | Route design, frequencies, fleet size | Heuristic | Real case: Municipal Bus Company of a small town of North England | Skeleton Method |
| 1979 | Dubois et al. | TNOP | Travel time | Route generation, frequency setting | Heuristic (Local Search) | Real case: 10 towns of France, 2 more significant Nice and Toulouse | - |
| 1979 | Newell | BRNDP | Total cost (operator and user) | Routes | Conventional (analytical, mathematical) | Example: rectangular grid network | - |
| 1980 | Mandl | TNDP | Transportation cost (passengers), travel time | Route distance, route directness, capacity | Heuristic | Real case: Swiss transit network | - |
| 1986 | Ceder and Wilson | TNDFSP | Minimizing excess travel time, waiting and transfer time, operator cost (vehicle) | Route length, minimum frequency, fleet size | Heuristic | Example: simple five-node network | Public transport process model |
| 1991 | Baaj and Mahmassani | TNDP | Total travel time, number of transfers, number of vehicles | Route generation, frequency setting | Hybrid (Artificial Intelligence-AI) | Real case: Mandl's Benchmark Network (Swiss network) | - |
| 1995 | Baaj and Mahmassani | TNDFSP | Waiting time, transfer time, number of direct trips | Route generation, capacity, fleet size, headway | Heuristic (Route Generation Algorithm-RGA) | Real case: Transit System of Austin - Texas | Skeleton Method |
| 1998 | Bielli et al. | TNDOP | Minimizing travel time and management cost | Route generation, frequency setting, number of vehicles | Heuristic (Simple and Cumulative GAs, Sensitivity Analysis) | Theoretical | - |
| 1998 | Pattnaik et al. | TNDFSP | Operator cost, passenger travel time | Route generation, frequency setting, load factor | Heuristic (GA) | Real case: Transport Network of Madras, South India (25 nodes and 39 links) | Urban Bus Transport System |
| 2001 | Chien et al. | TNDP | Total cost (operator and user) | Bus route location, operating headway | Heuristic/metaheuristic (GA and ES) | Example: Service area network 4x10km | Evolutionary Process Method |

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | Simple or Multiple | Constraints and Decision Variables | Type of Solution | | |
| 2002 | El-Hifnawi, M. | TNDP | Total welfare (operator cost, minimizing bus user and car user total travel time) | Bus cross-town routes design, capacity | Conventional (analytical) | Real case: Transit System of Monterrey, Mexico | UTP model (Urban Transport Planning) |
| 2002 | Fusco et al. | TNDFSP | Minimizing overall system cost | Route configuration, frequency setting | Heuristic (GA) | Theoretical (not finished) | - |
| 2003 | Chakroborty and Dwivedi | TNDP | Minimizing total travel time, unsatisfied demand and number of passengers with transfers | Route generation (with a given road network and demand data) | Heuristic / metaheuristic (GA) | Real case: Mandl's Benchmark Network (Swiss network) | Evolutionary Process Method |
| 2003 | Guan et al. | TNDP | Minimizing passenger travel time and number of transfers, and operating cost | Route configuration, line length, transit capacity | Mathematical (Linear Binary Integer program) | Real case: Hong Kong Mass Transit Railway network | Railway system |
| 2003 | Van Nes | TNDP | Maximizing social welfare (operator costs and user total travel time) | Stop spacing, route spacing, frequencies | Conventional (analytical) | Real case: Urban bus corridor of Utrecht, Netherlands | - |
| 2003 | Zhao and Gan | TNDP | Minimizing transfers, optimizing route directness, maximizing service coverage | Route shape (directness) | Mathematical and Heuristics (SA, tabu Search, NS) | Real cases: Mandl's Benchmark Network and Transit System of Miami-Dade County, Florida | - |
| 2004 | Aldaihani et al. | TNDP | Determining optimal number of zones | Route line, number of vehicles, number of transfers | Conventional (analytical) | Examples: small service area and large metropolitan area | - |
| 2004 | Fan and Machemehl | TRNDP | Total travel time (waiting, in-vehicle and walking time), number of buses, unsatisfied demand cost | Route length, headway, load factor, fleet size, number of lines | Hybrid heuristics (Variety of NS algorithms) | Theoretical | - |
| 2004 | Gao et al. | TNFSP | Operator and user cost equilibrium, system performance | Frequencies | Heuristic (Sensitivity analysis) | Theoretical | Bi-level programming |

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | Simple or Multiple | Constraints and Decision Variables | Type of Solution | | |
| 2006 | Zhao and Zeng | TNDP | Minimizing transfers, total user cost, and maximizing service coverage | Route structure (length, directness, feasibility) and headways with given demand and fleet size data | Heuristic / metaheuristic (GA and SA) | Real cases: Mandl's Benchmark Network and Transit System of Miami-Dade County, Florida | - |
| 2008 | Fernández et al. | TNDP | Minimizing total cost (operator cost and user travel time) | Direct routes, optimal frequencies with given load factor and demand data | Mathematical and Heuristic | Real case: Transit System of Santiago de Chile | Bi-level programming |
| 2009 | Pacheco et al. | TNDP | Minimizing waiting time and travel time | Route design and bus frequency assignment | Heuristic (Local Search and Tabu search) | Real case: Bus transport network of Burgos, Spain | - |
| 2010 | Amoroso et al. | BND | Minimizing surplus passengers (bus and cars user), operator costs and revenues | Route design, frequency setting and capacity of each bus line | Heuristic (Random Utility Model) | Real case: Transit Network System of Trapani, Italy | Bi-level programming |
| 2011 | Bagloee and Ceder | TNDP | Minimizing total passenger's discomfort | Route design and frequency setting, with constrained budget | Heuristic / metaheuristic (GA) | Real cases: Transit Network System of Winnipeg, Canada; Mandl's Benchmark Network; and Chicago's 2010 Rail System | Bi-level programming |
| 2011 | Fan and Machemehl | TNDP | Minimizing total cost (operator, user and unsatisfied demand cost), travel time and number of transfers | Route length, number of lines, headways, load factor, fleet size, spatial equity | Heuristic / metaheuristic (GA) | Theoretical | - |
| 2011 | Szeto and Wu | TNDP | Minimizing users number of transfers and total travel time | Route design and frequency setting, fleet size, number of intermediate stops | Heuristic / metaheuristic (NS and GA) | Real case: Transit Network of Tin Shui Wai, Hong Kong | Sub-urban bus network |
| 2011 | Wirasinghe and Vandebona | TNDP | Minimizing operating cost, passenger accessibility costs (waiting time, travel time) | Bus express routes generation, shortest path between passenger’s generators | Conventional (analytical) | Example: Regular grid network | - |

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | Simple or Multiple | Constraints and Decision Variables | Type of Solution | | |
| 2012 | Cipriani et al. | TNDP | Minimizing total cost and resources | Route choice, bus capacity constraints, route length and line frequency | Heuristic (Parallel GA) | Real case: Multimodal Public Transport Network of Rome, Italy | Rapid rail system, buses and tramways lines |
| 2012 | Tribby and Zandbergen | TNDP | Accessibility (saving total travel time) | Walking time, waiting time, in-vehicle travel time and transfers time | Conventional (Analytical) | Real case: lines of BRT of Albuquerque, New Mexico | High-resolution spatio-Temporal, GIS-based model |
| 2012 | Yu et al. | TNDP | Maximizing travel density | Route length and directness, direct demand and minimum transfers | Metaheuristic (ACO) | Real case: Transit Network of Dalian, China | ACO: Ant Colony Optimization |
| 2012 | Song et al. | TNP | Maximizing number of public transport users | Integrating metro and bus system, redesigning routes, route length, overlapping routes | Conventional (Analytical) | Real case: Daxing Line of Transit network of Beijing, China | Scientific approach |
| 2013 | Kuo | TNDP | Minimizing passenger travel time and number of transfers | Route configuration, travel path shape (circular, line) | Heuristic / metaheuristic (SA) | Real case: Mandl's Benchmark Network (Swiss network) | SA: Simulating Annealing |
| 2013 | Li et al. | TNDFSP | Operator profit, passenger waiting time cost | Bus headway, stop location, bus travel time | Hybrid intelligent algorithm (SS and GA) | Examples and comparison with previous authors applications | SS: Stochastic Simulation |
| 2013 | Sun et al. | UTNDP | Maximizing rail ridership and minimizing passenger total travel time | Bus route layout and stop location under given rail stations and operation rail routes | Heuristic / metaheuristic (GA) | Examples: network with 16 nodes and 32 links | Multimodal transit system (Railway and bus transport) |
| 2014 | Amiripour et al. | TNDP | Minimizing total waiting time, fleet size, short paths, and empty seats hours | Budget, unsatisfied demand, headways, deviation of shortest paths, number of transfers | Heuristic / metaheuristic (GA) | Real cases: Transit network of Mashad, Iran and benchmark network | - |

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | **Simple or Multiple** | **Constraints and Decision Variables** | **Type of Solution** | | |
| 2014 | Nayeem et al. | TNDP | Maximizing number of satisfied passengers, minimizing number of transfers and total travel time | Route configuration, frequency setting | Heuristic / metaheuristic (GAWE) | Real cases: Mandl's Benchmark Network and three real network of Yubei, China; Brighton and Cardiff, UK | GAWE: Genetic Algorithm with Elitism |
| 2014 | Ouyang et al. | BTNDP | Reducing total user and operator cost | Route configuration (city-wide and closely-spaced), fleet size, stop location | Conventional (Analytical) | Examples: a square city with four demand distributions: mono-centric city, twin city, asymmetric mono-city and commuter city | Continuum Approximation technique (CA) |
| 2014 | Tirachini et al. | TNDFSP | Maximizing social welfare (operator, bus user and car user costs) | Bus fare, bus frequencies, bus size, number of seats | Conventional (analytical) | Real case: Military Road in North Sydney, Australia | - |
| 2014 | Kenneth Loh | TNDFSP | Maximizing user total travel time (waiting time, in-vehicle travel time, transfer time) | Route design (route length, number of route, route circuity), frequency setting | Heuristic | Examples and real case of Singapore bus Network System | - |
| 2014 | Yao et al. | TNDP | Maximize transit network efficiency (passenger time cost, transfer time and transit reliability) | Travel time | Heuristic / metaheuristic (Tabu Search) | Examples: small and medium-sized networks | - |
| 2015 | Arbex and Da Cunha | TNDFSP | Minimize passenger and operator cost | Route configuration, frequency setting, passenger waiting time and in-vehicle travel time, cost, fleet size | Heuristic (Alternating Objective Genetic Algorithm AOGA) | Real case: Mandl's Benchmark Network (Swiss network) | - |
| 2015 | Cancela, et al. | TNDP | Operator profit and user convenience (service coverage, total travel time) | Number and itineraries of bus routes and frequencies with given street network, transfers and bus capacity | Mathematical (mixed integer linear programming MILP) | Small example network and real case 13 transit lines network of Rivera, Uruguay | Bi-level programming |

| Year | Authors | Problem | Objectives | Parameters | Methodology | Application | Observations |
|---|---|---|---|---|---|---|---|
| | | | **Simple or Multiple** | **Constraints and Decision Variables** | **Type of Solution** | | |
| 2015 | Pternea et al. | TNDP | Minimization of user and operator costs, and of environmental impacts | Type of buses (conventional and free-emissions or electric), route design (directness, structure), frequencies | Mathematical and Metaheuristic (GA) | Real case: transit network of the city of Heraclion, Crete, Greece | - |
| 2015 | Wang and Qu | BTRNDP | Optimal suburbs routes (shortest path between the bus stops) | Route design, bus stops | Mathematical (Dynamic programming) | Square Block example and real case of Pacific Pines, Suburb of Australia) | Sub-urban bus network |

### 3.5 SUMMARY AND DISCUSSION

On the whole, transit network design problem or TNDP has been received significant attention by researchers since the 1960's until nowadays. The approaches comprehend from ad-hoc practices to a superior performance, demonstrating varied strategies in solving the problem. From the literature review, this study presents the results of the different solutions analysed divided into three main features by analysing the problem: objectives, parameters and methodology that can be briefly seen below in Figure 6.

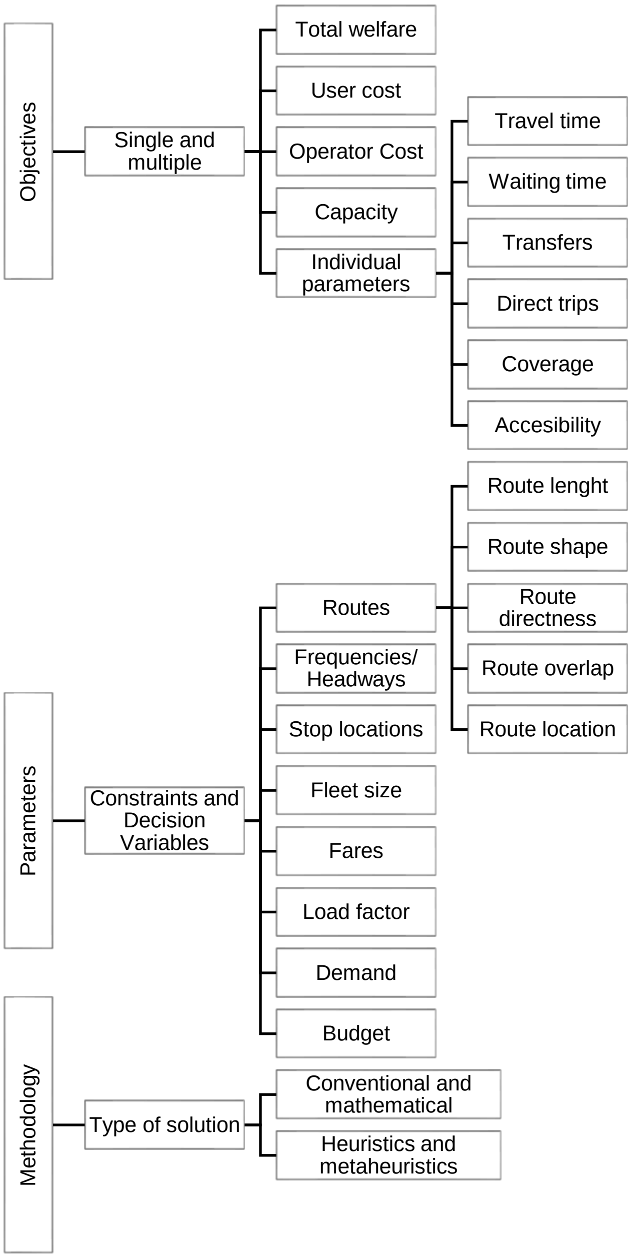



Figure 6: Key characteristics of TNDP models. Adapted from Kepaptsoglou and Karlaftis (2009).

From Table 4 is possible to show objectives and parameters are composed by several elements that indicates the complexity of TNDP. The most common objective found was the maximization of total welfare and generally it meant both minimum operators and users costs. However, several researchers analysed multi-objective issues, combining different goals. For example, minimization of travel time, waiting time and number of transfers are usually included in objectives that involves passenger cost concerns with capacity or fleet size constraints (Arbex and Da Cunha, 2015; Baaj and Mahmassani, 1995; Ceder and Wilson, 1986; Lampkin and Saalmans, 1967; Lo and Szeto, 2009; Zhao and Zeng, 2006).

Among decision variables and constraints, the most commonly were routes and service frequencies, but also stop locations, vehicles size and fares, in a lesser content. As stated in Guihaire and Hao (2008), there are typical considerations at the moment to analyse TNDP, such as coverage area, route and trip directness, route length and number of lines, as well as demand satisfaction.

Routes are in most cases the principal study field, especially route length and simple and direct route shape (Ceder and Wilson, 1986; Cipriani *et al.*, 2012; Fan and Machemehl, 2004; Guan *et al.*, 2003; Song *et al.*, 2012). Route directness is one of the most important criteria for the present work, although it was considered by very few researchers (Pternea *et al.*, 2015; Yu *et al.*, 2012; Zhao and Zeng, 2006; Zhao and Gan, 2003). When referring to the framework of this analysis, it is possible to consider those researches about route directness as the closest and similar approach.

The different methodologies applied in solving transit network problems were the main focus of the majority of investigations. Most authors analysed transit network design problems (TNDP), while other researchers studied design and frequency setting together (TNDFSP). Examples of the first group are Baaj and Mahmassani (1991), Cancela *et* al. (2015), Ceder and Israeli (1998), Chakroborty and Dwivedi (2002), Cipriani *et al*., (2012), Nayeem *et al.* (2014), Szeto and Wu (2011), Zhao and Zeng (2006). The last case can be seen in other works, as instance Arbex and Da Cunha (2015), Baaj and Mahmassani (1995), Ceder and Wilson (1986), Fusco *et al.* (2002), Li *et al.* (2013), Pattnaik *et al.* (1998), Tirachini *et al.* (2014).

Authors have implemented different solutions techniques, which depend on the required detail level of results, the quality of solution and the computational power available. In general, there are two principal approaches used: conventional and heuristics.

Conventional approaches include analytical and mathematical models that consider more idealized and simplified transit networks (specific constraints) and does not need huge computational power. Some examples are presented in the works of Aldaihani *et al.* (2004), El-Hifnawi (2002), Fernández *et al*. (2008), Guan *et* al. (2003), Van Nes (2003), Newell (1979), Ouyang (2014), Song *et al.* (2012), Tribby and Zandbergen (2012), Wang and Qu (2015) and Zhao and Gan (2003). Results of conventional models usually are used as references and recommendations for planners and not as extremely optimal solutions.

With the last computational power increase, researchers have introduced heuristics and metaheuristics models, new approaches based on genetic algorithm and other hybrid and efficient optimization procedures. There are many examples of this methodology, some authors applied heuristics and metaheuristics based on different algorithms, such Genetic Algorithms (GA), Hybrid Algorithms, Sensitive Analysis, Tabu Search, Local Search, and others. Some important works are Dubois *et al.* (1979), Ceder and Wilson (1986), Baaj and Mahmassani (1991 and 1995), Pattnaik *et al.* (1998), Chakroborty and Dwivedi (2002), Fan and Machemehl (2004), Zhao and Zeng (2006), Pacheco *et al.* (2009), Szeto and Wu (2011), Amiripour *et al.* (2014) and others. Heuristics provide the basis for more extended problems in order to use other methodologies such metaheuristics. From a planning perspective, Kepaptsoglou and Karlaftis (2009) stated that the existing approaches seem adequate, but to their knowledge, this is a topic yet to be thoroughly investigated.

Different examples of both models conventional and heuristics have been used by each research. So, there are numerical or theoretical examples and also real study cases. Regarding the first ones, some works presented small or large networks with preselected nodes and links, with which the authors wanted to identify the process of the solution method. However, for the real world they could not be used. On the other hand, varied real dataset was considered around the world. It can be said that the most common real transit network studied are from Asia, namely China (can be seen in Guan *et al.*, 2003; Nayeem *et al.*, 2014; Song *et al.*, 2012; Szeto and Wu, 2011; Yu *et al.*, 2012) and other countries such India (Pattnaik *et al.*, 1998) and Singapore (Kenneth Loh, 2014). European transit network have also been commonly studied, for instance Cipriani *et* al. (2012) applied his model on the city of Rome, Van Nes (2003) analysed the Urban Bus System of Utrecht – Netherlands, Pacheco *et al.* (2009) analysed the Bus Transit Network of Burgos – Spain. When referring to North America study cases, it is possible to find more USA transit network examples (for instance: Baaj and Mahmassani, 1991; Tribby and Zandbergen, 2012; Zhao and Zeng, 2006; Zhao and Gan, 2003). In a less number of works, there are some other real cases of America, so, El-Hifnawi (2002) studied the transit network of Monterrey in Mexico, Fernández *et al.* (2008) applied his method to the transit system of Santiago de Chile and Cancela *et al.* (2015) analysed the transit lines of the city of Rivera – Uruguay. There are also few instances of Australia, for instance Tirachini *et* al. (2014) studied a road in Sydney and Wang and Qu (2015) used a suburban bus network as study case.

The difference between complex techniques (heuristics) and conventional solutions (analytical and mathematical) is results can be more realistic and reasonable with the real case studies. And those cases were more applied when the methodology used was a simpler conventional or mathematical approach. However, complex methods such heuristic, metaheuristic and other hybrid solutions can show significant improvements but cannot guaranteed a total optimal solution, since the difficulties of a real huge network have many aspects to take into account.

All in all, different researches present a varied effective solutions employing analytical, mathematical, heuristic and metaheuristic methods, evolutionary algorithms and other techniques. Owing to the multi-objective nature of most of the problems and the different criteria in solving the transit network design problem, there probably is no single optimal solution, but rather a group of solutions that can be the best approach that fits in a specific system.

# 4

# PRACTICAL CASES: PROCESS EVALUATION ON THE IMPLEMENTATION OF NETWORK CHANGES

## 4.1 INTRODUCTION

The challenge of implementing changes on an existing transport network is a big issue in many aspects of all the participants (governments, institutions, public sector, operators, etc.). Many authors have expressed that while operators try to maximize their profit balancing operating costs, individual passengers or passenger groups consider their own benefit and in both cases, they often resist changes.

One common feature of success stories in public transport network planning is the role of the public participation in bringing about change. Some authors confirmed that Public Transport plans should be implemented gradually, with necessary complementary measures, and with the innovative and challenging ideas expressed (Ceder, 2004). Also, Wirasinghe & Vandebona (2011) recommended that new implementation on the bus routes system should be done with care since they are difficult to change once in place, especially because of the preasure from existing users that will lose a habit journey, either via loss of direct service or increased travel time, and also from non-users who object to bus routes passing near their homes. They also said that it is a complicated situation, where a route change can be made so as to positively impact all existing passengers. Wirasinghe & Vandebona (2011) recommended "new bus routes should be clearly labelled as experimental, and if necessary, two or more tried out in-service, before the final path is determined".

Some practitioners, such Mees *et al.* (2010), propose some characteristics from the institutional environment in order to succeed on new implementation of transport networks. For instance, it would be necessary a public agency with the responsibility to plan the network across the whole city; it is very important to understand the appropriate place for private sector in the provision of public transport services by producing best-values tenders. Managing changes depend on well-designed public programmes in different aspects.

In general, public support for the reorganisation of existing public transport services are fundamental for a functional network. Nowadays, public transport is within the political agenda of the majority of urban areas, however, the implementation process of policies and some changes in the services are critically important. The public involvement in planning service is fundamental, because there will be winners and losers in any change procedure.

In this section will be presented the importance of practical approaches and four real cases of implementation of transport network changes and the reactions, problems, solutions and positive aspects that were involved along their processes of implementation.

## 4.2 TRANSANTIAGO – SANTIAGO DE CHILE

Santiago de Chile is the capital city of Chile and has more than 6 million inhabitants making it the most populated city from this country. The urban transport system that currently operates in this huge metropolis is Transantiago and was implemented in 2005 after an urgently need to improve the efficiency to which was the public transport network by that time, composed by conventional buses called "*micros amarillas"* (Figure 7), few metro lines and shared taxis.

Fernández *et al.* (2008) expressed that Santiago de Chile, as other developing cities, had an explosive service of public transport system, mostly served by long bus itineraries operating independently. So, there was no integration between the different modes of transport with the exception of a few feeder lines to the end of the metro stations (composed by four lines). The bus transit system was constituted of a large number of small operators organized in cooperatives that were periodically assigned to a line service, in all 370 lines. Moreover, another critical situation were fares, which were charged by each service paying directly to each operator.


Figure 7: The old transport system composed by yellow buses called "micros amarillas" (EMOL Noticias, 2016).

The transport system was serving high rates of daily trips (4,2 million bus trips and 0,8 million metro trips). The system was inefficient, it presented low quality services at relative high cost, it was the cause of high number of accidents and congestion of the urban road network (Fernández *et al.*, 2008). With this situation, the local authorities made a very fundamental decision of restructuring the public transport service system with an integrated system of metro and buses including an integrated fare system, this project was called the Urban Transport Plan for Santiago (PTUS).

### 4.2.1 THE NEW URBAN TRANSPORT PLAN FOR SANTIAGO

The plan proposed consisted in various programs in short, medium and long-terms with the main purpose to encourage people to use the public transport system as the main alternative of urban mobility (Holuigue, 2011). In 2003, the name of this program was changed to Transantiago.

Transantiago was an ambitious project attempting to improve the whole transport service quality. One of the most notable program was the replacement of the existing yellow-bus fleet and thereby the minimization of air and sound pollution by reducing emission levels of buses. Also, the new transit network was designed (Figure 8), it consisted in a trunk feeder model (composed by metro and BRT model) and feeder lines (provided by private bus companies). It was fundamental to reduce travel time and eliminate the on-the-street buses competition

(Holuigue, 2011). Besides, a new fare structure was introduced, the smartcard, making users possible to change between buses and metro or do transfers between the same modes of transport.

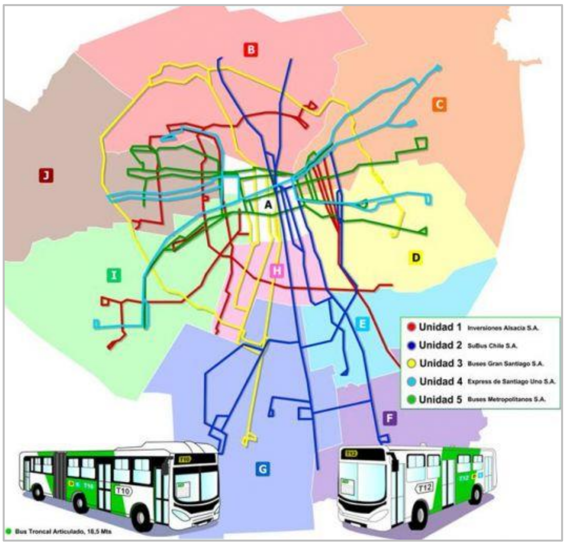



Figure 8: Initial itineraries of Transantiago system (Plataforma Urbana, 2006).

The main challenge was implement this whole transformation. The huge project of Transantiago started in 2005 in a first stage introducing new modern buses, many of them articulated and the older buses were gradually being removed from the system until 2010. February 10, 2007 was a memorable and unforgettable day for the population, when the new route network was introduced dividing the bus lines into main and local lines, and it was also implemented the new smartcard. Transantiago was become fully operational and the known "big bang" began.

### 4.2.2 PROBLEMS OF THE IMPLEMENTATION

Muñoz *et al.* (2014) described in their work that at that moment there were not enough conditions to implement the transport system changes simultaneously from one day to another. The stations infrastructure was not finished, the bus fleet were not sufficient for the demand, the fare system was still in process, and all this generated excessive waiting times and more crowding levels than in the previous transport system.

Furthermore, as buses contracts received a fixed payment, they had not good incentives to improve services, likewise the GPS system was not working and was not possible to control the buses frequencies, routes poorly designed and not sufficient stops. Since its implementation, the result was turbulent and Transantiago had to deal with serious operational problems and critics from the users and population in general.

The inadequate design of the system was one of the biggest problem that was generated, the service frequencies, capacity of buses, travel time and comfort was not covering the population demand. The fleet number of the initial project were 6000 buses and finally a new scenery of operations of Transantiago decreased to 4500 buses, making more rentable for the operators. That meant a considerable less quantity of the real fleet number required (Holuigue, 2011).

It was worldwide known the difficulties that the public transport system of Santiago de Chile overpassed has been investigated by many researchers from different perspectives. Muñoz *et al.* (2014) categorized the studies into descriptive articles before its implementation, evaluations after the crisis, and impacts analysis of particular aspects.

The government was forced to take measures in order to solve the problems because they defended the new transport system as necessary for a better quality of service for the population. Therefore, Muñoz *et al.* (2014) summarized some solutions that were applied: contracts were changed many times and sometimes there were even structure modifications; subsidies for students fare and also in order to covering the deficit of Transantiago operation costs; the number of articulated buses were increased and new metro lines were constructed. Additionally, there were frequencies and schedules adjustments, as well as itineraries expansion and introduction of new ones.

Although the system had improved among the last years, the bus transit service still manages the poorly perception of the users and the general population.

### 4.2.3 Pros of the implementation

Despite all the complicated problems that the new Santiago's transport system was suffering, there were also important achievements that several researchers analysed. Muñoz *et al.* (2014) cited a set of the positive goals of the new transport plan, such as:

- Urban mobility switched from a high number of small operators to a group of seven companies easier to control, coordinate and collect taxes;
- The accidents that involves buses had dropped because drivers did not work long shifts or competed for passenger in the streets, and vehicles were better maintained;
- Environmental effects improve positively, there was substantial air and sound pollution reduction;
- The usage of low floor buses that allowed users with reduced mobility and was accessible to a new group of costumer;
- The metro system moved twice as many passengers as before while still providing a good level of service;
- Students were no longer discriminated against by drivers not stopping for them (since operators are paid for the same by all types of passengers), and drivers no longer face assaults since buses run cash-less;
- Subsidies had improved the bus service quality and causes less congestion, pollution and accidents than cars.


Figure 9: Current Transantiago Buses (Diario Uchile, 2014).

Despite that Transantiago started providing minor quality of service than the previous conventional bus system, some indicators have illustrated the system improvement among the years and also generated a sustainable structure for the public transport in the future.

## 4.3 BVG – BUS TRANSPORT IN BERLIN

Berlin is the capital city of Germany with a population of 3,5 million people and covers an area of 892 $km^2$, becoming it as the second most populous city and the fifth largest city of the European Union (Statistiks Berlin Brandenburg, 2016).

The transport infrastructure of Berlin is very complex and present wide range types of urban mobility. The Berliner Verkehrsbetriebe (BVG) is the main public transport agency that manages the integrated urban mobility of the city since 1929. Currently, Berlin is served by different modes of BVG transports including 10 underground lines (U-Bahn), 22 tram routes and 151 bus routes. In 2015 the company transported over 1 billion passenger across Berlin (Webpage BVG, 2016).

The numbers of the 2015 company's report informed that 17 routes of the 151 bus routes network served are selected to be part of the "Metronetz", the network that provides high service frequency in areas poorly served by others transport modes (U-Bahn and S-Bahn). The bus fleet of the BVG is composed by 1349 different types of buses and 416 of them are double-decker buses (Figure 10), usually they are preferred over articulated buses because of the shorter length and larger number of seats available.

Figure 10: BVG double-decker bus (BVG, 2016).

The current situation of the BVG is a result of several years of hard work. Little time back, in 2002 the company had experienced a ticket revenue decrease for the first time after the unification of the BVG of the West Berlin and East Berlin in the earlier 1990's. The revenues of the company were increasing gradually until 2001 and in 2002 suffered a unusual decline (Report BVG, 2006).

BVG felt the need to improve some features with the purpose to find the best solutions to meet both the passenger and company requirements. Consequently, as it is described by Reinhold and A.T. Kearney (2008) the management of BVG company handled a series of studies and market researches in 2003 in order to find the best solution to increase tickets sales, by focusing on integrated marketing with four relevant mechanism: new services, fare structure, advertising, and sales; and by meeting customers' requirements in terms of service needed and how much they are prepared to pay for them.

### 4.3.1 NEW APPROACH BVG 2005 "PLUS"

The public transport company of Berlin in 2003 conducted a series of studies using different methods with the purpose of enlightening results on user preferences, identifying the aspects whose improvement could drive directly to an increase in the number of passengers. Figure 11 presents the different analysis that were made at the first stage before planning a strategically network. Results showed that generally Berliners gave more importance to route service speed (short travel times) and frequency than to issues related to safety and comfort.

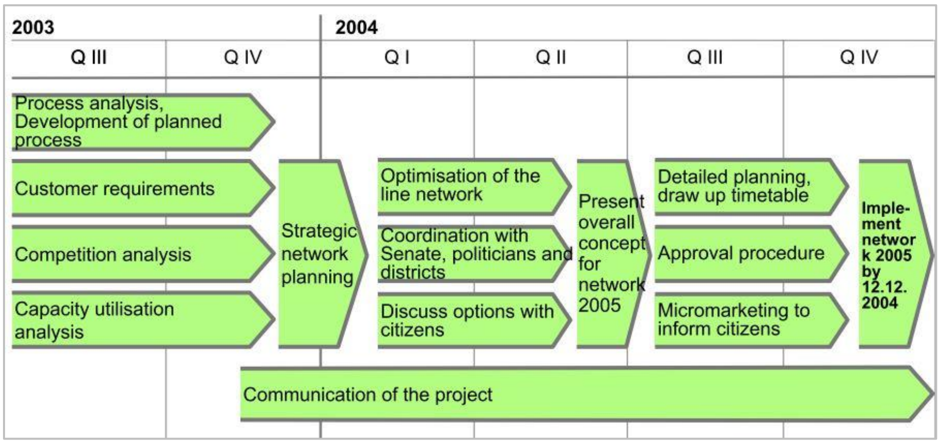



Figure 11: Overview of the BVG 2005 Plus Project (BVG, 2006).

Through the analysis of customer requirements, competition and capacity, results were used to develop a strategic process for the new network planning. The “BVG 2005 Plus” came about and was implemented in December 2004. The main purpose of this project was to optimize the whole transport service by making some modifications in the route network and timetables. BVG company undertook a route-by-route analysis of all traffic patterns in the city (BVG, 2006). Through the new timetables, BVG wanted to establish high frequencies service routes combining with the metro network. The principal objective of this project was increasing the income through gaining new users through an improved transit network system with a better coverage. As Die Welt newspaper published, BVG attempts to gain 18 million passenger in a year while reducing 16,8 million euros of deficit with the Metrolines concept (Die Welt, 2004).

Reinhold and A.T. Kearney (2008) described the basis on which the new project was established. Basically, the public transportation was divided into a core network that were improved, and a supplementary network with feeder function that ensured minimum services. The core network, composed by commuter rail (S-Bahn) and metro system (U-Bahn), were expanded with the introduction of two new products, Metrobus and Metrotram network which together were called “Metrolines”. These new services consisted in buses and trams that serve major travel roads where usually had poorly transport coverage. The main characteristics of this network were that vehicles run through the day in low headways (10 min or less), their lines were on main roads and as direct and straight as possible, and their links or connections were planned as a “spider web” effect. The Metrolines represented a spatial expansion of the core network covering more residents of Berlin.

Meanwhile, the secondary network continued to present the required characteristics so as to cover transport accessibility to residents living within 300 meters from a bus stop and 600 to 1000 meters from a railway or metro station. In this network, vehicles run in lower frequencies (20 min or more) and also higher frequencies (10 min or less) on high-volume lines. There were also applied some service reductions and few lines were entirely eliminated (basically because of historical parallel routes to the rail), but almost all of these were adequately covered by other routes.

An interesting issue of this project were the strongly consideration of customers and media collaboration in the planning process. Reinhold and A.T. Kearney (2008) confirmed that this was not only to increase acceptance for the project, but also in order to include as many ideas and suggestions for improvements as possible. The BVG Company established an intensive dialog with around 24,000 customers throughout different ways, such as public events, on the Internet, surveys, micromarketing with flyers and magazines, which was prepared to provide the necessary information and assistance to customers understand the reasons for the changes and to prevent possible disapproval at an early stage.

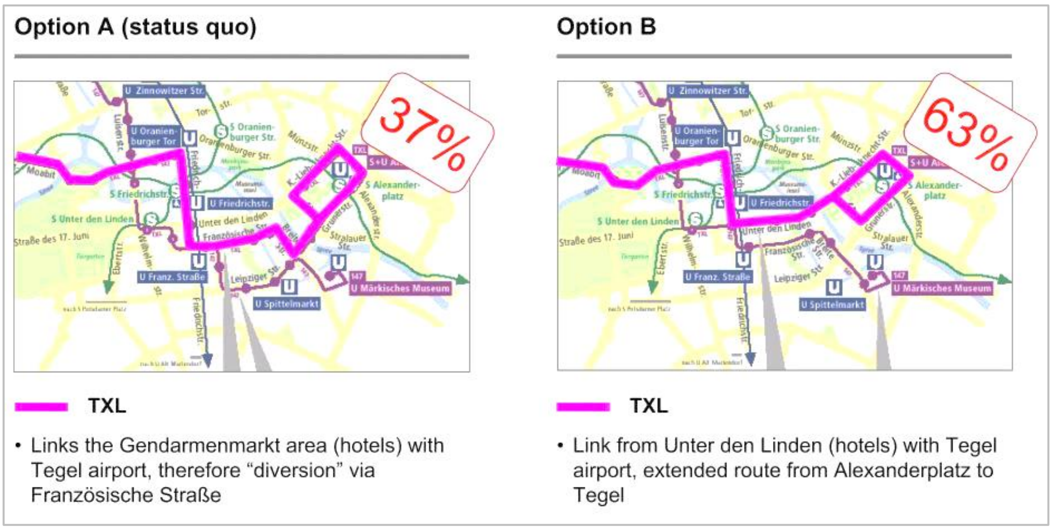



Figure 12: Results of customer dialogue of a specific line route (BVG, 2006).

Figure 12 make possible to appreciate the result of one survey made with customers about the TXL (Mitte) line, 63% of the answers have preferred the optimized route (increasing frequencies) and 37% voted to leave the line as it was. The company spent considerable resources in communications in order to strength customer loyalty.

### 4.3.2 FIRSTS REACTIONS

The newsletter of the IVU company (IVU, 2004) described "BVG 2005 Plus" as the first transport project in which 24,000 Berliners took part and that such a combination of studies, market search, customer surveys, traffic analysis, and passenger counts has never been driven on such a large scale and designed the basis for the planning transport concept. They also expressed that the Berlin's passenger association "IGEB" welcomed the new project and expected that it would result in a reasonable re-organisation in public transport.

Meanwhile, the Berliner's transport policy magazine "Signal", with critical and factual competencies, reported that the new project concept was probably the most comprehensive timetabling change of the BVG. However, an article of this magazine described that after the modifications of the BVG transport network, several sectors had received around of 20,000 complaints, and among them are BVG itself, the Urban Development Department of the Senate and also the IGEB. Most of the commonly reasons of the complaints were about the supplementary network, such as: transfer increase, longer waiting time because the frequencies reduction, less time service in the morning hours, gaps of service between day and night traffic, lack of school transport and fares disadvantages, among many others (IGEB, 2005).

Many newspapers of Berlin (Der Tagespiegel, Berliner Morgenpost, Die Welt, and others) expressed in December 2004 the reaction and situation of the customers, when the new project was shortly implemented. For instance, Der Tagespiegel (2004) made a short survey asking people if the new route network works as the BVG promises and 51,7% answered negatively and the other 48,3% were satisfied with the faster connections and shorter routes, making the system more effective. Similar, an article from Die Welt (2004) presented the disagreement of several commercial sectors about a specific line service (number 134) that stopped to pass along the Pichelsdorf Street and Adam Street in order to go more directly by Wilhelm Street, and they reported that sales were 20% less than usual and could put in danger their business. According to the BVG during the previous dialogue process with customers, there were 67% votes in favour for this specific modification.

As Reinhold and A.T. Kearney (2008) confirmed, the micromarketing was very criticized, particularly for not presenting all relevant information, the delayed distribution of the new timetables, which were not ready until the very day that the service changed. One of the reasons was that the Berlin State Senate specified some last-minute modifications on the approval process. Indeed, the BVG receive the legally-required authorization of the lines only one day before the implementation of the new services.

According to the transport company data with the new hierarchical network structure, 37% of the demand saw further improvements (more or new offer) and only 5% detected deterioration in the services, and stayed identical for about 58% of the residents, as can be seen in Figure 13. Nevertheless, a survey conducted in January 2005 presented different results: it was estimated that 66% of frequent travellers considered that the new BVG transport services got worse (IGEB, 2005). Due to the disadvantages that many people have encountered, especially elderly passengers on their regular routes, customers announced that they would no longer use the BVG regularly and proceed to cancel their annual subscriptions. Instead of the expected passenger growth by 2%, the BVG felt a loss of passengers.

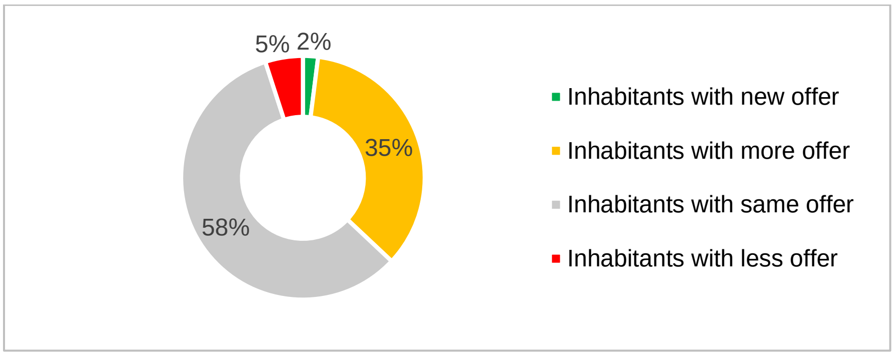



Figure 13: Change in offer. Adapted from (BVG, 2006).

The passenger association IGEB for its part requested through the submission of immediate specific action plans to the BVG for the improvement of the most serious problems of the new route network. The company was prepared for occasional reviews and reacted quickly to problems associated with the new implementations.

### 4.3.3 POSITIVE RESULTS

The new concept of metrolines represented a spatial expansion of the core network into the peripheral area of the city and also includes indirect connections. Reinhold and A.T. Kearney (2008) said that with the new core network including metro, commuter railway and the new metrolines, the city was covered in 87% of the residents. Without the metrolines, the previous network provided approximately 70% of premium services coverage.

Der Tagesspiegel newspaper announced on December 12, 2005 – exactly one year after the implementation of the “BVG 2005 Plus” project – that the new network of metrolines was a great success, although many passengers pronounced inconvenience. Twelve months later, the BVG was satisfied because almost all predictions were fulfilled. According to the BVG, passengers for which the offer was deteriorated have then given up, there were complaints but very scarce.

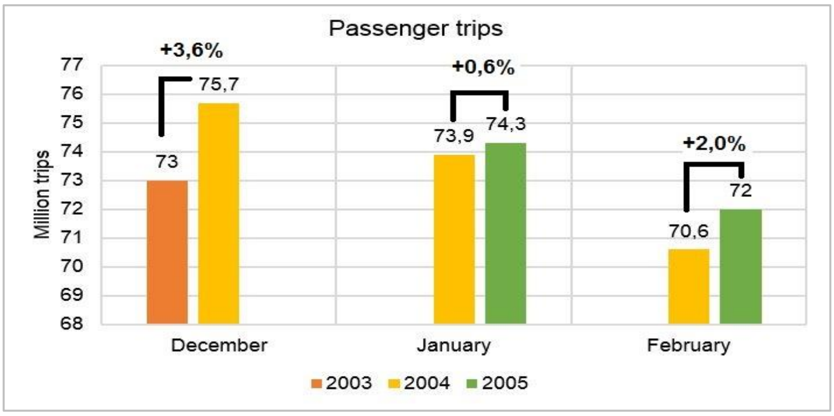



Figure 14: Changes in number of passenger trips per year (BVG, 2006).

All in all, one year after the new network implementation, the BVG Company experienced the expected increasing number of passengers compared to the same months in the previous year, growth of around 2% (Figure 14). With this, ticket revenues have also risen as it was expected. As can be appreciate in Figure 15, ticket receipts showed positive tendency.

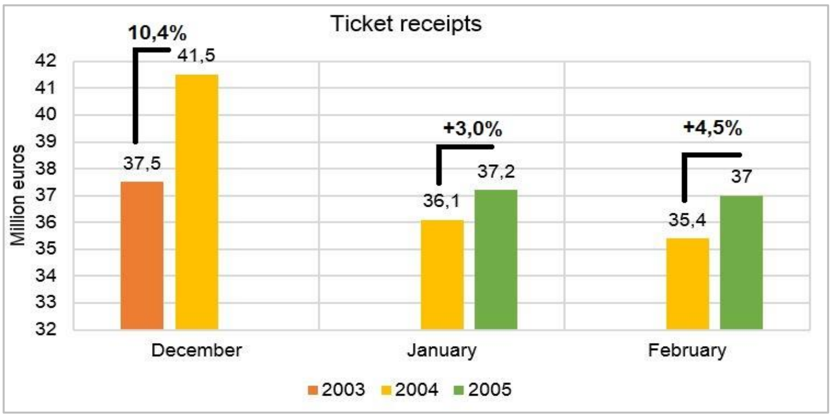



Figure 15: Changes in ticket receipts (million EUR) (BVG, 2006).

Moreover, a survey made by BVG based on 1000 user's answers, showed results that approximately three parts of different groups customers were satisfied with the new service (Figure 16).

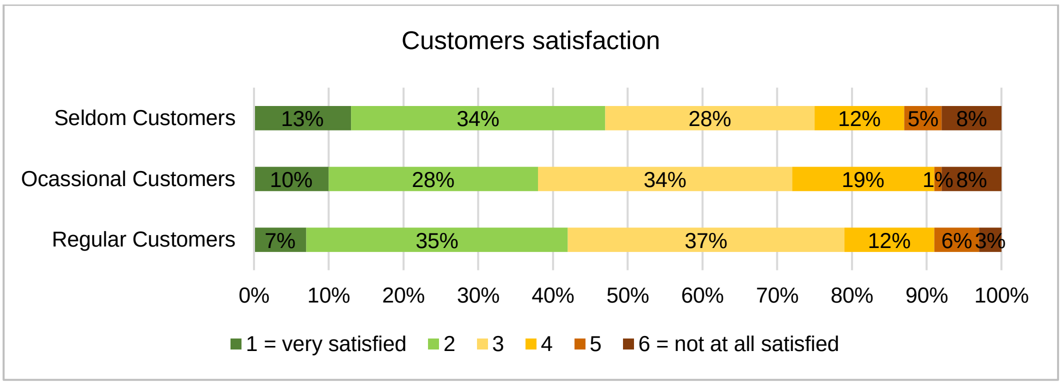



Figure 16: Customers satisfaction with the new BVG service (BVG, 2006).

Reinhold and A.T. Kearney (2008) described that the metrolines fulfil the promise of simplifying the transport service just like a BRT (bus rapid transit), because customers do not need to study the timetables anymore as a result of the high frequencies. The same effect occurred with the orientation improvement within the enormous network of Berlin. So, trains and metrolines could be used for long journeys and conventional bus and tram lines for more specific services. The idea of “always there” provides not only spatial orientation, but also a clear temporal coverage.

### 4.4 MPT – MALTA PUBLIC TRANSPORT

Malta is a European country located in the central Mediterranean Sea and consists of three islands: Malta, Gozo and Comino, covering 316 $km^2$ with a population of approximately 425.000 inhabitants in 2013, of whom majority live in Malta and Gozo (National Statistics Office Malta, 2015). This makes the country in one of the smallest and most densely populated around the world, where one of the major activity and industry on the island all year is tourism.

The principal public transport mode is bus transport system, additionally there is a small sea transport that connect the towns from the main islands, Malta and Gozo (Attard, 2012). The Malta buses services were both for public transport and also a tourist attraction on the islands, due to their unique appearance based on the ownership and operation model used in Malta, a notoriously ancient buses. The iconic types of buses of this country were different as in anywhere else in the world. The tradition of local buses ownership by the drivers itself and their historic practice of costuming them (decorating, in-house maintenance, body modifications in local workshops, see Figure 17) came to an end with the implementation of new modern buses in 2011, when a new transport reform were introduced to the bus network service of Malta.

The bus service offered in Malta based on individual owner drivers were successful at connecting different towns and points around the island, but has not changed dramatically since its start in 1905. The development of the bus service was going gradually over the years across the main island with one main terminal, the capital city of Malta, Valetta, from where all vehicles started or finished. Until today, the capital city is one major destination both in terms of employment and shopping, but also for interchange to other trips (Attard, 2012).


Figure 17: Classic Malta buses (Times of Malta, 2011)

In 2008 the public transport in Malta had good geographic coverage (Figure 18), nevertheless some operational issues have been declining the service quality to local people and also tourists. Childs and Sutton (2008) identified some of those aspects: poor timetable departure adherence, lack of intermediate timing points generating schedules uncertainty and longer waiting time for passengers, high number of inspectors and supervisors which do not reflect the performance standards, diverse buses quality – due to the maintenance, cleanliness, customer care and driving standards that depends on each driver –, inadequate usage of around 140 buses with modern low-floor purchased with government grants (25%) and no guarantee of the accessibility needed on particular routes, low quality of information causing difficulties to current and potential passengers to understand the offered services, fare system based on two zones with very little price difference making it financially unsustainable even with substantial loadings, poor value of the "tourist" multi-trip ticket, and the bad practice of ad-hoc irregular frequencies in the operations of public transport bus.

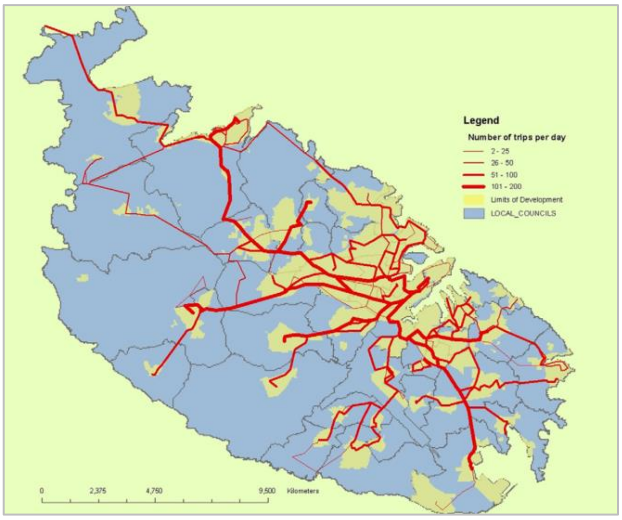



Figure 18: The public bus transport network in Malta in 2006 (Attard, 2012).

The Times of Malta online (Times of Malta, 2008) presented the usual complaints about the present public transport system: No connection between neighbouring villages; a lack of proper information and of punctuality; inefficient bus ticketing; impolite drivers; and buses that are old, grimy and polluting. Also, the newspaper said that the patronage of 65 million passenger trips a year in the 1970s dropped to 32 million in recent years. Additionally, the present system did not take into account the urban development that had taken place over the years.

The Government presented a document (Ministry of Infrastructure Transport and Communications, 2008) with several probably reasons why the public transport system had been failed in Malta. In addition to the weaknesses mentioned before, come other reasons are the following: bus routes were set out many years ago and the system reacts too slowly to the changes in demand for new routes or frequencies; the vehicles used on the routes are old and inadequate to meet the demand necessity, buses are all of the same size, too small for some of the most popular routes and too large for others; buses owned by the individual driver translates into a huge cost in subsidies; the daily roster system of drivers are exaggerated and dangerous, 16 hours of work makes drivers rude and frustrated; the public transport operators refuse to keep their potential clients updated; the operational routes are full of exceptions to frequencies, secondary routes and cuts in the service that are never communicated to the general public, and others.

The Public Transport Association (ATP), a strong private association of around 400 members – individual bus owners and drivers which inherited grandfather's rights the operation of scheduled services– was the monopoly that operated the public transport of the island of Malta. Additionally, the ADT (Malta Transport Authority) not only had no real control over the ATP operation on the roads, but should it detached itself as the regulator to deal with ATP as though it were a private supplier (Ministry of Infrastructure Transport and Communications, 2008). This situation of monopolistic environment and the lack of good management from part of the government was the complete circle of an inefficient transport system.

The aforementioned aspects pushed highly the increasing car ownership in this country declining the service level of public transport becoming one of the countries with highest dependence on private cars. The document “A Sustainable Development Strategy for the Maltese Islands: 2007-2016” (National Commission for Sustainable Development, 2006) has outlined the importance of encouraging people in using public transport.

As Attard (2012) expresses, socio-political and historical factors were basically the most important elements debilitating public transport network planning and design in Malta. This and the general dissatisfaction by the population about the transport service, the expectations for change were very high. A new Transport Minister was elected in March 2008 and that meant the Government had to be innovative. A new transport reform was announced.

### 4.4.1 THE REFORM OF MPT

The new public Government announced the decision to liberalise the transport service and that the transport monopolies were going to be withdrawn, this conducted to a general transport strike in July 2008 led by the Malta Transport Federation (Route Bus, Taxi and Minibus operators) during one week (The Malta Independent, 2008).

The population was in support of the Government’s plans to remove monopolies. The operators’ justifications for the general strike which affected the economy of the islands when tourism was at its peak were weak and focused on maintaining the protection by Government for these sectors and maintaining the status quo in the provision of services (Attard, 2012).

The public transport strike helped to push forward acceptance towards the radical reform that the government had proposed in order to organise all public transport system into one coordinated effort implemented by 2010 and completed by 2012 (The Malta Independent, 2008).

The detailed vision document that the Government launched (Ministry of Infrastructure Transport and Communications, 2008) for the public transport reform, which was prepared after the transport strike, was divided into three main features: (i) the failures of the current system, (ii) the proposals made by the government, and (iii) the ways the market can become more liberal. The reform would not only include buses, but also other means of transport including water taxis, mini-vans, normal taxis, ferries and electric cabs. Three different studies that form part of the reform were conducted, the first focuses on new routes around the island, another emphasizes on the type and cost of the fleet of buses and the third focuses on expenditure and financing.

The main concern of the new reform was addressing modal shif, from private transport to public transport, as a necessity to achieve sustainable mobility; and the Government described the new transport network and determined the high level conditions of the new operational service. Malta needed to have a new, energy efficient fleet of buses of different sizes as appropriate for the different localities, a new route network, new management for the bus service, and full utilisation of the buses every day. Rapid services to major destinations, more frequent and operated over 24 hours. Also very important the ticketing system needed to be introduced with incentives for frequent users (Times of Malta, 2008).

In her work, Attard (2012) summarized very well the new characteristics of the new transport service design: the Government removed as much as possible the redundancies of the old network, reduced the volume of traffic going to Valletta by distributing the trips amongst a number of interchanges, introduced the concept of interchange against the benefits of time-savings and developed a mix of fast, direct services (Cross-line services facilitating interchange) alongside more traditional services (Mainline services to and from Valletta) and local small bus services linking neighbouring villages together (Feeder-line services). The reform also includes the examination of fare structure making it easy for tourists, the social services provided and high accessibility to the bus stops with 73% of households living within 5 min from a bus stop.

After analysing the situation, the Government concluded that competitive tendering was the way forward to effectively manage public transport services in Malta through with the contract of services of a company in charge to operate the whole service on a basis for 10 years (Attard, 2012).

The operator had to respond on the following requirements: the network changes such as peripheral destinations, links between different cities, day and night scheduled bus services; the introduction of a modern, lower emission and accessible fleet of buses with different capacity of seats; the introduction of concession fares and discounted fares which encourage the public to use public transport more frequently; the maintenance of a clear distinction between scheduled bus services and occasional services; the application of improved working conditions for drivers including maximum driving time, minimum break periods and rest periods; the use of information technology in operational routes in order to keep the costumers informed in real time about the services (Attard, 2012).

The branch reform of public transport was launched in the public sector in 2008 by the Ministry of Infrastructure and Transport (Times of Malta, 2008) and in November 2012 was signed the 10-year contract with the new service provider Arriva.

Some important modifications in this new contract were about bus drivers, they would work eight-hour shifts including breaks and real-time information would be available for commuters. The government also proposed that the present 508 buses would be reduced to 270, with buses of various sizes and engines that are Euro III compliant, as well as electric and low-floor buses (Times of Malta, 2008). Some of the old buses that would be replaced with the new reform would be passed on to Heritage of Malta for display in a transport museum and others would be recycled (Times of Malta, 2009).

Moreover, the government was to apply with the Malta Environment and Planning Authority for the upgrading of termini of Valletta, Victoria and Bugibba and for the extension of the Balata I-Bajda Park and Ride and for the creation of new park and ride system in Marsa and Luxol (Times of Malta, 2009).

According to the local news (Times of Malta, 2009), the Transport Minister Dr. Gatt stated that the objectives of new system were economic, social and environmental. Economic because it would be cheaper to use public transport than one's own car, social because buses would serve areas never served before, and environmental because the service would be cleaner. The minister also expressed that over the years, the Association of Public Transport had operated more like a trade union rather than an operator.

### 4.4.2 MPT NETWORK PLANNING AND DESIGN

Government had to be innovative in order to satisfy the expectations of general public about the public transport in Malta. However, as Attard (2012) described there were a number of considerations which limited innovation. First was the fact that the current network service had been in operation for almost a century and the commuting costumers were used to that level of service and to a certain extent for those with no access to private cars, travel patterns were influenced by this network. Secondly was the fact that Valletta was and will always remain a major attraction for shopping and employment. The third consideration was the location of particular areas associated with specific activities like the university, entertainment spots and the main hospital, influenced the patterns of movement because these have had very good access by public transportation. Changing this access would upset current bus users as well as distract from new users using the service. Finally, the fact that 86% of tourists use public transport during their stay in Malta meant that the public transport provision to tourist areas must remain high (Attard, 2012).

All these aspects considered were used to identify travel patterns both for current bus users and potential ones (current car users) and ensure that corridors with high patronage would be provided with direct links without interchanges, which in turns were new elements of the network. The new proposed network allowed multiple interchange points to shorten as much as possible travel time and distance. This was aided by integrated ticketing and a proposed one-zone fare system which would not require, as was the case before, to buy a ticket every time on board (Attard, 2012).

It was designed different types of services reflecting their specific use. So, the “Crossline routes” were limited stops and running every 10 to 30 minutes linking main nodes in the network allowing for users to quickly cross the island without going to Valletta to interchange. The “Mainline routes” were the more traditional services that linked Valletta to the outlying towns and villages and would allow the possibility to interchange in many major or minor nodes along the network by covering extensively the route which they served. And the “Feeder-line routes” are at the more local level, which consisted in circular routes that operate within one particular locality, serve small communities and run every 30 minutes. This local services were the newest addition to the network which not only provided access in and around villages, but also served an important work to link adjacent villages to towns and their centres. The total services negotiated in the contract included 24 Mainline services, 2 Crossline services, 4 airport services, and 30 Feeder-line services for Malta (Attard, 2012; Times of Malta, 2008).

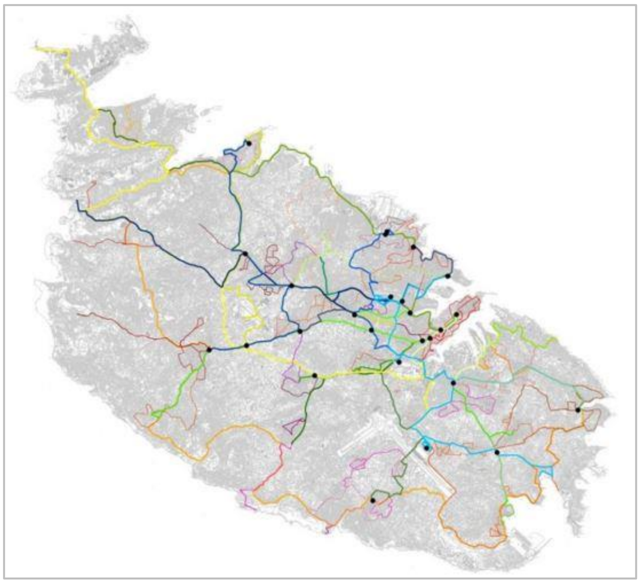


Figure 19: Proposed public bus network for Malta (Attard, 2012).

Figure 19 shows the proposed network for Malta Public Transport, from which the blue lines indicate the Crossline service, the green lines indicate the mainline service and red service indicate local Feeder-line services. The yellow lines indicate airport services and the orange line indicates a service linking the outer villages. Black point along the network are the interchange facilities to support transfers of passengers.

The varied service offered also need different types of buses. In this order, the range of vehicles were from mini buses for the Feeder-lines services, standard buses for Mainline and Crossline services and articulated buses where the demand is high along some corridors.

The Valetta bus terminus system would also be changed following the idea that not all buses start and end up in Valletta but another termini will be set up at the airport, Marsa, Rabat, Mosta Technopark, Bugiba, Paola and Mater Dei Hospital (Times of Malta, 2008).

### 4.4.3 REACTIONS, IMPACTS AND MAIN RESULTS

In this section will be identified the advantages and disadvantages that the public transport reform implementation brought about. According to Attard and Hall (2003) there were two main aspects that were happening during the transport reform, on one side there was the network design which was innovative and away from the historical approaches in the provision of public transport in Malta for almost a century. On the other hand, there was the Government decision to change the operational model by removing the monopoly and introducing competitive tendering.

As several online newspaper expressed (Gozo News, 2008; Times of Malta, 2008), the public support made an indispensable contribution to reach the reform of public transport service in Malta. The population hopped that the Government will go forward with the transport system needs and was set up “The Malta Transport Reform Action” in the wake of the shameful protest organized by the Transport Federation in July 2008. Over 1000 people have joined the Facebook group in one day. This shows clearly that the Maltese population was really fed up with the state of public transport system and was fully supportive of the Government actions.

Following the information given from the local news, during the launch meeting of the proposed public transport network in December 2008 (Times of Malta, 2008), the general public have supported positively contrary to the operator sector who had a negative position. Amongst other things the bus drivers complained that they are the only ones who really know what means being a public transport operator, that removing the monopoly will eradicate their livelihood, that the proposals of the network are not sustainable and that there were made by people who did not understand how public transport worked in Malta, and that the Government was breaking out his pre-election promise to maintain the status quo.

When the reform was taken form and the vintage yellow buses were replaced with a more modern and efficient fleet not all the people welcomed the change. A online blog (BBC News, 2011) expresses that some of the younger drivers were very angry, but they understand that it makes practical sense because old buses are polluting, unreliable and uneconomic. Nevertheless, it broke the heart of many drivers to see their buses scrapped.

With the implementation of the reform in 2011, the Malta Public Transport (MPT) improved in many aspects. The online Times of Malta (Times of Malta, 2011) published that the public transport usage in October increased by 28% compared to the same month of the previous year according to figures the operator Arriva gave Transport Malta, as can been appreciated in Table 5.

In particular, regarding the transport service provided to students, KSU (2011) analysed the previous bus network that served direct routes to university with the new transport reform. They agreed that new service provided by Arriva presented more frequent buses to University directly or indirectly with only one interchange if it was necessary. The new transport service presented a better fleet quality, buses more comfortable and increased the sense of security during the passenger journeys due to the CCTV cameras, and are also environmental friendly. Environmental protection and sustainable mobility are priorities for the well-being and development of a society in many aspects, if not all aspects. The new service was more inclusive to disabled and elderly people making an all-inclusive transport service, socially very important. Also they confirmed that bus driver's attitudes have got better and the negative attitudes have considerably diminished.

Table 5: Difference in public transport usage in 2010 and 2011. Adapted from Times of Malta (2011).

| MALTA | 2010 | 2011 | Variation (%) |
|---|---|---|---|
| August | 2.856.444 | 3.459.835 | +21% |
| September | 2.557.509 | 2.971.587 | +16% |
| October | 2.646.169 | 3.213.433 | +21% |
| **GOZO** | **2010** | **2011** | **Variation (%)** |
| August | 57.000 | 240.000 | +321% |
| September | 44.000 | 207.440 | +371% |
| October | 44.000 | 229.803 | +422% |
| **MALTA AND GOZO** | **2010** | **2011** | **Variation (%)** |
| August | 2.913.444 | 3.699.835 | +27% |
| September | 2.601.509 | 3.179.027 | +22% |
| October | 2.690.169 | 3.443.236 | +28% |

Regarding the transport network routes, the decentralization had made some remoter sites more accessible, as well as many routes have improved their schedules and frequencies. Moreover, the new facility to buy one day-ticket made the service overall cheaper for those using the service frequently. The communication between service operator and costumer also have improved through the online portal from which every passenger can access to a friendly portal in order to obtain all necessary information about their routes.

The University Student Council also analysed some problems that they have encountered, as the Arriva disillusionment about the promised standards, even though the fleet and staff have improved there were many complaints on the service. One important issue was the poor buses maintenance making the service a bit difficult. However, summarizing their opinion, KSU (2011) said that the impact of the public transport reform were mostly positive, improved bus aesthetics, and reached higher standards of services.

Figure 20: New buses of MPT (The Malta Independent, 2015).

The company Arriva Malta was the operator since 2011, but in 2014 the company ceased operations in Malta owing to financial difficulties and the Malta Public Transport had been nationalised by the government and a new operator would take over the service. The new operator chosen was a Spanish company Autobuses Urbanos de León and in January 2015 they assumed the charge of the bus service maintaining the name of Malta Public Transport (The Malta Independent, 2015).

The current fleet of MPT Company is composed by 360 buses, and 143 of them have been put into service in 2015, being one of the youngest and most modern fleet of Europe. The company operates in daily services every day and night services at weekends as well as on holidays, also offers a number of express routes basically with direction to the airport. The total coverage per year increased to 30 million km every year and it is estimated that in 2015 were transported 40 million passengers (Malta Public Transport, 2016).

### 4.5 STCP – PORTO

Porto is the second most important city of Portugal, after the capital city of Lisbon, and has almost 250.000 inhabitants. Moreover, the metropolitan area of Porto (AMP) population increases to 1,7 million people.

Figure 21: STCP bus in the city centre of Porto (STCP, 2016).

Since 1946, the Collective Transport Society of Porto (STCP) is the public company that manages the bus transit network in the city, as well as in many urban zones of the metropolitan area, and also the tram lines that subsisted from passed decades in the historical part of the city. The last report of the agency (STCP, 2016) described that in 2015 the transport service reached 72 lines, including night buses and tram services with a majority of natural gas and hybrid vehicles, that make a very positive environmental aspect. The network has a total route length of 481 km with 2448 stops and 69,2 million of passenger in this year.

In the 2000's the city of Porto has been experienced some developments in their population activities and manners. Therefore, the STCP have seen the necessity to implement some modifications in the public transport network in order to be adapted to the social changes and consequently on the demand variations. The report (STCP, 2007) expressed the main reasons that brought about a new transport network design:

- Demographic changes that were created by residential areas in peripheral cities of Porto, creating new passenger generators;
- Development in other modes of transport, significant private cars that were a reflection of the economic development of the previous 15 years;
- Creation of an integrated transport system with the introduction of the Metro of Porto;
- Improvement of operational levels and service quality provided by the public agency.

These factors pushed to establish a completely new solution abandoning punctual adjustment on a specific line on an old network. So, the new challenge was to overcome inefficiencies, reduce overlapping with the metro lines, and to improve travel times by implementing more regular frequencies.

### 4.5.1 Changes in the network

In October 2006, the STCP presented the new contactless ticketing network project and in a month later started the transition period of this system, applying the new infrastructure needed inside the buses. In the end of 2006, the public company STCP presented the whole new transport network to the social Medias, local authorities, and to public and private operators.

The new transport network design was based on several assumptions that are described in (STCP, 2007) such as: reduction number of bus lines maintaining the service coverage; decrease of the average of routes length with organized schedules in order to avoid negative effect of transfers; taking the metro system as a complementary transport by creating an integrated system; establishing main interface points among the city; creating different types of lines such as radial, transversal, circular, and pendulum routes; and distinguished schedules so as night service, weekends lines, and holidays.

Figure 22: STCP network in 2007 (STCP, 2008).

The 1th January 2007 the new integrated transit network was fully implemented, as well as the new contactless intermodal ticketing "*Andante*". The new network had some modifications on the schedules and frequencies, also reduction in the average of routes length, and elimination of 44 lines of the previous network and creation of 30 new lines. The total network length was 533 km distributed in 83 new lines and can be seen in Figure 22, with shorter and more direct alignments, but also more frequent and with a good interconnection to other transport modes, such as metro or tram.

### 4.5.2 Reactions about the new network

Customers and population in general did not hesitate in react to these modifications and generated negative and controversial feedback to the public agency. STCP expected to receive pressure from customers, since the changes results forced people to modify habits and mobility routines without perceiving the advantages introduced.

Initially difficulties were inevitable, several local news showed population public protest, and STCP started to adjust some performance, but users still considered them insufficient. The mobility solutions required time and experimentation to a better knowledge and habituation.

The administration of STCP were opened to make changes considered necessary in order to improve the service provided to the population. Among 2007, the company began to monitor supply and demand behaviour in order to evaluate the real needs of the population. The company was being included other measures according to the requirements, such as routes and schedules adjustments and frequencies, as well as consolidation of the night service and the weekend services in some specific neighbourhoods.


Figure 23: Public protest after the implementation of the new bus network of STCP (TVi 24, 2007).

### 4.5.3 Pros of the implemented network

Six months after the introduction of the new transport network, the results were "positive" and the number of claims returned to as same as previous years, said the STCP president Fernanda Menezes to a local newspaper. For the public company, this indicates that users were already familiar with the new lines.

It is fundamental to highlight the positive aspects of the implementation of the new network and extension of the ticketing contactless to all transport modes. The report of 2007 from the public company STCP expressed that the new changes contributed decisively to the creation of intermodal transport system in the city of Porto and their metropolitan area, despite the consequent market shift to other modes of transport, essentially to the metro system.

Several news (JPN, NP and others) reported in the first half of 2007 that despite the supply of STCP decreased by 10% over the same period in 2006, the combined supply of STCP and Metro services were at the same level of demand. The increase of intermodal costumers was a result from the integrated new ticketing service.

One elemental aspect arises from this development: intermodal ticketing system increased about 49% with reference to 2006. Also relevant was the increase of intermodal passengers that evolved from 11% in January 2007 to 21% in December (STCP, 2008).

The annual report from STCP expressed that in 2007 were transported 109 million passengers over 30 million km. This can be translated into the next positive aspects:

- Reduction of 8,7% of travel time average, evolving from 46 to 42 min;
- Increase of 27% in frequency average at peak periods with intervals from 22 min in 2006 to 16 min in 2007;
- Increasing of the vehicles speed in 3,3% (0.5 km/h);
- Reduction of 6% the average of lines length, ensuring regularity and better service;
- Supply reduction by 7% of the entire fleet of STCP (including contract operators) from 2006 to 2007.
-

## 4.6 Summary and Discussion

Now it is presented a summary of each practical case of network implementation in Table 6.

Table 6: Summary of transit system implementation cases.

| City | Population | Program implemented | Objectives | Principal changes | Reactions | Main reasons | Measures employed | Results | Observations |
|---|---|---|---|---|---|---|---|---|---|
| Santiago de Chile | 6 million inhabitants | Transantiago (February 2007) | Encourage population to use public transport.<br>Improve the public transport quality. | Redesign of the route network (Feeder Model with BRT and conventional buses to feed Metro system).<br>New route alignments.<br>New fare system: Smartcard "Bip!".<br>New fleet buses.<br>New timetables and frequencies. | Negative population perception.<br>Public protest.<br>Operational problems. | Not enough conditions to implement all changes in one day.<br>Stations not finished.<br>Insufficient number of buses.<br>Ticketing system still in process.<br>Excess waiting time.<br>High crowding levels.<br>No frequencies control (GPS on buses did not work correct). | Government modify contracts with operators many times.<br>Introduction of subsidies for students and other especial fares.<br>Increase of number of buses. | Urban mobility was easier to control, coordinate and collect taxes.<br>Traffic accidents have dropped considerably.<br>Drivers have started better work schedules.<br>Drivers did not compete for passenger on-street anymore.<br>Positive environmental aspects.<br>Inclusive mobility introduction.<br>Metro increase his passenger number twice.<br>Students were no longer discriminated.<br>Less congestion. | Transantiago still manages the poorly perception of the transport system until today. |

| City | Population | Program implemented | Objectives | Principal changes | Reactions | Main reasons | Measures employed | Results | Observations |
|---|---|---|---|---|---|---|---|---|---|
| Berlin | 3,5 million inhabitants | BVG 2005 Plus (December 2004) | Increase company income through ticket sales (number of passengers). | Redesign of the route network (Core Network and Supplementary Network).<br>Introduction of "Metrolines" on the Core Network.<br>New route alignments.<br>New timetables and frequencies. | Negative perception.<br>Complaints from users and population in general. | Increase number of transfers needed.<br>Reduction of frequencies on some routes.<br>Longer waiting time.<br>Gaps of services between day and night lines.<br>Some lines stop to pass in front of specific streets because routes were more direct.<br>Poor micromarketing and information.<br>Difficulties for elderly to enhance a bus station (need to walk more). | Small specific interventions following the demand complaints.<br>Occasional service reviews. | "Spider effect" of transit network, more coverage.<br>87% of intermodal service coverage (railway, metro and metrolines).<br>Faster connections.<br>Shorter routes, less travel time.<br>After one year, number of passenger growth 2%.<br>"Forget the timetable" effect. | During the planning process, customers and media were taken into account to increase acceptance and include ideas and suggestions. |

| City | Population | Program implemented | Objectives | Principal changes | Reactions | Main reasons | Measures employed | Results | Observations |
|---|---|---|---|---|---|---|---|---|---|
| Island of Malta | 425.000 inhabitants | Reform of MPT (Malta Public Transport) by competitive tender (2011) | Address sustainable urban mobility.<br>Modal switch from private to public transport (cheaper, cleaner and with good coverage). | New management.<br>Remove operator's monopolies and liberalise transport service.<br>New fleet buses replacing the vintage buses.<br>Redesign of the route network.<br>Diverse type of services: crossline, mainline, feederline.<br>Improve conditions for the operation service.<br>New fare system: Smartcard "Tallinja Card".<br>New timetables and frequencies. | Operators strike.<br>Bus driver's complaints before implementations.<br>Public support to the Government.<br>Users complaints after implementation because the disillusion of the new operator Arriva. | Bus drivers did not accept the removal of the monopoly (based on their knowledge of operating public transport service).<br>Poor bus maintenance. | Maintain constant communication between operators and costumers. | After one year increased 28% public transport usage.<br>Better frequencies and schedules (directly or with transfers).<br>Better route coverage.<br>Improve standard service quality.<br>More security in-vehicle.<br>Environment friendly.<br>More inclusive service.<br>Better communication between operator and user.<br>Cheaper ticket for frequent passengers.<br>Better bus aesthetics. | Operator Arriva started to work since 2011, but ceased in 2014 because of financial difficulties.<br>Since 2015, a Spanish operator assume the charge to offer the MPT. |

| City | Population | Program implemented | Objectives | Principal changes | Reactions | Main reasons | Measures employed | Results | Observations |
|---|---|---|---|---|---|---|---|---|---|
| Porto | 250.000 inhabitants | New STCP route network design. | Adapt the transport network to demand variations. | Redesign of the route network (radial, circular, transversal and pendulum routes).<br>Reduction of number of lines maintaining coverage.<br>New route alignments.<br>Decrease route length.<br>New fare system: Smartcard "Andante".<br>New timetables and frequencies.<br>Differentiation of services: weekdays, weekends, night, holidays.<br>Integrate STCP service with Metro System. | Negative and controversial perception from users and population.<br>Public protest. | Changes have forced some groups of costumers to modify their habits and mobility routines. | Performance adjustment of frequencies and schedules, specially of critical neighbourhoods.<br>Consolidation of the night service. | After six months, complaints have been reduced.<br>People were familiar with the new route network.<br>Increase intermodal passengers (Metro and STCP combined).<br>Travel time reduction of 8,7%.<br>Increase of 27% in frequencies.<br>Vehicle speed increase 3,3%.<br>Reduction of 6% average route length. | |

Each of those cases analysed presented difficulties when implementing their transit network changes and in addition, all of them experienced also positive results. In theory, public transport system of any city has many advantages (relieves traffic congestion, reduces pollute emissions and contribute to a better urban mobility), however, implementing transport network changes is not a simple issue.

The case of Transantiago has experienced drastic consequences by introducing new entire operational service at once in 2007 without transition between the previous transport system. The Government of Santiago aspired extreme changes of public transport system: redesigned route network, new fare system contactless “Bip!”, new schedules, timetables and frequencies, and also new bus fleet and reduced number of buses. The renewed network presented many failures and operational problems, consequently, people reacted with protests and showed discomfort and negative feedbacks. This transition demonstrated improvisation, negligence and contradiction that could show the arrogance of experts and politicians.

Similarly, the Berlin’s public transport service suffered a huge modification at the end of 2004 by introducing the new concept of “Metrolines” service and redesign the route alignments of the transit network. The public transport company BVG dealt with the ambitious project, which had as objective increasing 2% in number of passengers while simultaneously reducing operations by 3% in order to solve financial problems. So as with Transantiago, when implementing changes, BVG received thousands of complaints from passengers affected by the new route network.

The case of Malta presented a different background, where the public transport service experienced a huge reform in 2011. The main changes were management structure modifications from many individual private operators driving their own buses to a unique company service through a public tender process, as a democratically feature to incentive better transit service. Also, the Government developed a redesign route network with new types of services, replaced the bus fleet from vintage buses to modern ones, and introduced a new ticketing system, the “Tallinja Card”. The main objective was to encourage people to shift from private transport to public transport, because there was unacceptably high levels of private cars and unsustainable public services in the island. The negative reactions came from part of the bus drivers before the tendering process with a driver strike against the government.

Last, Porto presented similar challenge as Transantiago and BVG have experienced. After decades of successive small adjustments on the STCP services, it was necessary to implement a fully renovated STCP route network in order to adapt the transport system to multiple mobility changes in 2007. Routes have been reduced in number, length and directness, and there were introduced new types of routes (radial, circular, transversal and pendulum) in order to integrate them with the Metro system. A new ticketing system was also introduced, the “Andante” card.

It is visible that any kind of project implementation is very complex and requires huge efforts from different stakeholders. The initial preparation, information and support play essential roles when introducing a renovated transit network, specially to the public who already are well served and would be affected, as took place with Transantiago, Berlin and Porto.

In all cases, after some time, users and operators accepted and were familiarized with the redesigned public transport network and other concerns such the implemented ticket system. Despite the Government interventions, Transantiago still passes difficulties today, but the whole transit system improved drastically since it implementation in 2007. An organized and regulated management from the government is total necessary. Berlin achieved their goal to increase passenger after one year of the new concept of Metrolines introduced and the optimized route alignments of the bus network. STCP increased the number of intermodal passenger (Bus and Metro System) after a few months of the new network implementation and the Andante card, when people finally were familiarised with the optimized routes alignments.

The reform of Malta Public Transport needed something more, it was necessary a new attitude towards public transport, the success depended on the costumer's motivation to change it mind-set and collaborated in increasing the number of public transport users. The Malta case showed how difficult is to change the idea of public transport from the small private operators. This case demonstrates more social aspects than economical or financial implementations.

It is no easy to adapt new itineraries to the regular people habits from a city of the size of Santiago, Berlin, Malta and Porto. It is a bigger issue to assimilate. More than a lack of lines and frequencies, in my opinion, the problem resides on the mentality change of the users from a single journey to an intelligent integrated line taking advantage from all the possibilities offered by an optimized transport system.

Moreover, it can be seen the importance of how institutional sector and public processes can establish good relation between private agencies and the public transport service. It is fundamental to encourage well-designed information and education to population regarding manage of change. Community involvement is required in almost all stages of the process of implementing optimized transit services. It is noted particularly with the case of Berlin that passengers are more likely to accept change when they perceive clearly benefits in terms of less travel time and more frequencies services.

It can also be highlighted in all cases the introduction of changes as a whole network and not through individual routes. At the beginning it can have a negative impact, however, when costumers are used to the new public transport network it is may be easier to accept the change at once. However, introducing a new network and a new fare system at the same time can be too many changes for regular users, as occurred with Transantiago and Porto. People wanted simple and stable transport network structure and also easy to understand.

Finally, all these examples confirm that all process of change with the purpose of improve the public transport service is complicated and not easy. It is possible to perceive that the impact of a reform implementation can influence people lifestyle and can stimulate positive support, popularity and acceptability to public transport. A good public transit service improves the quality of life and the well-being of citizens of all society.

# 5
# ROUTE ALIGNMENT

## 5.1 INTRODUCTION

Transit network design have been studied and focused for several decades, the literature mentioned route directness as the parameter to deal with route alignment design. No studies have developed a methodology to analyse specifically the route alignment of a bus transport system and only a few documents are available for route alignment in terms of route directness and route shape.

Despite the lack of scientific researches about this theme, there are practical cases that already take into account route alignments when improving and optimizing transit route network of a city. Planners and public transport practitioners highly recommend to consider route alignment at the design steps.

Due to the less treatment that route alignment had in other texts on public transport network design, this chapter will synthetize the collected information available and present main elements to take into consideration when analysing route alignment for an optimized public transport system.

### 5.1.1 TRANSPORT NETWORK GEOMETRY

The geometrical elements from a transport system are defined by the planners according to the objectives of the transport network. There are some fundamental ways of speaking that are often used in transit systems, such as “nodes”, “routes”, “lines”, and so on. In order to clarify some of the common terms and notations it is defined the following conceptualisations.

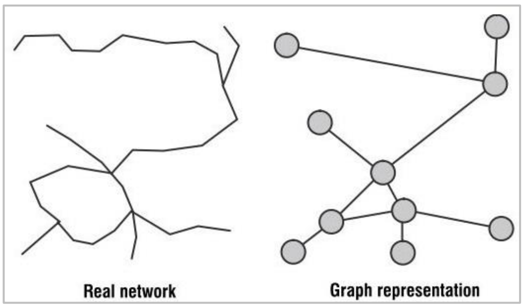



Figure 24: Graph representation of a real network (Rodrigue, Comtois and Slack, 2006).

Nodes are commonly used to refer a specific point of loading, alighting or transferring in a transport network service. Links are the representation of a mode of transportation and are formed by a pair of nodes. A graph is a symbolic representation of a network and of its connectivity (Figure 24). It implies an abstraction of the reality so it can be simplified as a set of linked nodes (Rodrigue *et al*., 2006).

Transport networks, like many other networks, are generally embodied as a set of nodes and a set of links representing connections between those locations and they illustrate the territorial organization of activities and their distances. A connection is a set of two points or nodes and considers the possibility of movement between those nodes and a link is the abstraction of the transport movement with a direction that can be also bidirectional. A path is a sequence of links that are travelled in the same direction. Figure 25 shows these concepts.

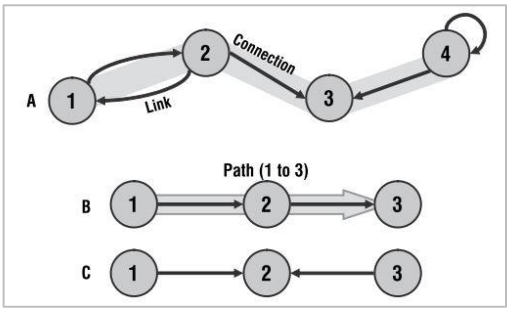



Figure 25: Geometric representations (Rodrigue *et al*., 2006)

Routes are the main element for a transport network system. Basically, routes, which are also known as "lines", are the operational component that public transport service offers with a physical path along which vehicles (buses, trains, etc.) travel. They are composed by a set of links that are connected sequentially, in other words, a fixed stopping pattern with a specific timetable. So, a transport network service is composed by a set of routes or lines.

## 5.2 DEFINING ROUTE ALIGNMENT

With the clarifications made about some concepts it is possible to establish a self-concept about this terminology used in this work. On the one hand, a "route" is the physical way that the public transport follows through the available road network of a city. On the other hand, the word "alignment" means the shape of the lines so formed. So, it is referred to "route alignment" as the designed path that a bus travel in order to reach the desired service coverage area. Figure 26 present a traditional representation of a bus route passing along stop places in an urban area.

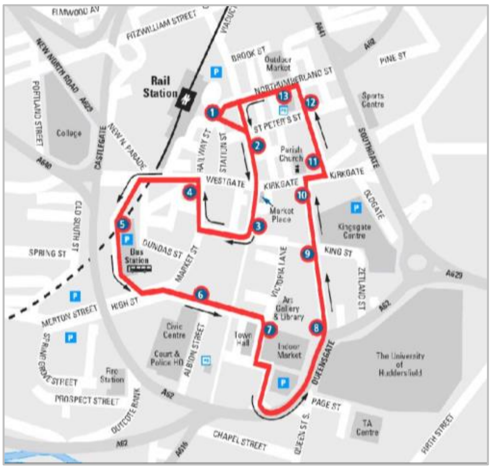



Figure 26: Example of bus route alignment on a map.

As an example, Nielsen *et al.*, (2005) made a comparison between two bus alignments, from which one is considered as a failed route alignment and the other successful (see Figure 27).

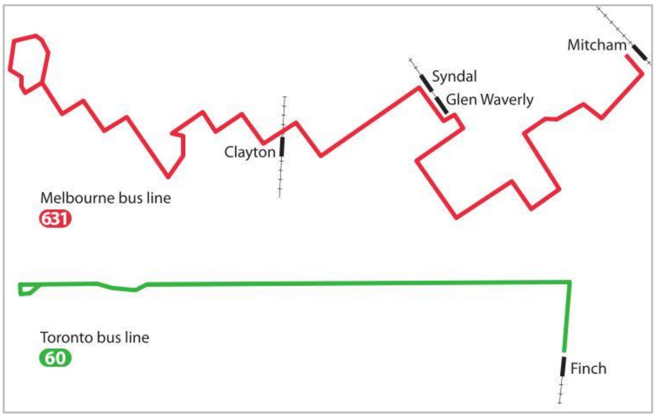



Figure 27: Differences between failure and successful route alignment (Nielsen *et al.*, 2005).

### 5.2.1 GEOMETRY ANALYSIS

The alignment of a bus route is particularly determined by the horizontal geometry of the specific road network of the city. More detailed, characteristics such street directions, road junctions, roundabouts and others constraints are important elements that should be carefully considered.

Route alignment is also a concern related to route length when speaking about optimizing benefits for both users and operators in public transport networks. As revealed by Guan *et al*. (2003), who presented an optimized method for transport network, the operation cost of any transport route can be linearly proportional to the length of the route. So, it is possible to say that minimizing the total length of the route network any transport system would be optimized. But, on the other hand, direct travel approaches may present unsatisfactory line configuration results owing to its partial measure of service coverage and quality.

Now, the route length is important at planning the final selection of route network looking towards the objectives of the transport system and the operation costs. In a common sense, the length of a route is also related with the directness of the route, in other words, a more direct route offers a faster service. At the same time this reduces the radius of passenger accessibility. Costumers would have to walk a little further to access to a bus stop in a more direct service.

Nielsen *et al*. (2005) also discussed the implications of indirect routes for bus services through suburban developments, arguing that indirect services created considerable inefficiencies, as shown in Figure 28. They said that indirect services were harder for users to understand and were difficult for the market.

Overlapping routes have also relationship with the length of routes, as (Kenneth Loh, 2014) expressed, longer routes mean fewer routes for the whole transit network reducing possible overlapping. In order to increase reliability, the author recommend to emphasis on more direct routes reducing deviation from the shortest path that routes may take. Nonetheless, it is inevitable to overlap routes in some situations because of different factors such as narrow entrances near bus terminals, bottlenecks where routes diverge or converge, etc. It will be explained the importance of connection of well-designed routes with optimal transfers points.

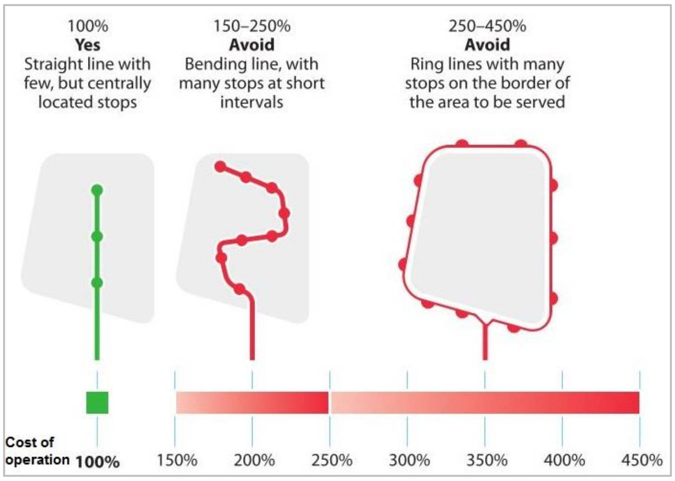



Figure 28: Operational efficiencies for direct routes (Nielsen *et al.*, 2005).

### 5.2.2 DEMAND REQUIREMENTS

Furthermore, as it was perceived, route alignment depends also on demand requirements. So, the generator points of interests, poles where the passengers are (i.e. residential and commercial areas), are fundamental characteristics that influences in the decision-making of optimizing transport services by route alignments.

Although, for instance, Wirasinghe and Vandebona (2011) described in their study that independent bus routes serving multiple passenger origins and destinations usually are very long and meanders through many roads. This can create difficulties in maintaining a good transport service in terms of travel time, reliability and also causing overlapping routes. So, after an analysis of deviations, it would be inevitable that specific passenger generator points may end up being excluded and considered in other routes.

There is usually more than one possible bus route that can be designed and chosen between an origin and destination, covering varied combinations of passenger generators. The challenge is to make a route that connects all the passenger generators possible along the shortest possible path. Wirasinghe and Vandebona (2011) confirmed that usually the shortest path can also be determined by simple calculations based on link travel time data and observations made on a map.

This brings about the important role that accessibility plays in order to make the transport system as competitive and attractive as possible. Many practitioners, such as Mees *et al*. (2010) recommend to provide accessible service for people that travel from all points without annoyance, especially talking about the walking accessibility to the stops allocations and the transfers points. Some authors confirmed that the walking distance to this location should be short, safe, comfortable and attractive. For instance, pedestrian paths which goes along urban streets or beautiful parks, protecting people from noise and pollution, among many others. As more attractive the walking journey, as more willing are users to walk longer distances. People usually walk around 5 minutes without annoyance, this means approximately 500 meters.

In this sense, stop locations should be very carefully planned with the purpose to ensure their optimal location regarding major trip attractors or passenger generators, making it very accessible by short walking distances. Also important is a well-designed transfer point, which should be easy to use, the distances between services should be very short, less than 10 meters, as Mees *et al*. (2010) recommend. Commonly, the need to transfer is a significant inhibitor to travel by public transport, so, practical guidelines recommend to avoid them if it is possible or do the necessary arrangements for easy transfers.

The theoretically extreme use of the “direct line” strategy in network design would be to offer a direct service between all combinations of origins and destinations in the region. But, in practice, there is not possible to offer direct services between all small interest’s points of travel in an urban region.

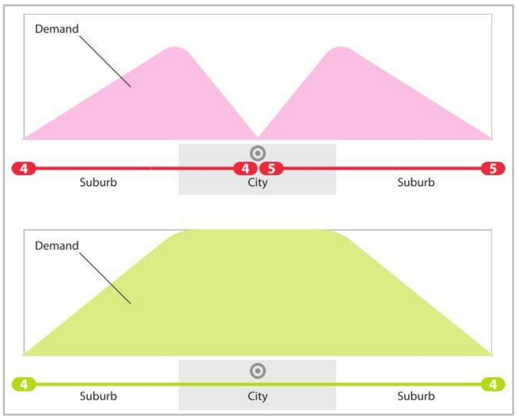
### 5.2.3 OPERATIONAL ASPECTS

It is fundamental to consider the resources that influence to the operation of the public transport network in order to optimize the whole system for both, users and operators. When a new route service is introduced, it requires elements that depend on the current level of resources available. It is then when is important to consider optimization approaches of the existing transport services. By designing a strategic network considering the route alignment of the existing lines could provide better service without using much resources.

An interesting approach are the pendulum routes. A terminology usually used in maritime transport, due to the circuit that watercraft make trough ports and it has the concept of oscillation, the single swing in one direction. Some researchers and professionals in the transport field recommend the use of pendulum routes in order to reduce the need for large terminals in some areas with high values or to take advantage to the capacity on the demand of a specific line.

For example, Nielsen *et al*. (2005) presented a pendulum approach (Figure 29), as a direct service to distant destinations of an activity centre with the purpose of increase demand and loadings on vehicles in a most space-sensitive portions of a route. About these, they said that lines that run from one side of a city or local interchange point too other without staying or waiting time in the centre create a number of advantages in public transport, such as direct service, better use of capacity and an efficient land use.

What is important in this point is that direct routes interconnected between them are optimal approaches in order to make the public transport service more attractive and efficient. So, the simpler and direct the routes are, the better. This is related to good transfers between the routes served.




**Results**

- New travel opportunities
- More efficient operations
- Improved use of capacity
- Less traffic space in the city centre
- Fewer buses
- Fewer lines
- More passengers

**Requirements**

- Time adjustments at end terminals
- New routines for the drivers
- Reliable speed

Figure 29: Pendulum approach (radial and diametral routes) (Nielsen *et al.*, 2005).

## 5.3 SUMMARY

Finally, a well designed bus route alignment should combine all factors here analysed in order to improve the service, without giving up efficiency of the operations. The main elements that should be presented at optimizing route alignment are presented in Figure 30, mainly:

- Geometric aspects, that is routes or lines as straight and direct as possible, depending on the road network constraints of the city;
- Demand requirements, that is passenger generator points, accessibility to the service, well-designed transfers points; and
- Operational aspects, taken into consideration the available resources and the benefits of both, users and operators.

It is known that the simpler, the better. When a transport network is simple, it is more attractive and easy to understand. The creation of a simpler bus network would improve the system and make it attractive. This is directly applied to the individual routes or line of a public transport service. Simplicity at designing is a “golden rule” for many academics, transport professionals and it is also a fundamental recommendation from part of practical guidelines.

Mees *et al*. (2010) expressed that simplicity offers two great benefits: first, it makes transport network easier for passengers to understand and second, it reduces resource requirements by limiting the number of lines that an operator mus provide. The authors said that efficiency and effectiveness of individual routes in a network would depend on a set of interrelated factors such as simplicity, directness, frequency, speed, stop locations, and others.

On the whole, it was explained the necessary elements here with the purpose to create an idea of what route alignment means and how important it can be for public transport network design planning.

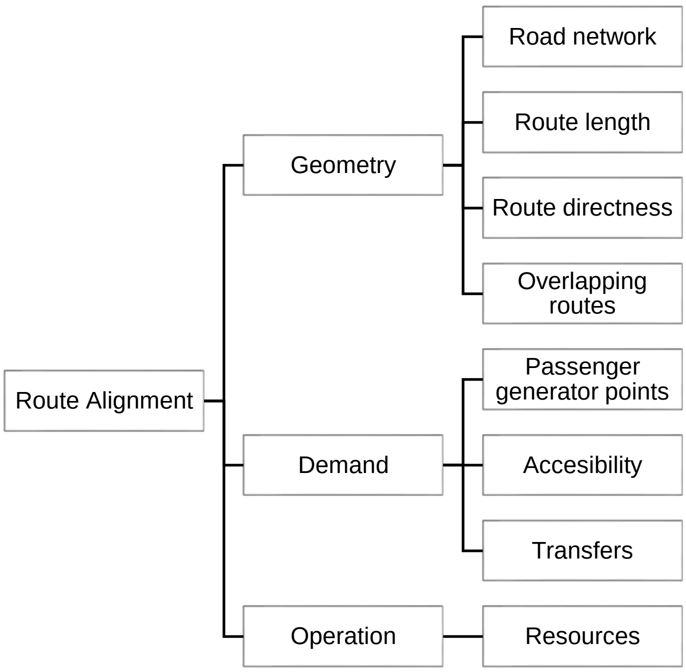



Figure 30: Summary about elements considered about Route Alignment.

# 6

# VISEU URBAN TRANSPORT SYSTEM

## 6.1 CONTEXT AND BACKGROUND

Viseu is a Portuguese city, capital of the District with the same name located in Central Region of the country and also the centre of Dão-Lafões inter-municipal community. The municipality of Viseu covers 507,10 $km^2$ and contains 99.274 inhabitants (INE, 2012) making it the second largest city in Central Portugal after Coimbra. Viseu is currently a regional economic hub with different industries and services, famous for its wine production, the Dão Wine. Besides, the city is also known for its cultural characteristics, local handicrafts such as embroidery, copper, iron articles, black pottery, and others.

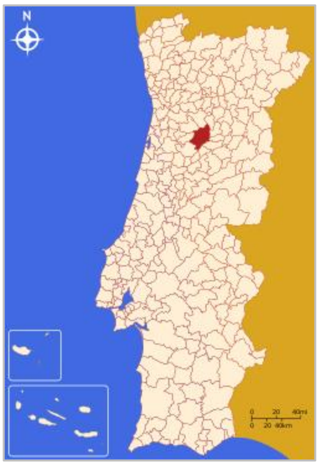



Figure 31: Location of Viseu within Portugal (Maps of Portugal, 2011).

One of the principal reason why Viseu stands out most is the high quality of living standards that offers. According to a DECO study in 2007, Viseu is the 17th best European City with highest quality of life among other 76 cities studied being also the first of the 18 capital cities of Portuguese Municipalities. In 2012 Viseu was considered, once again, the Portuguese city with the best quality of living standards and has repeatedly been recognize in recent years as "the best city to live".

The local government has taken it as a more challenging issue for the region (PUBLICO, 2007) and in 2015, the Municipality of Viseu have applied to the "Strategic Plan for Urban Development" (PEDU) of "PORTUGAL 2020". This initiative is the strategic framework that opens doors to the organizational aspect of the city in the Urban Authority of PORTUGAL 2020, an exclusive condition for higher level urban centres. One of the main intervention plans from is about the promotion of efficient and sustainable urban mobility (Município de Viseu, 2015). According to this, the city of Viseu present some priorities such as enhancing the accessibility and mobility within the district. It is considered a strategic complement the improvement of public transport with strong incentive to people to use it in urban and non-urban areas, as well as to promote daily journeys of other non-motorized modes of transport.

The distinctive attitude towards the urban planning and preservation that the Municipality of Viseu assumed generates a clear framework with the purpose to maintain and improve the standards of living that the city is experienced.

## 6.2 STUV – Serviços de Transportes Urbanos de Viseu

Viseu's public transport system is based on an urban and sub-urban network called STUV "Serviços de Transportes Urbanos de Viseu" (Figure 32), which consist in the Urban Network and the District Network. The Berrelhas de Camionagem Company holds the concession of the whole services since 1995 by a 10-years contract, two times extended for five years, and which should have ended in May 2015.

The current District Network currently is composed by 22 conventional bus lines between different parishes of the municipality and the central area of the city of Viseu. The lines are essentially a radial structure except one that is diametrical as can be seen in the map of Figure 33. Basically, the urban terminals are established in three locations: Rossio, Av. Alberto Sampaio and COMV (Centro de Operações para a Mobilidade de Viseu).

Figure 32: Bus of Viseu Urban Transport Service (STUV, 2016).

Moreover, the urban transport network includes a funicular service that connects the lower city (riverfront) with the upper city (historical centre). Additionally, there are 2 more lines of electrical mini-buses with high frequencies and not predefined stops called "the blue lines", from which the first one circulates through the centre among the most important commercial and historical sites, and the second blue line links the Bus Terminal with the São Teotónio Hospital. The whole service offered by STUV are summarized in Table 7.

Table 7: Current Transport Service of STUV (Município de Viseu; Perform Energia, 2015).

| **Public Transport Service** | **Type of Vehicle** |
|---|---|
| 22 Lines of Urban and Sub-Urban Transport | 30 buses |
| 1 Blue Line | 3 electric mini-buses |
| 1 Funicular Line | 1 Funicular |
| 1 Touristic Line | 1 Train |

The current transport service carries annually about 1,75 million passengers (2013). During the peak hours, the service works simultaneously with 27 buses.

The operation periods of almost all lines are usually between 6:45 in the morning and 21:00 at the latest during the weekdays, however, at weekends the operation period is reduced significantilly in terms of period of hours and also frequencies, and additionally not all lines have weekend's services.

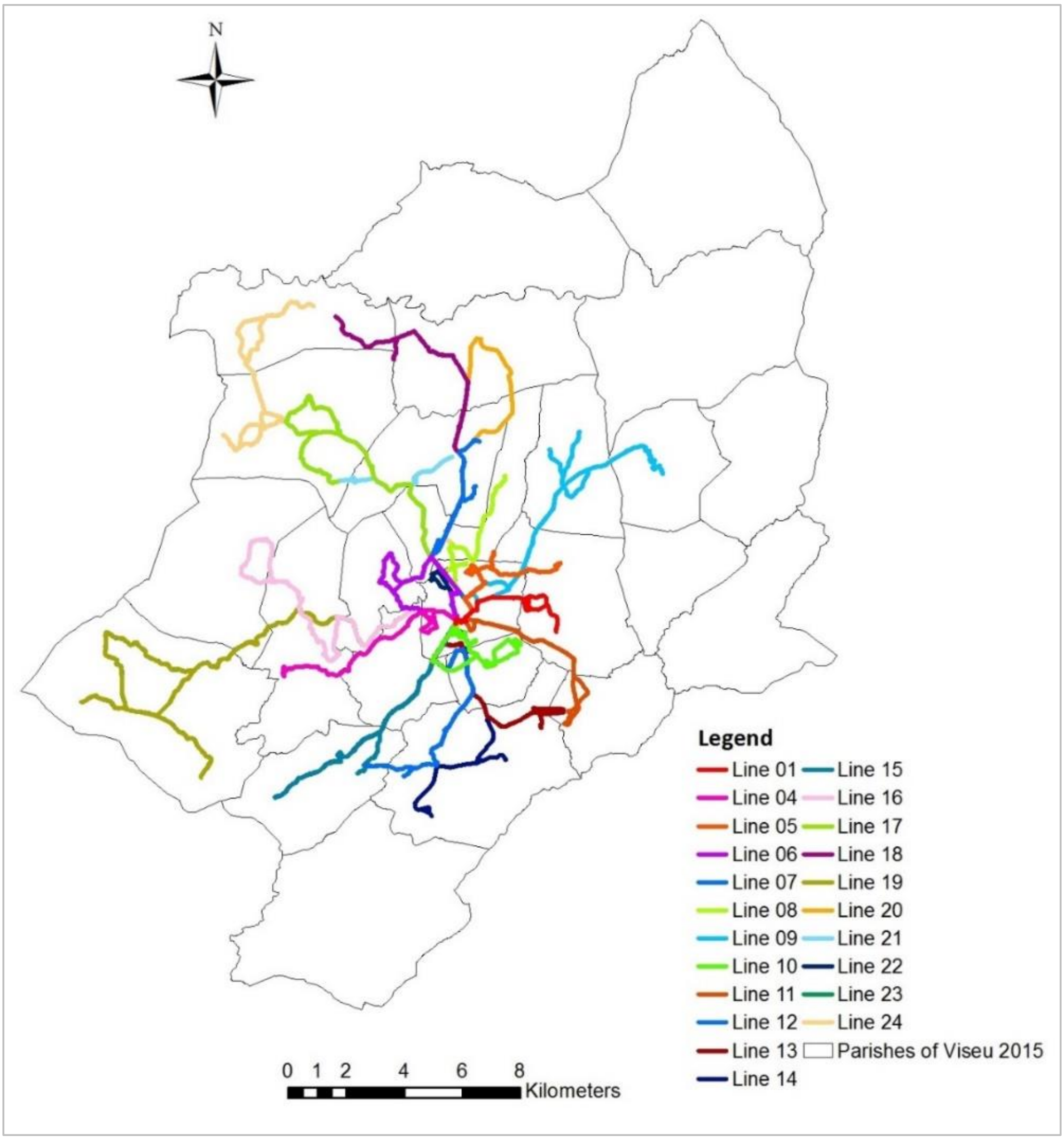



Figure 33: Map of the current STUV public transport network of Viseu.

Currently, the Municipality of Viseu is in an international tendering process for the new operational period of the public transport service of Viseu. To do this, a short time ago there was taken out a study and analysis of the state of the public transport network and its features (Município de Viseu; Perform Energia, 2015), which turned out a series of proposals and recommendations to be implemented in the next concession.

With the purpose to comprehend more about the actual transport service of Viseu, it is presented some of the results of the aforementioned study. One data extracted is regarding the passenger travel reasons and it verifies that the majority of passengers use public transport for work and studies (42,8%), while the remaining 57,2% have associated their trips to not mandatory reasons, such as shopping, services, leisure and others (Município de Viseu; Perform Energia, 2014). The city center consists as the principal point attraction of the people daily movement, that means general population come from peripheries to the center of Viseu in the mornings and return to their homes at noon or at the end of the day. The passenger flows is more radial.

Another important feature analysed by this study was related to the different service quality parameters considered by the customers of STUV. Items such as bus cleanliness, ease tickets acquisition and bus quality were the better valued features. On the contrary, the operational periods, number of travels, waiting time and price were the most criticized parameters. In Table 8 it is presented all the list of service parameters that show the improvement priorities from the costumer perspective. It can be highlighted the necessity to improve the extension of operating period and the number of travels (frequencies).

Table 8: Results of quality parameters of STUV service. Adapted from Município de Viseu, Perform Energia (2014).

| Parameters of Service Quality | % of Priority Improvement |
|---|---|
| Operational period | 25,9 |
| Number of travels | 23,2 |
| Waiting time | 20,0 |
| Price | 17,6 |
| Service information | 11,3 |
| Punctuality | 11,1 |
| Quality of stop and shelter | 9,9 |
| Appropriate route | 8,4 |
| Fare modality | 6,5 |
| Drivers willingness | 5,3 |
| Bus quality | 3,4 |
| Ease transport tickets acquisition | 2,8 |
| Bus cleanliness | 1,7 |

The population of Viseu were also asked about the characteristics that they valorise in a collective public transport service. It is noted that the people prefer two important parameters, first that the line paths passes along places of interest with a 45% and secondly low fare price with 38%.

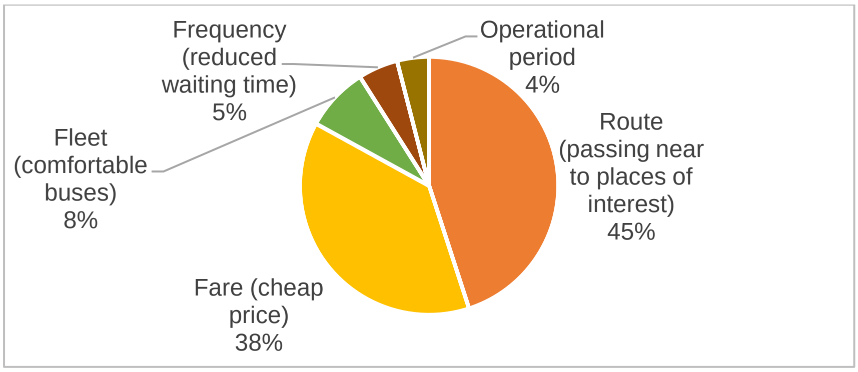



Figure 34: Parameters valorised by passengers about collective public transport service. Adapted from Município de Viseu, Perform Energia (2014).

With the launch of the new public transport service concession contract, the Viseu Municipality aims to ensure the continuity of the Urban Transport Service of Viseu (STUV) providing all the district and the city a series of innovative and optimized solutions focusing on urban transportation. The new urban approach is named MUV described below.

### 6.3 MUV – MOBILIDADE URBANA DE VISEU, THE NEW APPROACH

By October 2015, the Municipality of Viseu announced the launch of the international tender MUV "Viseu Urban Mobility" and the contract applies to a 10 years-contract of providing public transport services with a maximum total investment of €8 million (Município de Viseu, 2015).

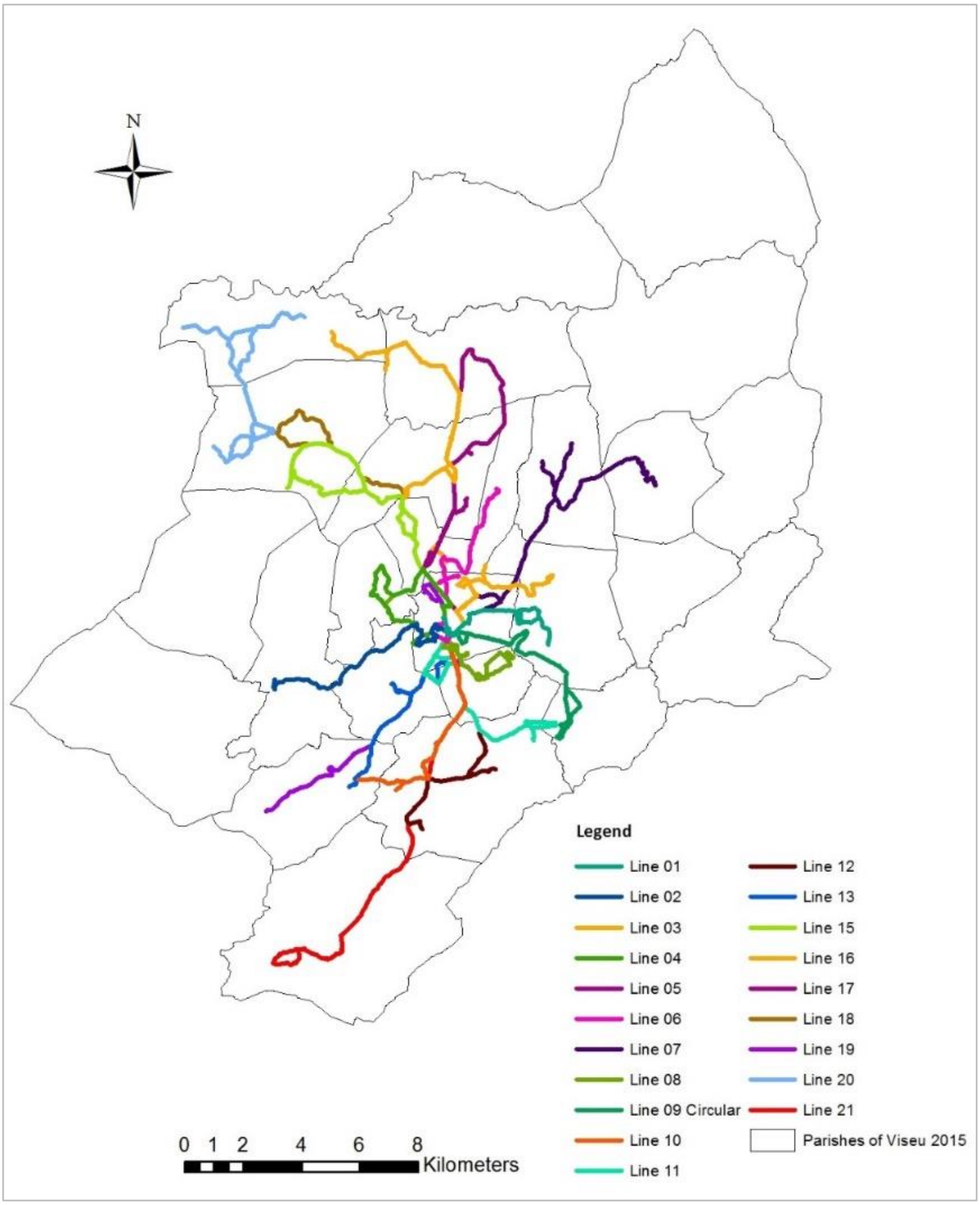



Figure 35: Proposed MUV transport network of Viseu.

The new concession includes the operation of 20 municipal network lines, nonetheless has many new features with the purpose to strengthen the "mobility for all" with better efficiency and less costs for the municipality, the costumers and the environment. One of the main innovations lies in creating a service "Transportation on demand" called Demand Responsive

Transport System (DRT) for those parishes of Viseu with low demand or low population density. Additionally, the new network of public transport of Viseu will also create a new municipal-council line (linha concelhia), which currently does not exist, between the city of Viseu and Salgueiros serving the towns of Silvares and Casal Meão.

The principal objective of the public transport service is improving in terms of operating periods, frequencies of travel, and expansion of network coverage. Then, another principal plan of MUV is the restructuration of links between major attraction points, then it will be created two new urban circuits, which connect the main points of collective use (shopping centres, high schools, etc.) and the city centre (replacing the current blue lines), expressed the online magazine Transportes (Transportes em Revista, 2015).

The blue line operations within the Historical Centre with new electric buses and the "stops on demand" is another novelty that have to be implemented. The bus fleet would be renewed with eco-efficient and more sustainable vehicles and regards the funicular, it would be oriented as a tourist service and for special events mobility, leaving his daily operation. The system will also include information totems to the users at strategically points improving the costumer orientation (Município de Viseu, 2015).

Besides the public transport network, the MUV will include a bike paths network, also a network of car parking with integrated management discouraging car traffic in the centre, and the creation of the Viseu Mobility Centre in the current Municipal Transport Centre (Município de Viseu, 2015).

The new municipal transport network of Viseu is the first step towards the implementation of the new local mobility plan MUV. The main objective is not only to increase the population mobility by public transportation in urban areas and between the city and peripheries, but also to grow economy and improve environmental and energetic sustainability of the different modes of transport.

The official webpage of the Municipality of Viseu expresses that the President of Viseu Municipality Almeida Henriques is confident respect to the initiative and he said that "it will be a gradually and serene change, however with important effects on the quality of life of all the population". For him this investment reinforces significantly the local cohesion and the conditions of attractiveness and the municipal quality of living (Município de Viseu, 2015).

### 6.4 ANALYSIS OF ROUTE ALIGNMENT OF STUV AND MUV

In the context of this study, it was considered appropriate to analyse the public transport service of Viseu by overlooking optimization of the bus network in terms of route alignment. This implies to maximize the efficiency and effectiveness of bus transport network, from both demand and supply perspective.

Georgiadis *et al.* (2014) presented clearly in their work these two general terminologies, and express efficiency as the process through which service inputs are transformed into produced outputs, while effectiveness explores the relationship between service inputs and consumed services (operational effectiveness) and also between produced services and consumed services (service effectiveness).

Hawas *et al.* (2012) give some examples of these two concepts. On one hand, for effectiveness people should feel that buses are available to meet their daily travel demand with lower cost, it can be measured by service utilization or ridership, service quality and accessibility. On the other hand, for efficiency, the service authority typically aims at minimizing the operational cost without hampering the daily travel demand of the people, and it can be measured by indicators of overall cost efficiency, labour utilization and vehicle utilization.

Moreover, it is important to emphasize the evaluation aspects at optimizing public transport services. Hawas *et al.* (2012) expressed that Lao and Liu (2009) evaluated the performance of bus routes from the operational and spatial aspects, more specifically, operating time, round-trip distance, and number of stops were used as inputs to measure operational efficiency.

Hawas *et al.* (2012) affirmed "the number of stops and the average travel time per round trip is associated with the route length, so, higher travel time or higher number of stops for a longer route length".

### 6.4.1 METHODOLOGY USED

There are different methods that researchers evaluate efficiency and effectiveness of public transport networks or lines. One commonly used is the Data Envelopment Analysis (DEA), a linear programming technique, such as the proposed by (Button and Costa, 1998; Georgiadis *et al.*, 2014). Simple GIS-technique is frequently used as a method to calculate output indicators representing efficiency and effectiveness of the services.

The scenario developed in this section aims to investigate the capacity to demonstrate how the performance levels service can be improved by slightly altering the route alignment. This approach takes into account variables that represent both reducing operational costs and maximizing passenger benefits.

In this work it is assumed that operational cost is related to the operational period. In other words, the increase or decrease of operational cost will be affected by a change in the operating hours that is referred to the total number of hours for which the bus service is provided. So, for example, if operating hours are reduced in 10% from the current service hours, operational cost will be reduced by the same percentage. Similarly, by reducing travel time, passengers arrive more quickly to their destinations. This means, the benefit for customers can also be measured by the difference of travel time saved.

It is fundamental to comprehend that travel time is directly related with the vehicles speed and total distance of the journey. Therefore, the principal element considered in this analysis is the route distance or round-trip distance. In this order, there were selected two measured inputs, round-trip distance and the average of bus commercial speed in order to obtain the difference of time saved by enhanced the alignment of the routes.

The analysis is focused to measurement builds upon earlier data collection for the study of evaluating public bus services in Viseu (Município de Viseu; Perform Energia, 2015) and GIS-Data provided by TRENMO Company. This involves analysing the data of selected bus routes in Viseu and it is intended to compare the current STUV network and the new MUV network proposed by the Municipality of Viseu for the new transport service tendering process.

As stated above, an important contemplation for this analysis is the Commercial Vehicle Speed. Considering the current timetables of the STUV service it was possible to take a bus speed average. Appendix B shows the process that was done for the calculations of the speed average, which resulted 18 km/h, considering the weekdays services.

The provided data were used to measure the round-trip distances through maps of the bus network system with GIS tools (ArcGIS). Finally, the output will represent the travel time variations of the different scenarios presented.

### 6.4.2 Routes selection and alignment

Considering the concept of route alignment described before in this work, it was relevant to select and analyse lines that present the needed characteristics, in other words, routes with some deviations and lack of directness. In general, Viseu bus routes are characterized by their long route lengths.

So, there were chosen two specific lines that present the needed performance, *Line 05: Rossio-Esculca/Travassós de Cima-Rossio* of the current STUV network and *Line 03: COMV-Esculca/Travassós de Cima-COMV* of the proposed MUV network that will replace Line 05 (Figure 36 and Figure 37 present the mentioned routes in a map). Additionally, after analysing those routes, it was developed a Proposed Line, self-version route, which present improved modifications considered, in order to compare it with the other two routes.

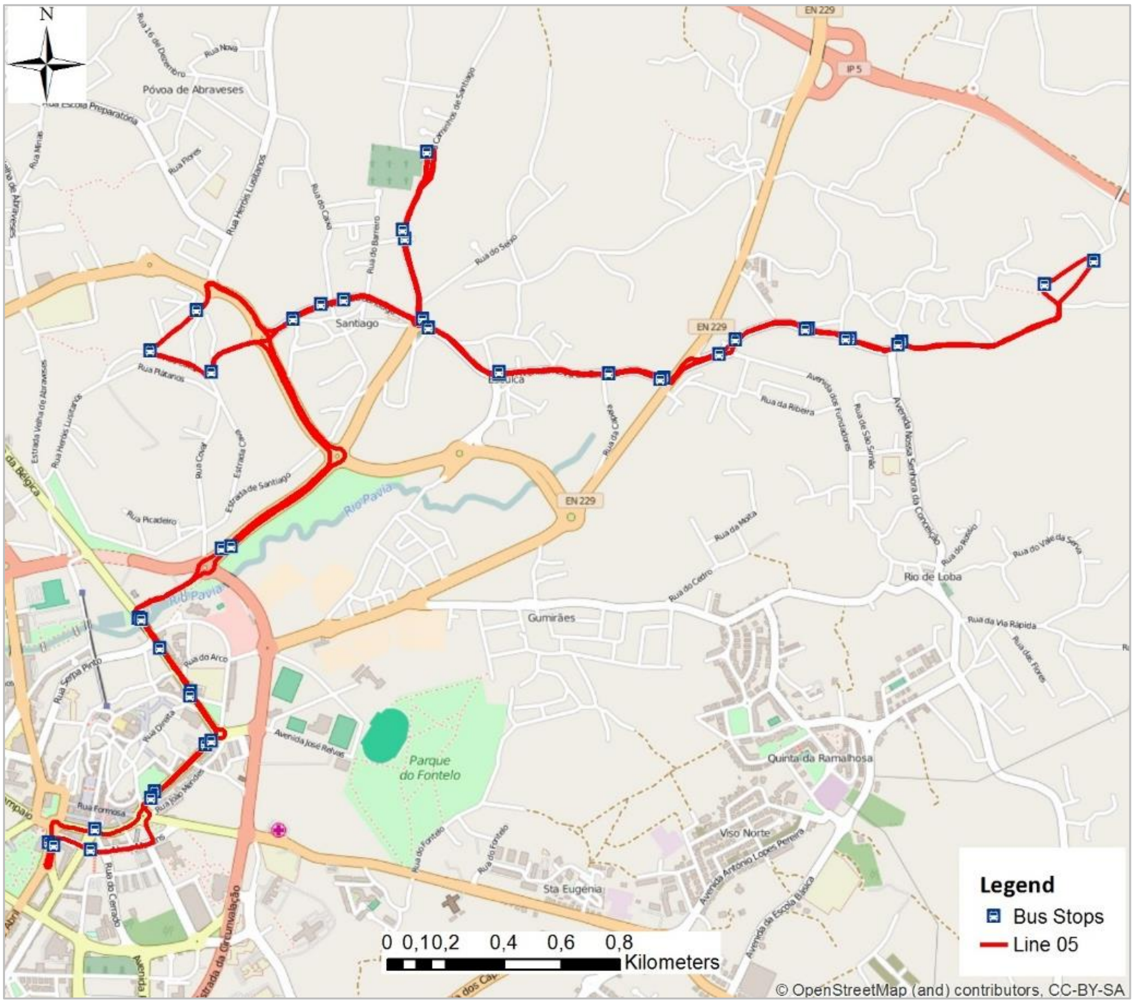



Figure 36: Line 5 (Rossio-Esculca/Travassós de Cima) of the current STUV network.

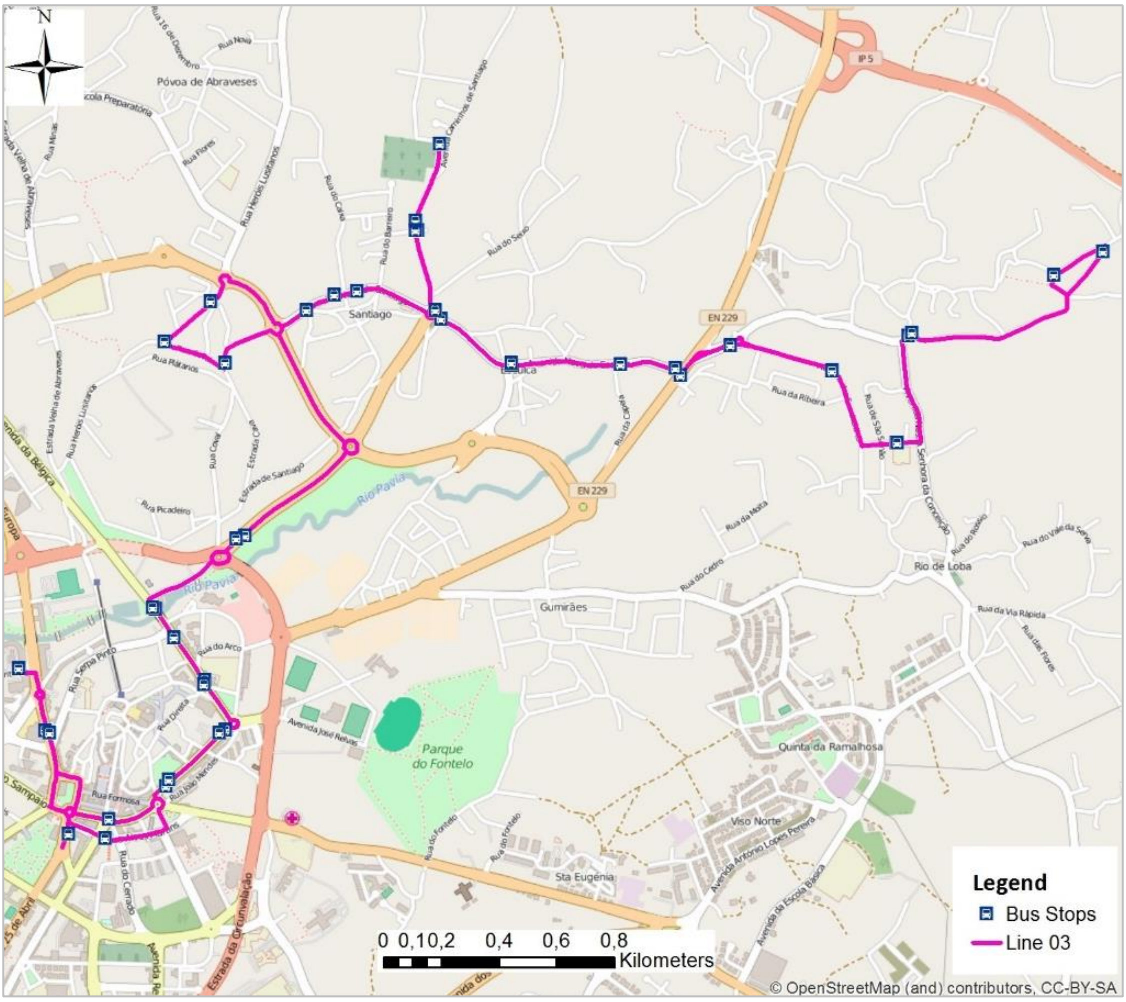



Figure 37: Line 3 (COMV-Esculca/Travassós de Cima) of the proposed MUV network.

Table 9 shows the route distances of Line 05 and Line 03. Then, there were analysed geometrical characteristics of the lines in terms of route alignment concept, and also the points of interests where lines should pass and should not be necessary. The purpose is to make the needed modifications in order to optimize the route length of the studied lines. It was considered the maximum walking distance to a bus stop 500 meters. Three principal study route alignments were defined, as can be seen in Figure 38 described below.

Table 9: Total round-trip length of Line 05 and Line 03.

| Transport System | Line Name | Origin | Destination | Total length |
|---|---|---|---|---|
| Current STUV | Line 05 | Rossio | Esculca / Travassós de Cima | 16,91 Km |
| Proposed MUV | Line 03 | COMV | Esculca / Travassós de Cima | 20,12 Km |

The route length and corresponded bus stops of the selected alignments were measured and the average travel time for each one was then calculated. A new proposed route has resulted after the optimized route alignments, as will be presented afterward. The next section will characterize and analyse each route alignment considered.

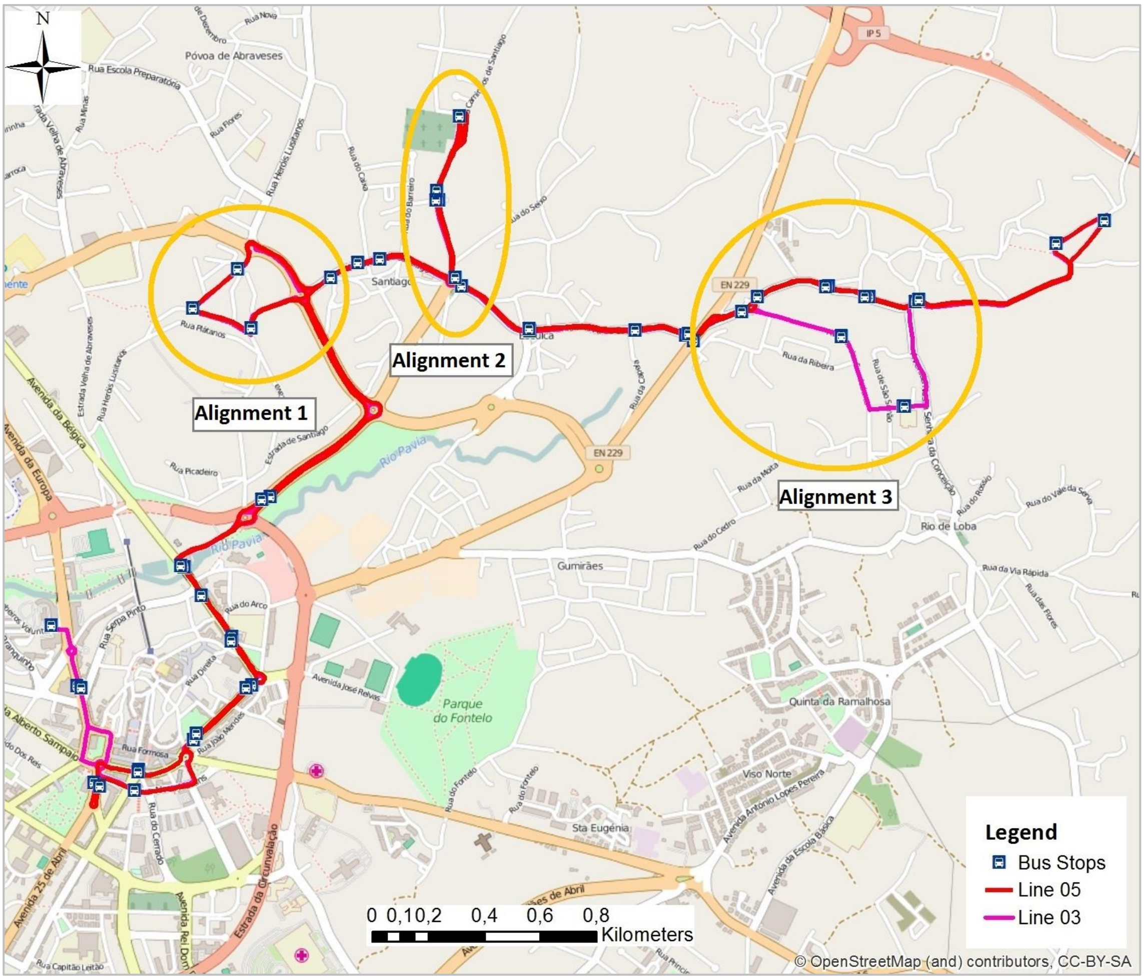
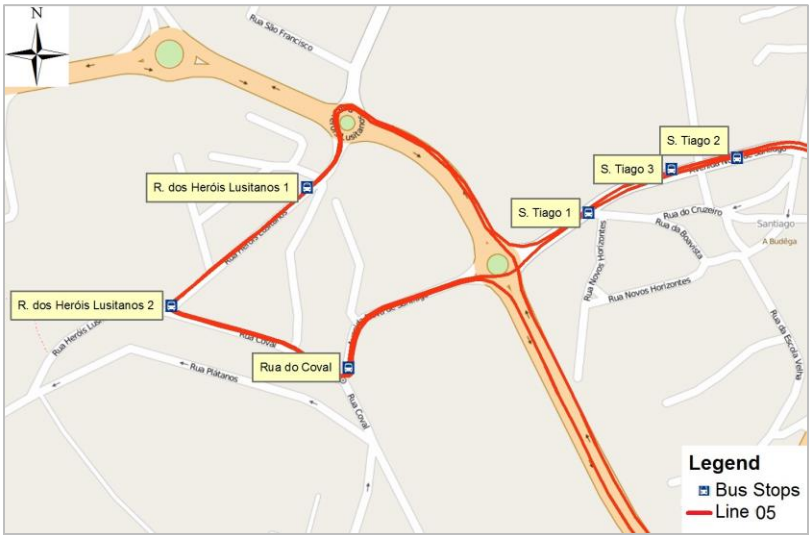



Figure 38: Line 05 and Line 03, showing the chosen alignments.

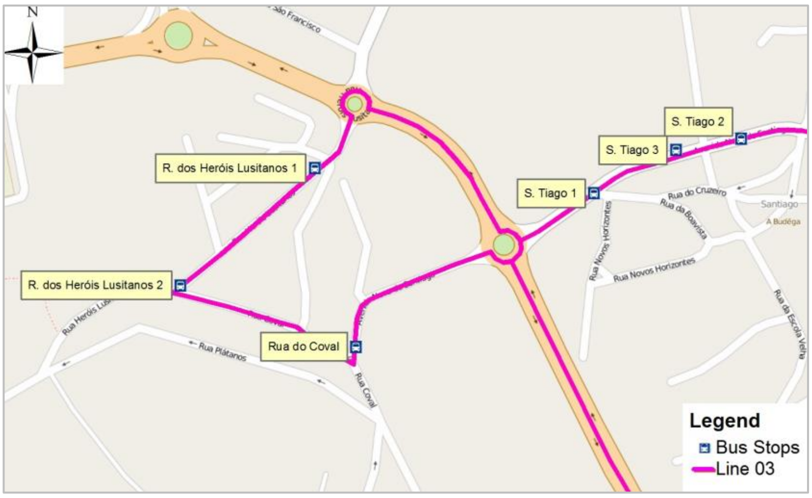
#### 6.4.2.1 Alignment 1: Roundabout Av. Nova de Santiago – Hérois Lusitanos

The first alignment analysed is almost a rectangular path, from which in both Line 05 and Line 03 buses came from Avenida Praça Grão Vasco and in the roundabout at the intersection with Av. Nova de Santiago they continue along three stops in a residential area (R. dos Heróis Lusitanos 1, R. dos Heróis Lusitanos 2 and Rua do Coval) and finish again in the same roundabout.

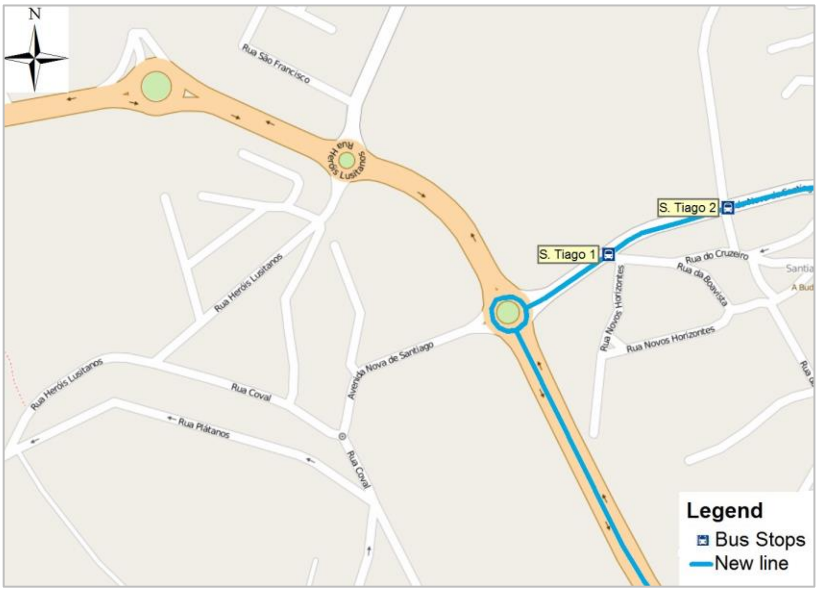
The proposed change is to eliminate this bus route alignment, as well as the three bus stops, as can be shown in Figure 39. When referring to the walking distance from the extreme point through which passes the bus line to the nearest bus stop (S. Tiago 1), the maximum walking distance resulted into 587,90 m. So, this correspond to a maximum acceptable distance path for people who live in this area and walk to the next stop in 5-6 minutes.




a) Line 05 (STUV)




b) Line 03 (MUV)




c) New Line (Proposed alignment)

Figure 39: Alignment 1, from roundabout to a residential area.

Table 10 presented the distances which buses could save by adopting alignment 1 modifications. In a round-trip, the total variation is around 2,27 Km.

Table 10: Distances measured for Alignment 1.

| ROUTE ALIGNMENT 1 | | | |
|---|---|---|---|
| **Origin** | **Destination** | **Distance (m)** | **Walking distance to next bus stop (m)** |
| Rotunda Av. Nova Santiago | R. dos Heróis Lusitanos 1 | 401,5 | 129,2 |
| R. dos Heróis Lusitanos 1 | R. dos Heróis Lusitanos 2 | 212,4 | 458,6 |
| R. dos Heróis Lusitanos 2 | Rua do Coval | 270,3 | 587,9 |
| Rua do Coval | Rotunda Av. Nova Santiago | 250,5 | 359,2 |
| Subtotal | | **1.134,7** | **-** |
| **Go and Return** | Subtotal x2 | **2.269,4** | **-** |

### 6.4.2.2 Alignment 2: Esculca – Cemitério S. Tiago

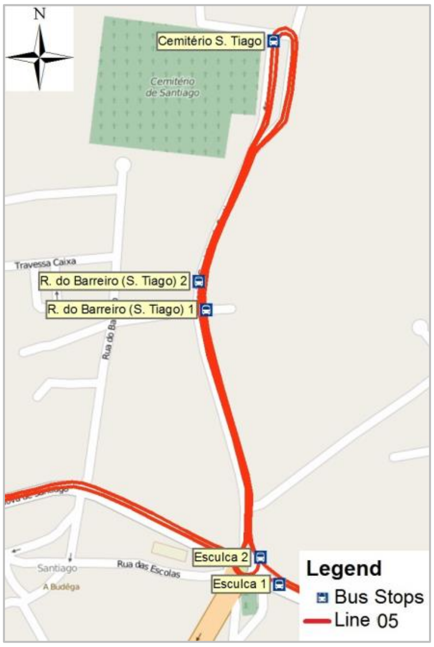
The second alignment studied is a straight line that starts in Esculca roundabout and goes to the Cemetery S. Tiago and returns through the same path. Both Line 05 and Line 03 travel through the same way passing along two stops (R. do Barreiro 1 and Cemitério S. Tiago).

As the first intervention, in this case it is also proposed to eliminate this path (Figure 40). The cemetery is almost the unique destination in this area, but the walking distance to the cemetery is around 605 meters. This is more than 5-6 min walking, so, as recommendation this can be solved giving the possibility to passengers to reach the cemetery with a "on demand" method, which consists in a service that the bus drivers goes to the destination only if there are passengers that want to go to this point.

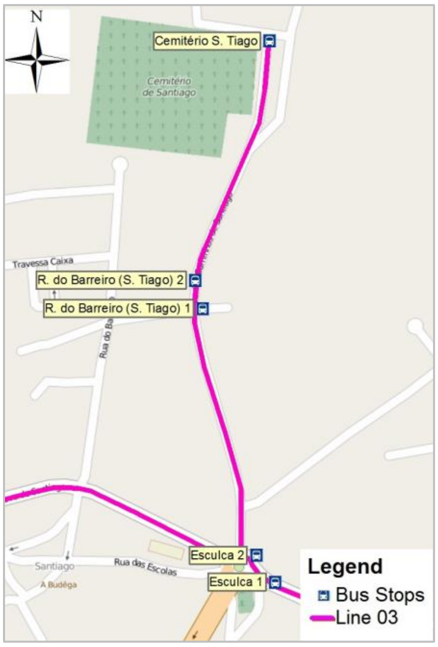
With this route alignment arrangement, it is possible to have a length variation of 2,5 Km, considering the round-trip (see Table 11).

Table 11: Distances measured for Alignment 2.

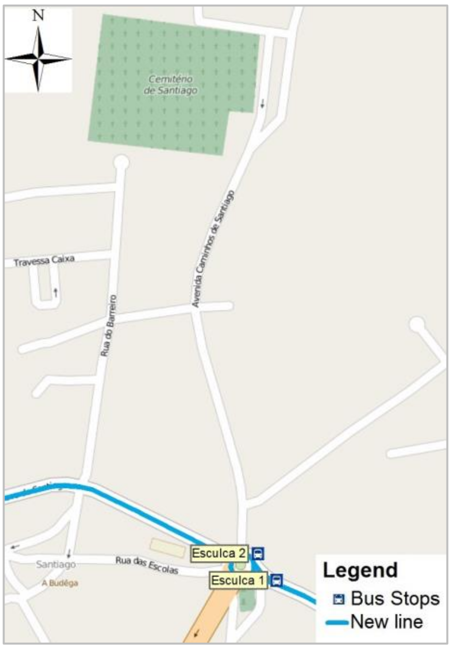
| ALIGNMENT 2 | | | |
|---|---|---|---|
| **Origin** | **Destination** | **Distance (m)** | **Walking distance to next bus stop (m)** |
| Rotunda | R. do Barreiro (S. Tiago) 1 | 285,0 | 290,4 |
| R. do Barreiro (S. Tiago) 1 | Cemitério S. Tiago | 314,7 | 603,5 |
| Cemitério S. Tiago | R. do Barreiro (S. Tiago) 2 | 333,4 | 320,3 |
| R. do Barreiro (S. Tiago) 2 | Rotunda | 317,0 | - |
| Subtotal | | **1.250,1** | **-** |
| **Go and Return** | Subtotal x2 | **2.500,2** | **-** |




a) Line 05 (STUV)




b) Line 03 (MUV)



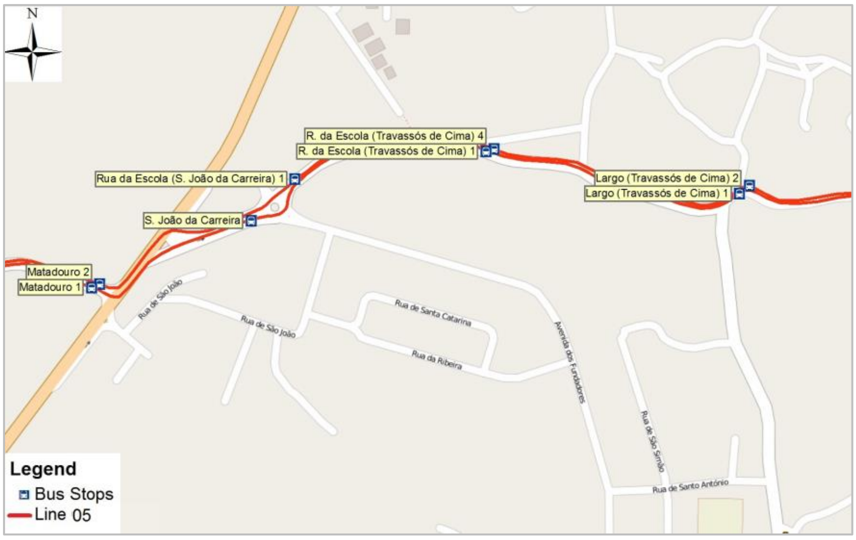

c) New Line (Proposed alignment)

Figure 40: Alignment 2, from Esculca roundabout to Cemetery S. Tiago.

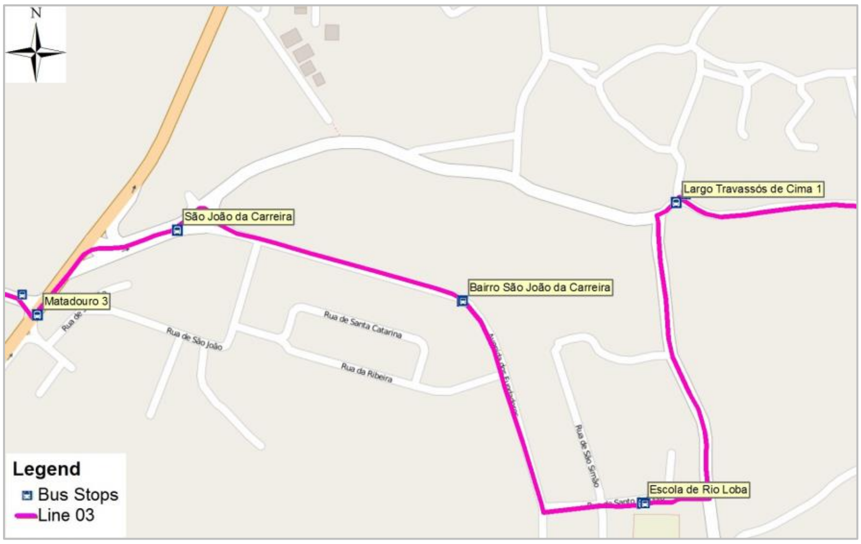
#### 6.4.2.3 Alignment 3: Largo Travassós de Cima – São João de Carreira

The last route alignment evaluated is an almost straight line of the current Line 05 that will be modified for MUV by introducing the bus route inside a residential area (Parish of São João da Carreira), as can be seen in Figure 41-b.

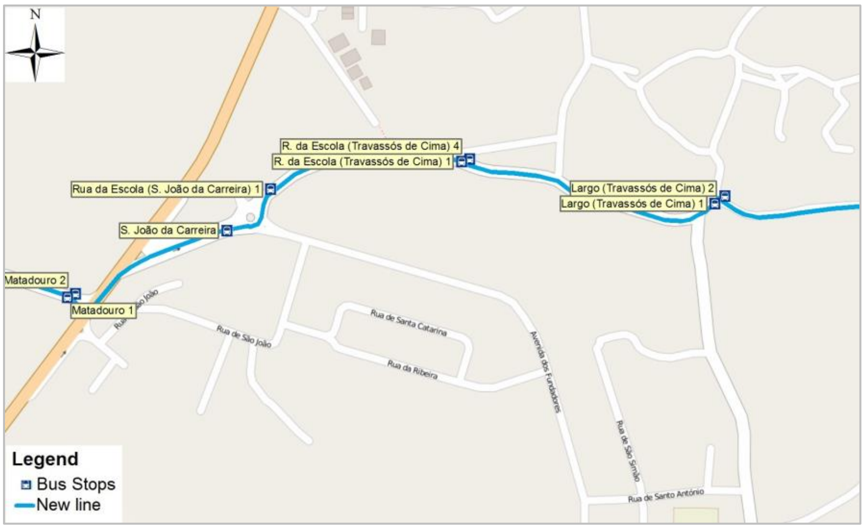
The proposed route alignment is to maintain as the current situation of Line 05 (Figure 41-a), passing along three stops: São João da Carreira, R. da Escola/Travassós de Cima, Largo Travassós de Cima. The residential area of São João da Carreira is not away from those bus stops, with a maximum walking distance of 470 meters, equivalent to less than 5 minutes walking.




a) Line 05 (STUV)




b) Line 03 (MUV)




c) New Line (Proposed alignment: maintain the same as Line 05)

Figure 41: Alignment 3, from Largo Travassós de Cima to São João de Carreira.

The distance saved by maintaining the service as the current round-trip of Line 05 is around 2,36 km as Table 12 presented.

Table 12: Distances measured for Alignment 3.

| **ALIGNMENT 3** | | | |
|---|---|---|---|
| **Origin** | **Destination** | **Distance (m)** | **Walking distance to next bus stop (m)** |
| Rotunda Av. Nova Santiago | Bairro São João da Carreira | 329,8 | 364,8 |
| Bairro São João da Carreira | Escola Rio Loba | 405,0 | 470,9 |
| Escola Rio Loba | Avenida | 443,9 | - |
| Subtotal | | **1.178,7** | **-** |
| Go and Return | Subtotal x2 | **2.357,4** | **-** |

### 6.4.3 Analysis and Results

The total difference between the routes studied are presented in Table 13, where can be noticed that the current service Line 05 (STUV) varied with the alignment 1 and 2 and maintain the same length in the third route alignment. Finally, the total distance of Line 05 resulted in 12,14 Km. Meanwhile Line 03 (MUV) was affected by all the route alignments considered and the final distance route came about 12,99 Km.

Now, in order to consider the better optimized route, it is also taken into account the start point of each route. The current Line 05 starts in Rossio and Line 03 in the new COMV (Centro de Operações de Mobilidade de Viseu), which is the new terminus of the bus transport network of Viseu. Consequently, in this analysis it is considered COMV as the initial point. Accordingly to the last considerations, the optimized line (self-proposed line) has a total route length of 12,99 Km, as can be seen in Figure 42.

Table 13: Variations of route length according to the introduced route alignments.

| Route Name | Alignment 1 (km) | Alignment 2 (km) | Alignment 3 (km) | Variation (km) | Initial route (km) | Optimized route (km) |
|---|---|---|---|---|---|---|
| Line 05 (STUV) | 2,27 | 2,50 | 0,00 | 4,77 | 16,91 | 12,14 |
| Line 03 (MUV) | 2,27 | 2,50 | 2,36 | 7,13 | 20,12 | 12,99 |


Figure 42: Proposed and Optimized Line with route alignments.

Now, having all distances needed and the commercial bus speed considered 18 Km/h, it is possible to calculate the travel time saved in each route scenario and make comparison in order to perceive the advantages (Table 14).

Table 14: Travel time variations compared with the optimized line.

| Route Name | Distance of round trip (km) | Speed (km/h) | Travel Time per round trip (min) | Difference with the Optimized Line (min) | Variation (%) |
|---|---|---|---|---|---|
| Line 05 (status quo of STUV) | 16,91 | 18 | 56,4 | 13,1 | 23,2% |
| Line 03 (proposed by MUV) | 20,12 | 18 | 67,1 | 23,8 | 35,5% |
| Optimized Line (own proposal) | 12,99 | 18 | 43,3 | - | - |

The difference between travel time of Line 05 and the Optimized Line (the final route with all alignments introduced) resulted in 13,1 minutes, which is equivalent to a 23,2% less travel time. While the variation between Line 03 and Optimized Line is 23,8 minutes or 35,5% less travel time.

There is empirical evidence to indicate a linear relationship between the input (route length) and output variable (travel time). It can be observed that the optimized line has an important improvement in terms of travel time and can be used to increase service frequencies of the transit network.

Considering the current timetable of Line 05 – STUV, it is analysed the opportunity to increase frequencies with the travel time saved. The current timetable presents 13 services during the day starting at 06:45 and finalizing at 20:15 (total time service: 13,5 hours). Each travel time trip is calculated in Table 15.

Table 15: Weekdays timetable of current service Line 05 STUV.

| Weekdays Timetable | | | | Go | Return |
|---|---|---|---|---|---|
| | | | | Rossio-Trav.Cima | Trav.Cima-Rossio |
| Nº | Rossio | Trav. Cima | Rossio | Travel time (min) | Travel time (min) |
| 1 | 6:45 | 7:00 | 7:25 | 15 | 25 |
| 2 | 7:25 | 7:50 | 8:20 | 25 | 30 |
| 3 | 8:20 | 8:50 | 9:20 | 30 | 30 |
| 4 | 10:00 | 10:30 | 11:00 | 30 | 30 |
| 5 | 11:15 | 11:40 | 12:10 | 25 | 30 |
| 6 | 12:35 | 13:05 | 13:35 | 30 | 30 |
| 7 | 13:05 | 13:30 | 13:50 | 25 | 20 |
| 8 | 13:35 | 14:00 | 14:30 | 25 | 30 |
| 9 | 16:05 | 16:30 | 17:00 | 25 | 30 |
| 10 | 17:15 | 17:45 | 18:15 | 30 | 30 |
| 11 | 18:30 | 18:55 | 19:25 | 25 | 30 |
| 12 | 19:25 | 19:50 | 20:15 | 25 | 25 |
| 13 | 20:15 | 20:35 | 20:55 | 20 | 20 |

Going back to Table 14 travel time saved between Line 05 and the Optimized Line has resulted in 13,1 minutes per round-trip. This represents the next total travel time per day:

(13 round trip) x (13,1 minutes per-round trip) = **170,3 minutes per day**

Now, it will be considered the real round-trip as twice the maximum travel time from the above table, namely 30 minutes x 2 = 60 minutes. It is considered the maximum travel time resulted because is the worst case. Then, the total number of services that would be possible to introduce are:

(170,3 minutes-per-day) / (60 minutes-per-round trip) = **2,84 services**

This means that it would be possible to introduce almost three new round-trip services with the same current time service (13,5 hours). In other words, the bus service frequency can be positively affected when route alignments are slightly shortened.

## 6.5 SUMMARY

Viseu Urban Transport System (STUV) is currently experiencing a tender process of a new bus transit network service that will be called Mobilidade Urbana de Viseu (MUV). According to the framework of this study and in order to apply a numerical example of route alignment in bus transit network, it was analysed one specific bus line service of STUV, one proposed bus line service of MUV, and in addition, it was proposed a self-optimized bus line by slight variations of route directness.

During the route alignment analysis, it was considered some fundamental elements of an effective transport network system, this is to say, walking distance to reach a bus station and travel time (passenger and vehicles). The measures obtained could reveal that small arrangements on route alignments can improve the bus performance service referred to travel time and consequently can increase frequency of services.

Some simple characteristics such as extra distances of route twists and turns can affect the performance of the transport service. Although people want to have the service on their doorsteps, it is important to understand that transport service is a community service and it is necessary to have common benefits.

From user's point of view, it is considered better to walk a little more (500 meters or maximum 5 minutes) and have a quickly service by travelling less time and more frequent, because less travel time for a round-trip means more available time to offer the service and consequently reducing waiting time of passengers. And from operator perspective, by improving operational period also improves operation costs.

It is important to notice that the new bus network services MUV present some modifications compared to the current services, but it does not mean that it is better. Herein was analysed only one line and it was worst than the current one. However, it is just a numerical application and not a complete transit optimization analysis. Nevertheless, is critical for the city of Viseu to evaluate the whole network system in order to contribute to social, economic and environmental urban and sub-urban development.

# 7

# CONCLUSION AND RECOMMENDATIONS

## 7.1 MAIN CONCLUSIONS

Nowadays, public transport planning is a big issue in transport industry, considering the current sustainable tendency of the cities all around the world. Community liveability is very important at the moment of designing transit routes. People need to access to work, school, commerce and residence. Also, the huge dependency on private transportation creates an urgent need to creates strategies to improve public transport for a more sustainable urban environment. This work focused on bus transport system because it is very common in many cities due to their flexibility and lower costs compared to other modalities such as metro system. Transport network planning was analysed and more specifically, transport network design problems (TNDP).

The summary of the actual literature about this topic was presented in a table with the principal researchers since 1960, when this issue started to attract people in academic fields. From the literature review about TNDP could be noticed that the main reason to study transit design is in order to achieve a total welfare both from users and operator's perspective considering in general parameters such routes (shape, length, directness, etc.) and their operational frequencies setting. Researchers and academics have handled TNDP through various methodologies, simplified and also complicated techniques that depend on computational power and tools available. They applied their models to numerical examples or real transit network of different cities around the world in order to test the proposed solution. Some authors realized that such procedures are in general complicated and cannot be realistic, does not work in an optimal way for real life. In other words, it is not easy to adapt theoretical approaches to real world requirements.

About transport network design, the existing approaches seem to be useful and adequate, but sometimes, real world present other features that academics do not take into consideration at the planning steps, and this topic should continue to be carefully investigated.

Through practical case studies of implementations of transport service changes, which were optimized regarding route alignment and introduction of new ticketing system, could provide some characteristics about real world transit problems. Four different study cases were selected and analysed, Santiago de Chile in 2007, Berlin in 2005, Malta in 2011 and Porto in 2007. This analysis showed the weaknesses and problems that a city can faced during any transit system project. Also, through the analysis it could be possible to understand the impact that any changes can produce over the urban structure and community liveability. It is a huge challenge that government and other stakeholders should work together because of the controversial aspect the concept of a public transport service. Moreover, those cases showed that initial problems and negative reactions can be used for new solutions and other benefit adaptations.

Finally, the numerical case study of Serviços de Transporte Urbano de Viseu (STUV) present support of all the information about transport planning and route alignment. Viseu Government tactic is to promote public transport as a more sustainable mode of urban and sub-urban mobility and the new strategy is to improve their current transport system (STUV) with a new optimized transport network (MUV). Through an analysis of route optimization by improving the route alignment of a specific line of the bus network, it could present the weaknesses and opportunities that a route network can present by elements, such road geometry, demand requirements and walking distances. Results showed that route directness improves drastically travel time and frequencies.

From a planning perspective through all this analysis, it can be highlighted the impact of a public transport reform and how it can influence people lifestyle, since a good service improves quality of life of citizens and consequently to society.

## 7.2 RECOMMENDATIONS FOR FUTURE WORKS

Transport network design should be an integrated feature between academics, researchers, practitioners and professionals. It could be analysed a methodology in order to combine them.

Route alignment is an important characteristic at transit designing steps and would be interesting to analyse a whole real transport network in order to establish support parameters.

Real cases of network implementation are all over the world and could be important to take more emphasis in this kind of analysis in order to create a basis of process of implementations and facts that should be avoided.

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# APPENDIXES

## APPENDIXE A – HORARIOS STUV (Berelhas Company)

### LINHA Nº 5 ROSSIO-ESC/TRAVASSÓS CIMA-ROSSIO

**DIAS ÚTEIS**

| ROSSIO | TRAV.CIMA | ROSSIO |
|---|---|---|
| 6.45 | 7.00 | 7.25 |
| 7.25 | 7.50 | 8.20 |
| 8.20 | 8.50 | 9.20 |
| 10.00 | 10.30 | 11.00 |
| 11.15 | 11.40 | 12.10 |
| 12.35 | 13.05 | 13.35 |
| 13.05 | 13.30 | 13.50 |
| 13.35 | 14.00 | 14.30 |
| 16.05 | 16.30 | 17.00 |
| 17.15 | 17.45 | 18.15 |
| 18.30 | 18.55 | 19.25 |
| 19.25 | 19.50 | 20.15 |
| 20.15 | 20.35 | 20.55 |

**SÁBADOS**

| ROSSIO | TRAV.CIMA | ROSSIO |
|---|---|---|
| 6.55 | 7.15 | 7.40 |
| 7.50 | 8.20 | 8.50 |
| 10.45 | 11.05 | 11.30 |
| 12.10 | 12.40 | 13.05 |
| 13.05 | 13.30 | 14.00 |
| 17.25 | 17.45 | 18.05 |

**DOMINGOS E FERIADOS**

| ROSSIO | TRAV.CIMA | ROSSIO |
|---|---|---|
| 9.25 | 9.40 | 9.55 |
| 11.05 | 11.20 | 11.40 |
| 14.30 | 14.50 | 15.10 |
| 17.25 | 17.45 | 18.05 |

OBS:TERÇA-FEIRA DE CARNAVAL E 2ª FEIRA DE PÁSCOA, EFETUAM-SE OS HORÁRIOS DE DOMINGOS

**ITINERÁRIO:**ROSSIO-R.AL.MARTINS-STªCRISTINA-AV.EMIDIO NAVARRO
SANTIAGO-ESCULCA-TRAVASSÓS CIMA

**EM VIGOR A PARTIR DE 1 DE JUNHO 2012**

# ANEXE B: AVERAGE SPEED CALCULATION

| Distances LINE 05 | | |
|---|---|---|
| Go | 8,48 | km |
| Return | 8,43 | km |
| Total Length | 16,91 | km |

| | TIMETABLE | | | GO Rossio-Trav.Cima | | RETURN Trav.Cima-Rossio | |
|---|---|---|---|---|---|---|---|
| | Rossio | Trav. Cima | Rossio | Time (min) | Speed (km/h) | Time (min) | Speed (km/h) |
| WEEKDAYS | 6:45 | 7:00 | 7:25 | 15 | 34 | 25 | 20 |
| | 7:25 | 7:50 | 8:20 | 25 | 20 | 30 | 17 |
| | 8:20 | 8:50 | 9:20 | 30 | 17 | 30 | 17 |
| | 10:00 | 10:30 | 11:00 | 30 | 17 | 30 | 17 |
| | 11:15 | 11:40 | 12:10 | 25 | 20 | 30 | 17 |
| | 12:35 | 13:05 | 13:35 | 30 | 17 | 30 | 17 |
| | 13:05 | 13:30 | 13:50 | 25 | 20 | 20 | 25 |
| | 13:35 | 14:00 | 14:30 | 25 | 20 | 30 | 17 |
| | 16:05 | 16:30 | 17:00 | 25 | 20 | 30 | 17 |
| | 17:15 | 17:45 | 18:15 | 30 | 17 | 30 | 17 |
| | 18:30 | 18:55 | 19:25 | 25 | 20 | 30 | 17 |
| | 19:25 | 19:50 | 20:15 | 25 | 20 | 25 | 20 |
| | 20:15 | 20:35 | 20:55 | 20 | 25 | 20 | 25 |
| | Speed Average (km/h): | | | | 19 | | 17 |
| | Speed Average Weekdays (km/h): | | | | 18 | | |
| SATURDAYS | Rossio | Trav. Cima | Rossio | Time (min) | Speed (km/h) | Time (min) | Speed (km/h) |
| | 6:55 | 7:15 | 7:40 | 20 | 25 | 25 | 20 |
| | 7:50 | 8:20 | 8:50 | 30 | 17 | 30 | 17 |
| | 10:45 | 11:05 | 11:30 | 20 | 25 | 25 | 20 |
| | 12:10 | 12:40 | 13:05 | 30 | 17 | 25 | 20 |
| | 13:05 | 13:30 | 14:00 | 25 | 20 | 30 | 17 |
| | 17:25 | 17:45 | 18:05 | 20 | 25 | 20 | 25 |
| | Speed Average (km/h): | | | | 22 | | 19 |
| | Speed Average Saturdays (km/h): | | | | 20 | | |
| SUNDAYS AND HOLIDAYS | Rossio | Trav. Cima | Rossio | Time (min) | Speed (km/h) | Time (min) | Speed (km/h) |
| | 9:25 | 9:40 | 9:55 | 15 | 34 | 15 | 34 |
| | 11:05 | 11:20 | 11:40 | 15 | 34 | 20 | 25 |
| | 14:30 | 14:50 | 15:10 | 20 | 25 | 20 | 25 |
| | 18:50 | 19:10 | 19:30 | 20 | 25 | 20 | 25 |
| | Speed Average (km/h): | | | | 30 | | 27 |
| | Speed Average Sundays and Holidays (km/h): | | | | 29 | | |
| (shaded) | It is not considered for the calculation; it is despised due to not belong to the average | | | | | | |