INTERCHANGE IN URBAN PUBLIC TRANSPORT: 
A NECESSARY OR MISJUDGED PROBLEM?

A case study in Porto.

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NEW mobility patterns associated with the exponential increase in the use of the private car have been responsible for new mobility problems like congestion and lack of sustainability.

Integration of different transport means is seen as a potential contribution for the solution of current mobility problems. The objective of integration is to achieve “seamless journeys” by providing a “door to door” mobility chain and thereby creating an alternative to the car. The existence of interchange points enabling transfers between different transport modes or services is therefore required. Although knowing the importance of interchange for the sustainable development of urban mobility, it is reasonable to believe that there is a preference for direct journeys.

This thesis aims to contribute to the study of the effect of interchange on public transport demand with regard to its role in sustainable urban mobility. This analysis is developed with special attention to the potential contribution of interchange to network efficiency. Following a theoretical model, the main potentialities and limitations of interchange implementation are studied from the operator’s and the individual’s perspectives (as the two main urban mobility stakeholders within the scope of this study). This discussion is complemented by a case study concerning the introduction of interchange in public road transport in order to understand personal perceptions and attitudes towards interchange. With the purpose of taking advantage of the potentialities of interchange, the necessary trade-offs between efficient public transport chains (enabled by interchange) and the effects on demand are evaluated, in the context of mutual influence between individual and operator, from an urban mobility perspective.

The research developed during this thesis has shown that, apart from being acceptable, interchange enables potential trade-offs enhancing network efficiency, which can even be perceived as a global improvement of public transport service with a positive effect on demand. Being so, interchange has the potential of producing global benefits for urban mobility and for its main stakeholders.
**Resumo**

Os novos padrões de mobilidade, associados ao crescimento exponencial do uso do automóvel têm sido responsáveis por novos problemas de mobilidade como o congestionamento e a falta de sustentabilidade.

A integração de diferentes modos de transporte é vista como uma potencial contribuição para a solução dos problemas de mobilidade actuais. Entre outros aspectos, a integração possibilita a implementação de cadeias de transporte que permitam um serviço porta-à-porta criando uma alternativa viável ao uso do automóvel. A existência de pontos de transbordo, possibilitando a transferência entre diferentes modos ou serviços é, por isso, essencial apesar da preferência por serviços de transporte directos.

Esta tese pretende ser uma contribuição para o estudo do efeito do transbordo na procura do transporte público, tendo em atenção o seu papel na sustentabilidade da mobilidade urbana. Esta análise é desenvolvida incidindo sobre a contribuição potencial do transbordo para a eficiência da rede de transporte. Recorrendo a um modelo teórico, são estudadas as principais potencialidade e limitações da implementação do transbordo da perspectiva do operador e do indivíduo (os dois principais intervenientes no âmbito de estudo da tese). Este é complementado por um caso de estudo (introdução do transbordo em transporte público rodoviário) com o objectivo de entender as percepções e atitudes dos indivíduos perante o transbordo. Com a finalidade de aproveitar as potencialidades do transbordo, foram discutidos os compromissos necessários entre a criação de cadeias de transporte eficientes (tornada possível pelo transbordo) e o efeito na procura, tendo em atenção a mútua influência entre operador e indivíduo, no contexto da mobilidade urbana.

A investigação desenvolvida durante a tese mostra que, para além de ser aceitável, o transbordo permite melhorar a eficiência da rede de transporte, podendo mesmo ser percepcionado como uma melhoria para o serviço de transporte público com reflexos positivos na procura. Sendo assim, o transbordo encerra o potencial de beneficiar a mobilidade urbana e os seus principais intervenientes.
Les nouveaux modèles de mobilité, associés à la croissance exponentielle de l’utilisation de l’automobile, sont responsables des nouveaux problèmes de mobilité tels que les embouteillages et le manque de sustentabilité.

L’intégration des différents moyens de transport est considérée comme une contribution potentielle à la recherche d’une solution aux problèmes actuels de mobilité. L’intégration, entre autres, permet la mise en place de chaînes de transport permettant un service porte à porte, créant ainsi une alternative viable à l’utilisation de l’automobile. L’existence de points de transfert permettant l’échange entre différents moyens ou services est essentielle même si un service de transport direct est préféré.

Cette thèse prétend être une contribution pour l’étude de l’effet des transferts dans la recherche du transport public, notamment sur son rôle sur la sustentabilité de la mobilité urbaine. Cette analyse est développée en se concentrant sur la contribution potentielle des transferts sur l’efficacité des réseaux de transport. En ayant recours à un modèle théorique, les différentes potentialités et limites de la mise en place des transferts dans la perspective de l’opérateur et de l’individu (les deux principaux intervenants dans l’étude de cette thèse). L’étude sera complétée par une étude de cas (introduction des transferts dans le transport public routier) avec pour objectif de comprendre les perceptions et attitudes des individus par rapport aux transferts. Afin de tirer profit des des potentialités du transfert, ont été discutés les compromis entre la création de chaînes de transport efficaces (rendus possible par les transferts) et l’effet sur la recherche, avec une attention spéciale sur l’influence mutuelle entre opérateur et individu, dans le contexte de la mobilité urbaine.

L’investigation développée au long de cette thèse démontre que au delà de son caractère acceptable, le transfert permet d’améliorer l’efficacité du réseau de transport, pouvant même être vu comme une amélioration pour le service de transport public avec des répercussions positives sur la recherche. Le transfert contient donc le potentiel d’être bénéfique à la mobilité urbaine et à ses principaux intervenants.
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Chapter 1

INTRODUCTION

1.1. Background

Urban areas assumed a new role in economic and social activities with Globalization. Cities enclose a human and technological capital, which is responsible for the continuous production and dissemination of information, knowledge and innovation. They have taken the place of countries in the global economy. The world has been structured into a net of urban areas, on several levels, which interact in competition and/or cooperation, and in which distance has been losing its influence. We are living in the era of the global market, where virtually everyone or everything is connected and where the level of connection determines the possibility of survival and success. The network of urban areas, connected by transportation and communication, is the core of this global economy. In this context, the importance of urban mobility lies mainly in its capacity to improve accessibility and enable economic development.

Mobility is one of the main factors determining the desired accessibility to social and economic activities, since it “enables people to overcome distance” [WBCSD, 2001] within an urban area and throughout the global network of urban areas. Global and local accessibility is essential for the integration in the global network of urban areas and therefore essential for their success of in the context of globalization. Mobility is also considered a key factor for the economic growth of urban areas. Global mobility is...
giving rise to specialization, allowing each person, company or city to focus on its core activity regardless of its physical location. Specialization brings higher efficiency rates, which are essential to economic development.

Powerful forces have shaped urban mobility in recent years. There has been an evolution in mobility problems that started with the historical problem of lack of mobility. Modern mobility problems, like pollution and road accidents arise from the developments in transportation. Nowadays the new problem limiting mobility, especially in urban areas, is transport infrastructure saturation, generally known as traffic congestion.

After World War II, the transport industry has expanded considerably due to important technological developments. In this context, travelling is becoming cheaper and faster. The automobile industry has been undergoing important developments and in developed countries car ownership is no longer a privilege of a few wealthy people. Faster and cheaper transports associated with higher incomes brought higher mobility rates. People travel more, over longer distances and for an increasing number of reasons. This is a consequence of an interrelated evolution in mobility, urban sprawl, economic development and social changes. As mobility grew, human activities became more distant due to the continuous urban sprawl. At the same time, personal incomes have been increasing far beyond mere survival needs, and working time has been decreasing. The household has also experienced many changes, with women having full time jobs, therefore having fewer children, which are also born later also because people tend to marry later in their lives. The whole family has a different structure, higher incomes and more spare time, which they use for ever growing extra activities. Consequently, mobility needs continue to rise and to become more complex due to new travel patterns and extensive urban areas. The travelling purposes are less predictable, and those that still are, are losing their share.

Mobility used to focus on overcoming distances (enabling accessibility) but nowadays mobility is no longer just a means of surviving. With the general rise of the average income in developed countries, survival is largely assured and mobility is recently becoming a way of personal achievement (by travel itself or by the choice of a better
transport mean) and even an indication of social status. The most recent mobility need has to do with what Piet et al. (1993) call “free mobility”.

Car ownership has been growing above expectations, as density decreases in spreading urban areas. It is certainly the most flexible and reliable transport mean adapting to all new mobility requirements. As regards urban areas, there has been a continuous increase in car usage in association with car ownership growth. It has even surpassed public transport, which has shown to be inefficient for lower urban density. Cities are facing high levels of car use, but this transport mode presents the least efficient use of energy especially because of its low occupancy rate.

Mobility has been growing in quantity and distance, and in flexibility and reliability due to the growth of passenger car ownership and usage. Nowadays, a higher number and distance of trips, with a very high share of car usage, have brought new mobility problems for urban centres. These are congestion and lack of sustainability.

Road transport infrastructure saturation is becoming a very complex problem in many urban areas. The growing use of the individual transport mode is the main reason for congestion problems in urban centres. This has brought severe problems to urban accessibility. Although mobility has been increasing in recent years, accessibility to urban centres is becoming a serious problem. This produces a negative feed back on the economic development of congested urban areas. Higher mobility has a positive effect on the economic development, but when it causes low accessibility its positive effects are reduced.

Besides road congestion there is also a lack of sustainability of urban development. Urban traffic congestion is responsible for important increases in pollution, which is destroying the quality of air and of the living standards in urban areas. The excessive use of the private car is wasting precious and limited urban space with ever-growing road infrastructure and parking places. This is perfectly illustrated by Figure 1.1. There has also been an accelerated increase in road accidents. “The total number of deaths in Europe per year due to traffic accidents are equivalent to a small war.”[UITP, 2001].
“75 people are carried either by 60 cars or, only by one bus”

Source: UITP (2001)

**Figure 1.1:** Comparative use of urban space by private and public transport mode

These aspects put urban development in jeopardy. There is a need for sustainable development in urban areas and the excessive use of private cars is putting this at risk. “The private car has brought undreamed levels of mobility and liberty to individuals, but its unlimited use in urban areas has a negative effect on society, environment and the economy” [UITP, 2001].

Many possible solutions have been presented in order to grant urban mobility, accessibility and sustainable development, but few of them are able to grant these three aspects simultaneously. One of the most effective contributions for the solutions of current mobility problems is the integration of different transport modes. Transport Integration, also called Intermodality, has the potential of enabling the use of each transport mode in the most efficient way. “Integration […] holds the key to mobility problems in urban and regional areas and provides a vital step towards sustainable mobility.” [Mezghani, 2003]

Integration strives to create a mobility system with the ultimate objective of achieving “seamless journeys” by providing a “door to door” mobility chain through the most efficient use of available resources, using several transport modes and taking advantage of their existing synergies [PORTAL, 2003].

There is broad agreement that Integration has the potential to provide an inclusive answer to mobility problems in urban areas. Instead of using the private car for “door to door” travel, a more sustainable model of integrated transport should be used to provide the desired mobility.
In order for integration to offer the expected advantages, it has to be complete. Milan Janic mentions four levels of integration, “hardware (terminals, multiple use of rail tracks), software (information systems), orgware (better coordination of timetables) and fineware (combined ticketing and common tariff system)” [JANIC et all., 2001]. The coordination of transport routes is not enough, everything else concerning the mobility service must be coordinated and integrated. To maximize the modal shift from the private car to public transport, integration must achieve the “seamless journey”. Maximising the modal shift does not necessarily imply the exclusion of the private car, on the contrary, it has an important role to play in a complete transport chain due to its unique characteristics.

To make integrated transport systems work there ought to be points of contact between different transport modes or between different vehicles of the same transport mode, where interchange is made possible. Apart from the coordination and integration of transport modes and services, interchange points are needed to create operational transport chains. This transfer point is considered to be the drawback in an otherwise potential contribution for the solution of mobility problems. The basic idea of integration is easily understood and accepted by public opinion but the need to transfer within the integrated transport system is seen as a loss in service quality and as a stop during the trip. It is believed to have very low public acceptance. Therefore, interchange is a decisive study theme within integration, as it is one of the key contributory factors in its success. «So if we want to get a large “modal shift”, from car to public transport, we have to work in priority on the intermodality black spot. One of these is what is sometimes called the “transit hub”, or, like in the Vienna UITP Colloquium of November 1998, the “Intermodal Interchange Points”» [AMAR, 1999].

### 1.2. Study Scope

This thesis will concentrate exclusively on interchange in the context of the several aspects worth mentioning and studying in integration as a potential contribution for the solution of current mobility problems. Within the different transport modes involved and worth studying for Integration, this thesis is focused on discussing the real effect produced by interchange on public transport services. Public transport presents specific
characteristics (for example: fixed timetables, routes, and access points) that enhances its limitation to the introduction of interchange points, without which integrated transport systems would not be possible.

This thesis intends to draw attention to new opportunities offered by interchange within public transport, exploring its potential benefits. According to AMAR (1999) the first conclusion of the Vienna UITP Colloquium of November 1998 was that “[…] interchange points constitute a strategic challenge for public transport”. It can even help to attract new passengers by offering new travelling opportunities, increasing speed or even improving the overall journey [T/L, 2001]. This thesis will, therefore, discuss the theoretic potentialities and limitations of interchange as an essential element of integration.

According to MVA (2000) interchange has been largely discussed with regard to its location and necessary facilities\(^1\). The EU-funded GUIDE project built a conceptual structure, considering different aspects of the study of interchange, around four main topics: location-specific, organization, strategy and evaluation. The objective of this thesis’ research could be included in the “strategy” topic\(^2\) (excluding the sub-topic related to fares and ticketing): “[…] concerned with the function of interchange within a public transport network, with sub-topics including fares and ticketing, passenger propensity to interchange, impacts on modal split and the contribution of interchange to network efficiency.” [MVA, 2000].

![Figure 1.2: Scope of the thesis](image_url)

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\(^1\) More than 70% of the literature reviewed by this research team for the GUIDE report was “location-specific”.

\(^2\) This topic represented less than 1/5 of MVA’s literature review for the GUIDE project.
This thesis will study social acceptability of interchange within the network effect it creates, evaluating the potential contribution that interchange can bring to network efficiency and on how these can influence personal propensity to interchange (and the consequent effect on modal split). Figure 1.2 shows the thesis’ scope.

1.3. Research Objective

The objective of this thesis is to discuss the acceptability of interchange in public transport (with special attention to its effect on demand) and its contribution for the success or failure of integration (as a potential solution for current mobility problems). It will concentrate on the evaluation of the potentialities and limitations of interchange within public transport, from the perspective of network efficiency.

1.4. Methodology

This thesis is essentially divided into two phases:

- Theoretical analysis;
- Case study.

The first phase, developed in the second chapter, is a theoretical analysis of interchange and of its potentialities and limitations. The case study presented in the third chapter culminates the analysis of interchange with an application on a real situation of interchange implementation within a public road transport network.

The following guide line research questions were defined for the analyses developed during the first phase:

- Can interchange bring benefits for urban mobility stakeholders and to urban mobility itself? If yes, within which conditions?
- What is the potential effect of interchange on public transport demand?
The objective of the case study, developed during the second phase of this thesis, is the evaluation of personal perception and attitudes towards interchange (for a particular situation) within the specific conditions of road public transport.

To achieve this objective two operational objectives were defined for the case study:

- Evaluation of the relative importance and satisfaction level of several network features changed through interchange introduction.
- Evaluation of the effect of interchange introduction on demand (forecasted and real).

1.5. Thesis contents

This thesis is divided into four chapters (see Figure 1.3). After the introduction developed in the first chapter, the second chapter presents the theoretical analyses of interchange, evaluating its influence on the success or failure of integration, as a potential contribution for the solution of current urban mobility problems. It begins with a conceptual discussion of interchange and its definition for this thesis, in section 2.1, followed by a simple theoretic model with the purpose of comparing public transport networks with and without interchange, in section 2.2. The next sections of this chapter discuss the potential gains and losses from the operator and individual perspective (as the two main stakeholders of urban mobility within the scope of this thesis), based on the theoretical model developed. Section 2.5 presents a discussion of the effect of interchange on demand, crossing the analyses of the operator and individual perspective. The last section presents some concluding remarks on the theoretical analyses developed during this chapter and discusses the effect of interchange on urban mobility.

Some of the analyses developed in the second chapter and some of its main conclusions are tested in the third chapter through a case study. This involves the introduction of an interchange within routes of a public transport operator in the city of Porto. This chapter starts with the presentation of the case study and its background. The second section presents the case study’s methodology including the main objectives and a brief
description of the developed tasks. In the third section follows the discussion of the main results of the developed tasks. The chapter ends with the discussion of the main findings of this case study.

**Figure 1.3:** Structure and connection between the different chapters of the thesis

The last chapter presents the main conclusions reached through both, analyses of the third and fourth chapter, discussing the question posed in the title of this thesis: Interchange, a necessary or misjudged problem? This chapter ends with some guidelines for further research.
Chapter 2

Theoretical Analysis of Interchange

In theory, integration of different transport modes is one of the most effective solutions to simultaneously grant urban mobility, accessibility and sustainable development. The creation of an integrated transport system is, therefore, seen as a potential contribution for the solution of current urban mobility problems (congestion and lack of sustainability) mainly because it enables a more efficient use of urban transport modes and the construction of highly efficient transport chains.

By taking a quick look at the characteristics of each transport mode it becomes rather clear how integration of different transport modes can produce an overall more efficient transport system, in alternative to the private car.

The next table (Table 2.1) shows some of the main characteristics of several urban transport modes (walking, bicycle, powered two wheeler - ptw, taxi, private car, bus, tram, subway and train) and risks some superficial comparison. The main characteristics used in the analysis were: technical features (number of passengers, capacity, travel speed with and without congestion, flexibility and noise); average operational distance; pollution (per passenger); consumption of fuel (per passenger); accessibility/penetration of the urban tissue; price; some limitations of use (by age, by physical and economic limitations).
Table 2.1: Comparison between transport modes characteristics

<table>
<thead>
<tr>
<th>URBAN MOBILITY</th>
<th>Transport Mode</th>
<th>Walking</th>
<th>Bike</th>
<th>PTW</th>
<th>Taxi</th>
<th>Private Car</th>
<th>Bus</th>
<th>Tram</th>
<th>Subway</th>
<th>Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Features:</td>
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<tr>
<td>&quot;Passengers&quot; (passengers per hour in a 3.5m corridor)</td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4 - 6</td>
<td>2 - 9</td>
<td>≈70</td>
<td>variable</td>
<td>variable</td>
<td>variable</td>
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<tr>
<td>Speed (km/h) (with congestion)</td>
<td></td>
<td>2 - 5</td>
<td>15 - 25</td>
<td>15 - 30</td>
<td>5 - 15</td>
<td>15 - 30</td>
<td>5 - 15</td>
<td>5 - 15</td>
<td>25 - 40</td>
<td>30 - 50</td>
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<tr>
<td>Speed (km/h) (without congestion)</td>
<td></td>
<td>2 - 5</td>
<td>15 - 25</td>
<td>15 - 30</td>
<td>5 - 15</td>
<td>15 - 30</td>
<td>5 - 15</td>
<td>5 - 15</td>
<td>25 - 40</td>
<td>30 - 50</td>
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<td>Flexibility</td>
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<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
<td>very high</td>
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<td>none</td>
<td>medium</td>
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<td>medium</td>
<td>medium</td>
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<td>very low</td>
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<tr>
<td>Average Operational distance (km)</td>
<td></td>
<td>0 - 1</td>
<td>1 - 3</td>
<td>2 - 5</td>
<td>3 - 100</td>
<td>1 - 50</td>
<td>1 - 10</td>
<td>1 - 10</td>
<td>30 - 300</td>
<td></td>
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<tr>
<td>Pollution (per passenger)</td>
<td></td>
<td>none</td>
<td>none</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
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<tr>
<td>Consumption of fuel (per passenger)</td>
<td></td>
<td>none</td>
<td>none</td>
<td>medium</td>
<td>very high</td>
<td>very high</td>
<td>medium</td>
<td>low</td>
<td>medium</td>
<td>medium</td>
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<tr>
<td>Accessibility (penetration)</td>
<td></td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>high</td>
<td>medium</td>
<td>low</td>
<td>low</td>
<td>very low</td>
<td></td>
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<tr>
<td>Price</td>
<td></td>
<td>very low</td>
<td>very low</td>
<td>low</td>
<td>high</td>
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<td>medium</td>
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<td>Type of limitation:</td>
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<td>age (too young or too old)</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>physical (for example: blind)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>economic</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Scale: Best, second-best, medium, second-worst, worst

1 European Commission (2000) "Ville cyclables, Villes d'avenir", EU
2 PORTAL (2003) "Integrated transport chains", EU

To discuss the integration of different transport modes in accordance to its characteristics in the construction of efficient transport chains, three major types of urban travel are considered:
– short distance travel patterns within urban road congestion;
– medium distance travel patterns within urban road congestion;
– commuting (between urban centres and suburbs, considering only long distance travel).

**Short Distance Travel Patterns**

The analyses of Table 2.1 shows that, within those transport modes with operational transport distance ideal for short distance travel (taking into account the existence of congestion) walking and cycling are the best modal choices (for an ideal distance up to 5km). These modes have important environmental advantages besides providing high level of capacity, accessibility and flexibility (as other less environmental friendly modes do). Travel speed is very low but is not susceptible to road congestion, and in the case of the bicycle, can have higher velocities then private cars with congestion\(^3\).

**Medium Distance Travel Patterns**

When urban roads are congested high capacity transport modes should be used. In this case, ideal transport modes would be bus, tram and subway (walking and cycling are inappropriate for these travel distances). The subway and the tram operate on rail tracks giving them no flexibility unlike the bus that operates on regular roads having higher flexibility only limited by predefinition of routes. Low flexibility limits accessibility; however buses, trams and subways are still light public transport (capacity and velocity adapted for urban travel) and therefore provide some accessibility. The subway allows transport flows to be independent from the remaining road traffic while the bus is usually mixed with general traffic being limited by road congestion. The use of each of these transport modes should be calibrated by mobility problems of each urban area. Higher congestion calls for public transport solutions with higher capacity and segregated infrastructure. These have to be complemented with other more flexible modes and providing higher accessibility, in order to give answer to urban mobility patterns.

\(^3\) It is interesting to notice that approximately 30% of European car trips have length of less than 3km, and 50% of them have length of less than 5km [EC, 2000]. Being so, half of all car trips in Europe could be substituted by walking or cycling, which by it self could solve a great part of sustainability problems.
Commuting

In commuting it is possible to distinguish between two different travel segments. One is travel in urban areas (at the beginning or/and end of the trip) the other is outside urban centers (within disperse urban patterns). The first travel segment has already been discussed within the previous two travel types. For the latter travel segment two main transport solutions can be proposed. Whenever there are radial corridors with considerable urban concentration, efficient public transport routes can be established (using trains or buses depending on length and passenger flows). These routes have to consider complementary transport modes (with lower capacity) feeding the main radial transport routes by concentrating disperse passengers, which is essential to accomplish high levels of passenger concentration in a small number of predefined corridors. When urban settlement patterns, outside urban centers, are disperse no efficient public transport system can be designed. In this case, the most efficient transport mode is the private car (within reasonable travel distances). In both situations, an efficient integration is needed between this systems and the urban transport system.

This analysis shows that integration (and therefore interchange) is a valuable instrument to achieve higher efficiency in the use of available resources (from transport resources to environmental resources), by using several transport modes and taking advantages of their synergies. This would also produce efficiency gains within urban mobility. Nevertheless, for there to be a real positive effect on urban mobility, accessibility and sustainable development, there has to be a considerable modal shift from the private car towards non-motorised modes for short distance travel and towards public transport for medium distance travel. Without that, efforts towards urban transport integration will not have positive effects on urban mobility and will therefore have failed its goal.

One limitation of integration is the need to transfer between or within modes. Interchange is seen as an important drawback in the integration process. It is even considered as a “black spot” [AMAR, 1999] within the integrated transport system. It may be a “black spot” but interchange is inescapable in integration. Knowing the potential of transport integration in solving urban mobility problems it is of the utmost importance to understand the role of interchange and its effect on urban mobility.
The effect of interchange on urban mobility is dependent on the perception and reaction of the main urban mobility stakeholders towards interchange implementation. An analysis of the effect of interchange on the different urban mobility stakeholders is, therefore, essential to understand its potentialities and limitations. The two main stakeholders are urban transport operators and individuals. These two urban mobility stakeholders and the expected theoretical effects produced by interchange introduction on each of them and on urban mobility are presented in Figure 2.1.

![Figure 2.1: Effect of interchange on urban mobility and their main stakeholders](image)

The necessary modal shift towards public transport modes depends on the effect on public transport passenger demand and these depend on individual attitudes towards interchange. These effects will be further discussed in the following sections after a discussion of the necessary concepts relating to interchange (section 2.1) and the presentation of a simple theoretic model comparing direct origin-destination networks with networks using one interchange (section 2.2). The operator and individual perspective of interchange will be evaluated with regard to this model, considering interchange within the network (sections 2.3 and 2.4).

### 2.1. What is interchange

There is no clear universally accepted definition for the concept of Interchange. Each author uses its own concepts and usually gives no clear definition for its meaning. Many
similar concepts can be found without clear meanings giving range for conceptual confusion an ambiguity. This problem can be identified in several publications in this scientific area. Table 2.2 summarises a discussion of meaning and function found in two publications.

Table 2.2: References showing conceptual ambiguity concerning interchange

| Publication | “Public transport interchanges tend to have the dual function of providing access to public transport and transfer between public transport vehicles. In addition, the word interchange has two meanings: It can describe the action of interchanging, as passenger transfer between vehicles as part of a journey; But it can also mean a location where interchange takes place.” […] “Interchange facilities, and the interchange activity by travellers, are not topics that are well-conceptualised, and there is no tradition of treating them as distinct topics for research.” |
| Intermodal Transport – interchange for London [T/L, 2001] | “‘Interchange’ can mean a number of things: the act of changing between modes the place where you change between modes a purpose-built facility to improve interchange quality” |

| Concepts used for each meaning: | “Interchange” “Interchange Zone” “Interchange Facility” |

A simple comparison of the two statements in Table 2.2 is enough to recognise that the first paragraph from the GUIDE has the same message as the T/L reference, although the latter refers only to different meanings and the former also includes different functions. This small example clearly illustrates the ambiguity of concepts within interchange. The general idea is the same in both cases but there is no general accepted systematisation of the concept. This situation clearly justifies the need for a conceptual discussion in the beginning of this chapter in order to clarify the meaning of the concepts used in this thesis relating to interchange.

There are two main meanings usually associated with interchange, the action of transferring within a journey and the location where the transfer takes place. The lack of distinction between location and action is well illustrated by this statement, “The transport interchange is the point where passengers change mode and/or service, but is
also meeting point for different transport operators and modes” [PORTAL, 2003], referring to interchange as a location but also to the action of transfer. Two different concepts are necessary to distinguish location from action and avoid misinterpretations.

In this thesis, **Interchange** will be used only in reference to transfer action within a journey, for transfer location or purpose-built facility will be used **Interchange Point or Facility**.

Many concepts can be created within the interchange concept, mainly to classify different characteristics, as for example, function, dimension, location, etc. Interchange should assume the wider meaning including all classification and characteristics.

Interchange can be classified in two *types of actions*, between modes and within the same mode. These could be named as **Intermodal Interchange** and **Intramodal Interchange**, respectively. When referring to the transfer point or facility, where these types of interchange action occur, the concepts **Intermodal Interchange Point** and **Intramodal Interchange Point** could be used.

Interchange involving public transport (which is the scope of this thesis) can be classified by *function* as:

- Access to public transport;
- Transfer between modes (between or within public transport operators);
- Transfer within modes (between vehicles of the same mode, between or within public transport operators).

The first two *functions* are Intermodal Interchange by *action type*. The concepts used for these could be **Intermodal Interchange of access to public transport** and **Intermodal Interchange within public transport**. The last function is an Intramodal Interchange type and therefore could be called **Intramodal Interchange within public transport**.

As there is no formal distinction of possible action between different interchange points there is no need to classify them by function. Interchange points can have all interchange functions simultaneously, and even the most simple interchange point allows interchange within public transport, except when that transport point is stop for
only one public transport route. In this case we could say that it is exclusively an Interchange Point of access to public transport. The concept **Public Transport Interchange Point** can be used for all other situations.

Many other classifications can be made for other characteristic. For example, the PORTAL project “Integrated Transport Chains” (2003) presents a classification of interchange points for its location and role in the urban structure:

- City centre interchange;
- Sub-centre interchange;
- Peripherals (near a town or in the middle of nowhere).

Another important classification of interchange or interchange points is **hierarchy**. As integration is (or should be) organised into different hierarchic levels (see Figure 2.2) so should interchange and interchange points. In this case both interchange and interchange points must be at the same hierarchic level and therefore have the same classification. According to **hierarchy** interchange can be at local (**Local Interchange** or **Local Interchange Point**), at regional / national (**Regional/National Interchange** or **Regional/National Interchange Point**) or at supra-national level (**Supra-National Interchange** or **Supra-National Interchange Point**), in each case interchange can be of access to the level or within the same level. From local level to higher levels, transport networks become less dens, with lower travel destinations and frequency, higher capacity and providing less accessibility.

**Figure 2.2:** Integration levels
Having presented some of the main concepts within interchange and their meanings it becomes essential to define Interchange for this thesis, being this its central concept:

**Interchange**: is the action of transferring between vehicles or between vehicles and walking, within a journey; there has to be change of mode or of service or vehicle within the same mode, during a journey.

**Interchange Point**: the place, location or building where interchange takes place.

### 2.2. The theoretic model

For this model two simple situations were proposed for the comparison of direct service and indirect service (using interchange within public transport), which are presented in Figure 2.3. The first comparison will be made within a system of three origins/destinations – the three nodes model – which is the simplest situation for the use of interchange. A second situation is included in the analysis in order to draw some conclusions regarding to the variation of number of nodes linked through an interchange – the four nodes model.

![Figure 2.3](image)

**Figure 2.3**: Two situations chosen for the construction of the model, three and four nodes

The nodes represent origins or destinations for which two types of networks will be proposed and analysed – with and without interchange. The network with interchange includes an extra node, the interchange point, which is an “artificial” node were origins/destinations are negligible. This simple model is far from representing real
network effect but is very useful for comparing differences (potentialities and limitations) between the two types of network in analysis. The analysis of this model is totally theoretical and its importance relies on the fact that it allows a reliable comparison between direct service networks and integrated networks.

The construction of this model requires a restricted number of fundamental variables. These variables and the relations between them are presented in the following table.

**Table 2.3:** Variables used in the model and their relations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable name</th>
<th>Relation within variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>distance</td>
<td>$F = N / T$ (see assumption 1)</td>
</tr>
<tr>
<td>L</td>
<td>length of the route</td>
<td>$H = 1 / F$</td>
</tr>
<tr>
<td>N</td>
<td>number of vehicles</td>
<td>$T = k_1 D$ or $D = k_1' T$ (see assumption 2)</td>
</tr>
<tr>
<td>F</td>
<td>frequency</td>
<td>For the PT vehicle $D = 2 L$ (see assumption 4)</td>
</tr>
<tr>
<td>H</td>
<td>headway</td>
<td>For the PT vehicle $T = k_2 L$ (see assumption 2 and 4)</td>
</tr>
<tr>
<td>T</td>
<td>time</td>
<td>$k_1' = 1 / k_1$ and $k_2 = 2 k_1$</td>
</tr>
<tr>
<td>$k_1$, $k_1'$, $k_2$</td>
<td>constants</td>
<td>Legend: PT – public transport</td>
</tr>
</tbody>
</table>

Besides choosing the necessary variables, some assumptions needed to be defined in order to simplify the construction of the model and the comparison of networks with and without interchange.

**Assumption 1:** Public transport vehicles are always in circulation.

This assumption is essential to simplify calculation of frequency. Within this assumption vehicles do never stop to wait for pre-defined periods of time before initiating the next journey, i.e. they leave the terminal point immediately after arriving without a considerable wait period. Being so, frequency can be estimated through the number of vehicles divided by time. Generally frequency is measured in vehicles per hour.

\[
F = \frac{N}{T} \quad [2.1]
\]

with $T$ being time spend by each vehicle on a roundtrip (h)
Assumption 2: Vehicle velocity is constant, independent of circulation conditions.

For this theoretic model no real values of circulation velocity can be estimated, being so, velocity will be considered constant, due to homogeneity of the model, simplifying relations within other variables. Within constant circulation velocity, distance is proportional to time, therefore, for any time variations exists an equal distance variation.

\[ T = k_1 D \quad [2.2] \]

\[ D = k'_1 T \quad [2.3] \]

\[ \Delta T = \Delta D \quad [2.4] \]

Assumption 3: All routes have the same frequency, independent of length and demand.

Within a symmetric model with a homogeneous distribution of routes and in the absence of demand information or origin-destination matrixes, frequencies and headways were considered equal for all routes. This assumption allows a considerable simplification of the comparison between networks with and without interchange.

Assumption 4: Each route follows the same course for coming and going.

Within this assumption, the distance travelled by each public transport vehicle in a roundtrip is twice the route length.

\[ \text{For vehicles } D = 2L \quad [2.5] \]

In consequence of this, time is also proportional to route length, with a constant of proportionality of twice as that of distance.

\[ \text{For PT vehicles } T = k_2 L \quad [2.6] \]

\[ \text{with } k_2 = 2k_1 \quad [2.7] \]

Assumption 5: Waiting time is on average half of the headway.

Urban public transport is guided by headways and not by timetable, therefore, costumers do not usually know the routes timetable but the interval between vehicles. In
this context costumers arrive at vehicle stops randomly and therefore are expected to wait in average approximately half of the headway.

\[ T = \frac{H}{2} \]  

where \( T \) being waiting time.

**Assumption 6:** Interchange walking distance is negligible in comparison to travel distance.

Within these circumstances, travel distance with interchange will be considered as the sum of the length of each route used excluding the distance walked at the interchange point.

**Assumption 7:** Interchange does not represent an extra charge on costumers.

This assumption is unnecessary to the construction of the model but essential to its analysis. It will be consider that no extra charge is inflicted on costumers by interchange introduction, in other words, it is considered that through ticketing is correctly implemented and therefore no increase in travel cost is expected.

This summarizes the assumptions used for the construction of this model. In order to establish some comparisons a number of aspects were calculated for the three and four nodes model, for both network types, with and without interchange, allowing an analysis of the gains and losses produced by the introduction of interchange in a public transport network, in terms of network effect. This analysis was divided into two different perspectives; that of the transport service (Network) and that of the public transport service user (Costumer).

**Network**

Within the perspective of transport service, analyses could be divided into two parts. The first, comparing basic aspects: number of routes; length of each route; total length of routes; total distance of routes. The second, comparing different scenarios of the use of transport resources saved with the introduction of interchange from which public transport operators can choose.
CHAPTER 2: THEORETICAL ANALYSIS OF INTERCHANGE

The first comparison was sufficient to evidence considerable network optimization with the introduction of interchange. The considerable reduction of theoretical route length and distance allows operators to reduce necessary resources without deterioration of the service level (reduction of necessary vehicles) and/or enhance service levels without an increase in necessary resources (improvement of frequency and network reach). Public transport operators have basically three extreme scenarios of action, within this context:

- **Scenario 1:** Provide better service for the same network and resources.
  Keeping the same number of vehicles operating the same origins/destinations considerable improvements can be obtained for service frequency (increase) and headways (decrease).
  \[ N \text{ – constant; } F \text{ – maximum; } H \text{ – minimum; same network} \]

- **Scenario 2:** Optimization of the use of available resources for the same network reach and service.
  Keeping the same service level (maintaining frequency and headways) considerable reductions can be obtained within necessary vehicles for operating the same origins/destinations.
  \[ F, H \text{ – constant; } N \text{ – minimum; same network} \]

- **Scenario 3:** Network expansion for the same transport service and resources.
  In this scenario, vehicle savings produced by interchange introduction are used for network expansion (for the service of new origins/destinations) within the same service level.
  \[ N \text{ – constant; } F, H \text{ – constant; maximum network} \]

Other scenarios are possible besides this three; combining different degrees of network expansions, service level and/or vehicle reduction. From the three scenarios only the first and second were used within the comparison model. For the first scenario, frequency and headway were compared for each route of the networks with and without interchange. For the second scenario, the aspects compared were the number of vehicles on each route and the total number of vehicles. The last scenario was not included in the analyses of the model because of its simple interpretation: within this scenario the
network can be expanded until its original size enabling passenger market enlargement, due to interchange introduction.

Costumer

The costumer has a different perspective of the network and its use, the main comparison aspects are travel time and distance. In relation to basic variables, networks with and without interchange were compared through the distance for each origin destination and in-vehicle time. For travel time, besides in-vehicle time, waiting time must also be considered. These were only considered for the first scenario (defined in the network analyses) since in the second scenario (within constant headways), total waiting time for networks with interchange would always be superior to that of networks without interchange. This occurs because waiting time was considered proportional to headway and therefore constant and because, without interchange, costumers have only one waiting time and, with interchange, they have two. Being so, aspects measured for comparison of networks with and without interchange, within the first scenario, were: average waiting time at origin (approximate); average total waiting time (approximate); total time.

Table 2.4 presents the values of the referred aspects, for the two proposed models comparing networks with and without interchange. Gains and losses brought by the introduction of interchange into the public transport network are evident through the comparison of the results for each aspect. The last column of each model presents variation (in percentage) of several aspects in relation to the network without interchange. The main calculations needed for the construction of Table 2.4 are presented in Annex A.
### Table 2.4: Comparison between networks with and without interchange

<table>
<thead>
<tr>
<th></th>
<th>Model with 3 nodes</th>
<th>Model with 4 nodes</th>
<th>variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without interchange</td>
<td>With interchange</td>
<td>variation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of routes</td>
<td>3</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>length of each route</td>
<td>a</td>
<td>a\sqrt{3}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Route type A (4a) = a</td>
<td>a\sqrt{2}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Route type B (2a) - a\sqrt{2}</td>
<td>a\sqrt{2}</td>
<td>-</td>
</tr>
<tr>
<td>total length of routes</td>
<td>3a</td>
<td>a\sqrt{3}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>(4+2\sqrt{2})a</td>
<td>2\sqrt{2}a</td>
<td>-</td>
</tr>
<tr>
<td>total distance of routes</td>
<td>6a</td>
<td>2a\sqrt{3}</td>
<td>-42%</td>
</tr>
<tr>
<td></td>
<td>(8+4\sqrt{2})a</td>
<td>4\sqrt{2}a</td>
<td>-59%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>number of vehicles in each route</td>
<td>n</td>
<td>n\sqrt{3}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Route type A (4n) = n</td>
<td>n\sqrt{2}</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Route type B (2n) - n\sqrt{2}</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>total number of vehicles</td>
<td>3n</td>
<td>n\sqrt{3}</td>
<td>-42%</td>
</tr>
<tr>
<td></td>
<td>(4+2\sqrt{2})n</td>
<td>2\sqrt{2}n</td>
<td>-59%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>frequency in each route in n(k_oa)</td>
<td>n/k_oa</td>
<td>n\sqrt{3}(k_oa; (f' = \sqrt{3}f))</td>
<td>73%</td>
</tr>
<tr>
<td></td>
<td>Route type A (4k_oa) = n</td>
<td>(1+1\sqrt{2})(k_oa; (f' = \sqrt{2}f))</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>Route type B (2k_oa) - n\sqrt{2}</td>
<td>n\sqrt{2}</td>
<td>-</td>
</tr>
<tr>
<td>headway in each route in k_oa/n</td>
<td>k_oa/n</td>
<td>k_oa/n(\sqrt{3}; (h' = h/\sqrt{3}))</td>
<td>-42%</td>
</tr>
<tr>
<td></td>
<td>(k_oa/\sqrt{2})(1+1\sqrt{2})n;</td>
<td>(h' = h/(\sqrt{2}+1))</td>
<td>-59%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>distance for each origin destination</td>
<td>a</td>
<td>2a\sqrt{3}</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Route type A = a</td>
<td>\sqrt{2}a</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>Route type B = a\sqrt{2}</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td>in-vehicle time</td>
<td>t</td>
<td>2\sqrt{3}t</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>Route type A = t</td>
<td>\sqrt{2}t</td>
<td>41%</td>
</tr>
<tr>
<td></td>
<td>Route type B = t\sqrt{2}</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>average waiting time at origin (approximate)</td>
<td>h/2</td>
<td>h/2 (- h/(2\sqrt{3}))</td>
<td>-42%</td>
</tr>
<tr>
<td></td>
<td>Route type A = t+h/2</td>
<td>h/2 (- h/(2\sqrt{2}+2))</td>
<td>-59%</td>
</tr>
<tr>
<td>average total waiting time (approximate)</td>
<td>h/2</td>
<td>h/2 (- h/(2\sqrt{3}))</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>(h' = h/(\sqrt{2}+1))</td>
<td>h/2 (- h/(\sqrt{2}+1))</td>
<td>-17%</td>
</tr>
<tr>
<td>total time</td>
<td>t+h/2</td>
<td>2\sqrt{3}h/\sqrt{3}</td>
<td>0.15 t+0.05h</td>
</tr>
<tr>
<td></td>
<td>Route type A = t+h/2</td>
<td>\sqrt{2}t+h/(\sqrt{2}+1)</td>
<td>-59%</td>
</tr>
<tr>
<td></td>
<td>Route type B = t\sqrt{2}+h/2</td>
<td>-17%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Main findings produced by the model

This model leads to some interesting observations revealing network potentialities and limitations brought by the introduction of interchange in the public transport network. First of all, a clear simplification of the transport network is visible just by comparing the schematic representation of the networks without interchange and after interchange is introduced. This reflects the reduction of routes that is made possible by interchange within transport networks. The number of routes necessary to have direct transport service is easily determined by Metcalf’s Law:

$$NR = \frac{(N^2 - N)}{2}$$  \hspace{1cm} [2.9]

with, NR – number of routes;
N – number of nodes.

The same network with a central interchange point would need only N - 1 routes. This clearly shows that the higher the number of nodes connected through an interchange point the higher the reduction of the number of necessary routes from a direct service network to a network with one interchange. This does not mean that the number of nodes linked through one interchange point should be as large as possible because other conditions must be taken in consideration, operational conditions that give upper limits for the number of nodes connected to an interchange point. This also depends obviously on real transport conditions that could not be analysed through this model.

The introduction of an interchange does not only reduce the number of necessary routes, it also potentially reduces the length of these routes, up to a theoretical maximum of half the initial length (when the original route passed through the central point where interchange was placed). This is a very considerable reduction, in terms of operational conditions. The introduction of interchange holds extraordinary gains in vehicle use optimization since it allows considerable reductions in route number and length. Both reductions combined in the aspects of “total length” and “total distance” present even higher reductions. These can potentially reach 42% in the case of the three nodes model and almost 60% for four nodes. The total distance of a network is a very important
operational aspect and a 40 or 60% reduction is equivalent to have a reduction of 40 or 60% in necessary vehicles and drivers. This shows that interchange can produce important saving for the operator maintaining the same transport service level.

This savings can be capitalized by transport companies by the reduction of operational cost, by the growth of transport service levels and/or by the expansion of the transport network with the same transport resources. Table 2.4 shows a potential growth of 73% and 141% of frequency if the entire fleet is kept on each network of 3 and 4 nodes, respectively. This means that the introduction of interchange can produce gains that in the case of the 4 node model exceed the duplication of the number of vehicles per hour. Consequently the headway suffers important reductions that in the same 4 node model can drop to less than half of the existing before the introduction of interchange.

As frequency and headway are inversely proportional a high growth in frequency does not give proportional reduction in headway. There is also a physical limit for headway reduction and frequency increase. The economic concept of marginal gain is the best to explain these limits. For example, when headway is already very low, for example 2 minutes, an extra vehicle will obtain a very low marginal gain in headway which is no longer relevant. If the initial headway is poor, lets say, 30 minutes, the introduction of an extra vehicle can reduce the headway in, for example, 5 minutes, which is very significant.

This to say that a 42% reduction in headway can or not be relevant depending on the existing headway. Real transport conditions have to be taken in consideration to understand the real extend of these results. This means that if transport service levels are already good (although, this is not the general situation in urban public transport systems) interchange may not present a considerable gain and therefore may not be an interesting solution. One of the reasons for low public transport demand is their low service levels. This means that there are still cases in which interchange can considerably optimize the use of transport resources and therefore produce significant gain in transport service, with reduced budgets.

The analysis of journey distance and time from the customer’s point of view is rather more complex. In case of journey distance, although routes have become shorter with
interchange introduction as each costumer has to use two routes to get to his destination, interchange has always a negative effect on individual journey distance. A neutral effect can be found in this model only for the situation in which the route used before the interchange introduction passed through the central point. Within this kind of model the larger the number of nodes connected by one interchange point the larger the growth of journey distance between neighbour nodes⁴. As in-vehicle time is proportional to travel distance (travel speed is constant) the same remarks can be drawn for this aspect as for travel distance.

Besides in-vehicle time, waiting time is also a very important aspect in the analyses of the individual perspective. With the introduction of interchange costumers have now two waiting times. Instead of one at the origin of the journey, an extra waiting is introduced at the interchange point. Considering that, on average, waiting time is approximately half of headway, waiting time can be decreased due to reduction of headway accomplished within the first scenario. Even so, total waiting time can be higher for networks with interchange than for direct service networks, because people have to wait twice. This is the case with the three nodes model. Models under the same conditions and with more than three nodes will always show gains in total waiting time.

The total time depends on waiting time and in-vehicle time. In-vehicle time always growths with interchange but waiting time can reduce. The determination of variation of total time (in percentage) produced three interesting equations presented in Table 2.4. These show that variation in total time, with interchange introduction, depends on in-vehicle time and on the headway. In the case of the three nodes model there is always a growth in total travel time when interchange is introduced, independent of in-vehicle time and headway. The result of the equation is always positive although the relative growth in travel time may vary. In case of the 4 nodes model this is no longer the case. There are two different situations to analyze. Fist of all, in case of the diagonal routes, the equation of the variation of travel time presents always negative results, independent of in-vehicle time and headway. This shows that in any situation, introduction of interchange produces gain in terms of total travel time, even though these gains are

⁴ In the case of a 6 nodes model the travel distance becomes twice of the original distance between neighbour nodes.
relatively marginal (as can be concluded by the low numerator). This was an obvious result since it had already been shown that in-vehicle time remains the same for these routes when interchange is introduced and that total waiting time is lower for the integrated network than for the direct service network.

The variation equation for route type A brings no immediate conclusion about rise or fall of total travel time. Nevertheless, it allows a very interesting conclusion: introduction of interchange within a travel network of four nodes, for travel between neighbour nodes can produce reduction of total travel time in case the direct service presented low in-vehicle time and high headways. In other words, reduction in journey time can be expected when direct service condition offer quick journeys and long waiting periods due to high headways. This reduction is obtained because of considerable reductions in waiting time. Therefore it is possible to conclude that for small travel distances, headway is a very important aspect and should be as low as possible.

It is important to recall that the analysis of this model is totally theoretical and its importance relies on the fact that it allows a reliable comparison between direct service networks and integrated networks.

The results produced by this model will be used for the analyses of operators and individual perspective presented in the following sections.

2.3. The operator perspective

Urban mobility patterns have been changing over the past decades, these have increasingly become more complex and difficult to predict. Highly predictable journeys, like work and school related travel, are losing relative importance in urban mobility patterns. Within this context, if high levels of modal shift towards public transport (which is the most efficient transport mean within medium travel distance in concentrated urban settlements) are to be achieved, public transport network is in need of considerable expansion and its service level of important improvements.
From the operators’ perspective, interchange, as the necessary element for integration, allows the optimization of the use of its transport resources. This can produce important gains for the public transport operator. The model presented in section 2.2 shows several potential transport resource savings that can be achieved by the introduction of interchange within an existing network. These savings are essential for the necessary public transport network expansion. Public transport market is generally in decline and several companies have been reducing services to reduce costs. Within the few profitable routes competition is severe; the remaining routes have experienced considerable public transport service losses. Within this context, interchange may bring important advantages for public transport, holding a solution for the necessary network expansion within limited transport resources (and even potential savings of resources).

“There is a sound economic basis for having effective interchange as a goal, as it enables the optimal use of resources within a transport network” [Oscar Farber, 2000]. Considering the three scenarios of operator action, built for the model of section 2.2, operators can achieve several gains through the optimization of the use of transport resources made possible by the introduction of interchange:

- Reduction of route length (shorter routes are easier to manage which can have a positive effect on reliability) – all scenarios;
- Reduction of the number of routes for the same network – scenario 1 and 2;
- Reduction of the number of necessary vehicles – scenario 2.
- Improvement of transport service (for example: extension of the network, increase in frequency) – scenario 1 and 3;

These aspects clearly show that interchange is an important opportunity with the potential to diminish operational cost through transport resource optimization and/or increase the profits through transport service improvements.

Besides operational optimization, the operator perspective must also consider the effect the introduction of interchange may have on demand, which is more difficult to predict. The effect on demand is dependent of individual perspective, which will be analysed in the next section.
Basically, individual perspective can have three distinct effects on demand, either increase, decrease or preserve demand levels. If the effect is negative, revenue will decrease. Even so, if operational cost reduction is higher than revenue decreases the operator can still achieve positive results from interchange. Nevertheless, when public transport companies are obliged to public service duties (operation of unprofitable routes requested by local or central authorities in order to assure public service) passenger loss can be negatively regarded even with profit gains.

As has been said before, integration should induce a considerable modal shift towards public transport use in order to achieve sustainable mobility. Would interchange represent demand losses for public transport operators, success of integration as a potential contribution for the solution of urban mobility problems would be at stake.

2.4. The individual perspective

As has been discussed, success of interchange depends strongly on the effect it has on demand and therefore on the individual perspective that is discussed in this section.

From the individual perspective, interchange when analysed in isolation from the network effects it produces, is almost always regarded as a negative feature within a journey. If the introduction of interchange within the public transport network would only represent an extra transfer for the passenger, this would always be negatively perceived\textsuperscript{5}. Interchange will therefore be analysed within the network effect it produces. This network effect can be responsible for the creation of advantages and disadvantages. The balance between these will result in gains or losses of public transport demand.

The analysis of the theoretical network model, presented in section 2.2, from an individual perspective reveals potential changed on several aspects influencing personal

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\textsuperscript{5} With exception of situations where travellers feel the need to stop during a journey, which is not usually the case in urban travel.
decision with interchange introduction into the public transport network. The main aspects are:

- The need to transfer (number of transfers) / uncertainty;
- Frequency / headway;
- Number of destinations;
- Distance;
- Time (total journey time and in-vehicle time);
- Reliability.

The changes on each of these aspects can reflect into advantages or disadvantages from the individual perspective. Regarding the referred model (and its assumptions), this section presents an analyses of the potential changes on each aspect with the introduction of interchange and whether these have positive or negative effects on personal perceptions.

The need to transfer (or the number of interchanges in case of multiple interchange situations) is the most obvious change introduced by interchange. For each interchange introduced into a transport network, several passengers are obliged to transfer, losing their former direct service. If transfer is already necessary before, the change is simply of the number of needed transfers. In the theoretical model built for this thesis the case is of introduction of interchange within a network where none exists. As has been previously said, transfer is almost always regarded as a negative feature within a journey, when considered separately from the net effects it produces. Focus group and in-depth interviews conducted for the project “Interchange and travel choice” [Wardman et al., 2001] confirm this negative view people have about transfer. So does Wardman’s (1983) study of the most disliked aspects of interchange for inter-urban rail, for which 16% chose “having to move”. Clearly any increase in transfer number will create an obvious disadvantage from individual perspective. This, by itself, is a considerable drawback within the public transport service. Associated to this there is a potential growth in uncertainty, related to the doubt about the presence of the necessary

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6 Some of them had already been identified in the analysis of the theoretical model from the customer’s perspective; the others cannot be identified through the model but are directly related with those aspects and also influence personal decision.
CHAPTER 2: THEORETICAL ANALYSIS OF INTERCHANGE

connection at the transfer point. This is also considered as a disadvantage from individual perspective. Focus groups interviews conducted by Wardman et al. (2001) found that serious consequences are expected when connection is missed or fails. Concerns about catching the wrong train or missing the connection were rated 5th and 6th (with 9% and 7% of interviewed respectively) as the most disliked aspects of interchange for inter-urban rail [Wardman, 1983]. A study by MVA (1985) found missing a connection as the second worst aspect of interchange. A guaranteed connection is one of the important features to improve personal perception of interchange [Steer Davies, Gleave, 1998].

The introduction of interchange within a public transport network allows considerable transport resource savings from the operator’s perspective. The analyses of the theoretical model shows that the same service can be provided with considerably less vehicles within an interchanging network than within a direct service network. Being so, the introduction of interchange within public transport networks enables considerable gains in transport service without representing an extra effort for transport operators. Consequently, interchange introduction, enables frequency increases (reduction of headways) and/or network expansion, rising the number of destinations. Although operators may decide to reduce frequency or even network size these reductions are independent of interchange potentialities and solely a result of company strategy. Even so, interchange gives operators the potential of rising service levels without extra charge. Frequency is considered as one of the most important features to grant public acceptability of interchange [Steer Davies, Gleave, 1998]. One of the top priorities of bus service to improve experience of interchange should be frequency, since lack of frequency is one of the major barriers to interchange [Oscar Farber, 2000]. Focus groups interviews about interchange and the influence on travel mode choice found that interchange works reasonably when there is good frequency of service and connection to a large number of destinations [Wardman et al., 2001]. The London Transport Planning study of interchange outside central London (1997) found that the number of interchange movements in this area at National Rail Network stations was smaller then the number of interchanges to underground service because of higher frequencies in the underground system and because this system provided greater number of destinations in the central area. This clearly shows the considerable
advantage higher frequency and larger public transport network systems would bring from the individual perspective. These advantages may potentially be introduced due to interchange implementation.

Another aspect that suffers changes with the introduction of interchange is travel distance. The model shows a potential increase for this aspect. Within the regular condition of the theoretical model travel distance with interchange is always higher or (at least) equal to that within the direct service network. Within real conditions this may not be the case, since the public transport network is dependent of road infrastructure layout and the introduction of interchange may allow better combination of path choice and therefore contribute to travel distance reduction. Even so, the potential of interchange introduction is of travel distance increase (even though exceptions may occur). The increase of distance is only a potential disadvantage from the individual perspective. Since public transport users pay for transport service and do not use their own transport resources, they are not concerned with there in-vehicle travel distance but with the time spend travelling. As these aspects are directly related it is more relevant, from the individual perspective, to analyze travel time change with the introduction of interchange than travel distance.

Within the theoretical model, as speed is considered constant, in-vehicle time is proportional to travel distance and therefore presents equal variations. Within these conditions, the model shows that in-vehicle time is always higher or (at least) equal to that within the direct service network. Naturally that in a real situation (were conditions are not homogenous) this may not always be the case and interchange may introduce reductions in travel time, due to the transfer to a faster service. More important than in-vehicle travel time is total travel time since it presents the real time spent from the origin to the destination of the journey. Time spent traveling is generally considered as a disutility of personal use of time, it is normally an unproductive time. Total travel time consists of in-vehicle time, waiting time and transfer time (in case of need for interchange). From the analysis of the theoretical model was shown that in-vehicle time, within the presented conditions, is always higher or equal to that of the direct service network; no transfer time was considered because the interchange facility was a point; waiting time could have any possible evolution (increase or decrease) within a context
of headway reduction with interchange introduction. Within this model, variation of total travel time depends on the variation of in-vehicle time and the headway. Although in real conditions travel distance tends to grow with interchange introduction, total travel time may present decreases (even without introduction of faster transport means) due to waiting time reduction enabled by headway reduction. A 50% reduction in high headways can produce considerable waiting time reductions. Nevertheless, if in-vehicle time is very large, relatively to waiting time, this may have low influence on total travel time. On the other hand, if in-vehicle time is short this may have very considerable influence on total travel time. Within individual perspective, time increase is considered as a disadvantage at the same time that time decrease is considered an advantage. MORI (1995) concluded that journey time reduction is one way to obtain increase in bus use. This means that time reductions are positively perceived by public transport users. Even so, a stated preference survey conducted by Gunn (2001) found that “[…] small time savings seem not to be valued”. Interchange potentially produces increase or decrease of total travel time, which may reflect in advantages or disadvantages from individual perspective if variations are considerable.

Reliability is another aspect on which interchange introduction can have influence. “The most usual reference of reliability is to possible late arrival, spending longer in certain activities than desired or expected” [Bates et all., 2001]. The theoretical model showed a potential reduction of transport routes length because of interchange introduction. This reduction can have a potential beneficial effect on reliability of transport service. It is believed that shorter routes are easier to manage and that this makes transport service more reliable and less exposed to condition that can cause unexpected delays. “Long […]” routes “[…] are likely to be unreliable in terms of schedule adherence” [Ceder et all, 1998]. Focus groups interviews about interchange and the influence on travel mode choice showed that when interchange is necessary, reliability is seen as extremely important [Wardman et all, 2001]. The same conclusion was reached by Bates et all. (2001) through its own case study and its literature review. Being so, reliability is very highly rated from the individual perspective. Mori (1995) concluded that the increase in reliability was the most effective way of increasing bus use.
Concluding this evaluation of the potential changes on several aspects influencing personal decision of transport mode choice, which were found to be, potentially, caused by the introduction of interchange in public transport networks, the following figure summarizes the main potential advantages and disadvantages produced.

![Diagram showing advantages and disadvantages of interchange](image)

**Figure 2.4:** Potential advantages and disadvantages of the introduction of interchange from the individual perspective

Although these potential advantages and disadvantages are relatively clear the effects these have on public transport demand is harder to identify. To draw conclusions about interchange effect on public transport demand, an analysis of the balance between advantages and disadvantages from the individual perspective is needed. The effect on public transport demand clearly depends on two main conditions:

- the degree of each advantage and disadvantage caused by interchange introduction within real conditions of transport network;
- the relevance of each of these aspects from the individual perspective.

The first condition depends on operator strategy for transport service (the use of transport resources saved through interchange introduction defining frequency and network gains to offer costumers) within the context of urban transport integration and also on the combination of different transport operators’ strategies within a global
public transport integration strategy. The second condition depends on personal perception of different interchange features and these can vary considerably with different characteristics like, gender, age, trip purpose, availability of private car, etc. It is therefore rather difficult to establish theoretical analyses for each condition. Being so, there is clearly a mutual influence of the operator and individual perspective on public transport demand. The following section provides a discussion of the theoretical possibilities for each condition and on how these can influence each other and the outcome of public transport demand on a real situation.

2.5. Discussion of the effect on demand

Several case studies and empirical studies have been conducted in order to identify personal perception of interchange and further understand individual reaction towards its introduction within public transport networks. These are, obviously, dependent on local conditions, as for example, public transport conditions or transport habits, and on the conditions in which case studies were conducted. Several studies present interesting results of the relative importance of some of the aspect influencing personal decision of the use of public transport with need to transfer. Table 2.5 summarizes some of the results of case studies and empirical studies found in the literature.

The need to transfer (or the number of transfers) was found to be an important aspect within personal perception of interchange by Wardman (1983), this being the third most disliked aspect within inter-urban rail. Associated to transfer need, people face uncertainty of having a connection at the interchange point that may allow the completion of their journey. Besides Wardman (1983), MVA (1985) and Steer Davies, Gleave (1998) also found this aspect as being one of the most important, through their studies. Wardman’s and MVA’s surveys revealed that the missing of the connection at the interchange point was one of the major concerns for public transport users. The uncertainty of connection missing is related with the last of the analysed aspects – reliability. If there were total reliability there would be no reason for uncertainty, the arrival and departure time at each interchange would be exactly as predicted and therefore no connection that could be caught would be missed because of transport service circumstances. Steer Davies, Gleave’s considers guaranteed connection as an
Table 2.5: Summary of the main results of case studies and empirical studies about the personal importance of some aspects influencing demand of public transport

<table>
<thead>
<tr>
<th>Author</th>
<th>Study</th>
<th>Main results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wardman (1983)*</td>
<td>Most disliked aspects of interchange for inter-urban rail</td>
<td>- luggage handling 22%; - waiting time 20%; - having to move 16%; - concerns about a seat in the second connection train 15%; - concerns about catching the wrong train 9%; - missing the connection 7%.</td>
</tr>
<tr>
<td>MVA (1985)*</td>
<td>Attitudes towards various aspects of interchange</td>
<td>- Worst aspects were: - Waiting 37%; - Missing the next train 25%; - Frequent users were more concerned with missing connection than with waiting time.</td>
</tr>
<tr>
<td>MORI (1995)*</td>
<td>Evaluation of the relationship between actual and expected performance of different aspects of bus service</td>
<td>How to improve service in order to increase bus use (by decreasing importance): - More reliability; - Journey time reduction.</td>
</tr>
<tr>
<td>Steer Davies, Gleave (1998)*</td>
<td>Evaluation of the obstacles to seamless travel</td>
<td>Important features for good interchange: - Guaranteed connection; - Frequency.</td>
</tr>
<tr>
<td>Oscar Farber (2000)</td>
<td>A new perspective on public transport interchange</td>
<td>Two of the fundamental factors about bus service that can change interchange experience and can also improve modal shift are: - Frequency; - Reliability.</td>
</tr>
<tr>
<td>Bates et al. (2001)</td>
<td>Study of the valuation of reliability for personal travel</td>
<td>“Many qualitative and attitudinal studies of travel choice behaviour have found that punctuality, reliability and dependability of transport systems are rated by users as very important features [...]”</td>
</tr>
</tbody>
</table>

Importance of travel aspects:

<table>
<thead>
<tr>
<th>[Column %s]</th>
<th>Bus</th>
<th>Train</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Column %s]</td>
<td>A  D Rank</td>
<td>A  D Rank</td>
</tr>
<tr>
<td>Journey is quick (total travel time)</td>
<td>85 2 13ths</td>
<td>90 &lt;1 12ths</td>
</tr>
<tr>
<td>Service is fast (in-vehicle time)</td>
<td>87 1 10ths</td>
<td>90 &lt;1 11ths</td>
</tr>
<tr>
<td>Service is frequent (frequency / headway)</td>
<td>96 1 2nd 97 2</td>
<td>2nd</td>
</tr>
<tr>
<td>Service is on time (reliability)</td>
<td>97 1 1st 97 3</td>
<td>1st</td>
</tr>
</tbody>
</table>

Legend: A – Agree; D – Disagree.

* This references were found within the publication “Interchange and travel choice” (Wardman et al., 2001)
important feature for seamless travel, and therefore, good interchange. Another aspect considered important by this author is service frequency (or headway). Oscar Farber (2000) also found this to be one of the fundamental factors of bus service influencing personal perception of interchange. A survey performed by Wardman et al. (2001) showed this to be the second most important aspect of public transport service (more than 95% of the interviewed agreed this to be an important aspect)\(^7\).

Although Wardman et al. (2001) and London Transport Planning (1997) studies clearly show the considerable advantage higher frequency and larger public transport network systems would bring from the individual perspective, there was found no prove of the importance of the number of destinations served by public transport, from individual perspective. This might be due to lack of analyses of the aspect or simply because this aspect was not included in personal importance surveys, for the analysed references. An indirect prove of the importance of this aspect is the generalized idea that the number of possible origin/destinations is one of the arguments used in defence of the intense use of the private car. Integration aims to make public transport experience similar to car travel (solving some of its limitations as for example, lack of flexibility and accessibility) through a wider variety of origin/destinations possibilities. This transport policy aim, by itself, supports personal importance of the number of destinations.

Travel distance is another aspect that was not found within the analyses of importance. In this case this may be due to real lack of importance of travel distance from the costumer’s perspective, as has been argued in the former section when presenting the discussion of the advantage or disadvantage of travel distance variation. Public transport costumers are usually concerned about travel time instead of travel distance. There are several examples of studies finding this to be one of the most important aspects for personal perception of interchange, as in Wardman (1983), MVA (1985), MORI (1995) and Wardman et all. (2001). The first two found a classification of first and second most important aspect of interchange, respectively, for waiting time, which is an important part of total travel time, and in the case of the model of section 2.2, makes the difference between total travel time and in-vehicle time. MORI’s evaluation revealed

\(^7\) Although importance of this aspects generally drops when it reaches high values, it is always a very important aspect from individual perception, on the other hand, growth of frequency are considerably less valued in this situation. This has to be taken in consideration in the evaluation of the effect on demand.
journey time reduction as the second most important aspect to improve bus use. The importance of total travel time and in-vehicle time was evaluated by Wardman et all. through a large scale survey inquiring the agreement of passengers with the importance of fastness of transport service and quickness of journey, respectively. Although in this analyses these aspects retained the 10th and 13th place (for bus service) within the most important aspects, it is relevant to notice that these were achieved with more than 85% of interviewees agreeing with its importance (for the bus service and 90% for the rail service).8

In this same survey, Wardman et all. found that reliability was the most important of the analysed aspects within public transport service with 97% of the interviewed agreeing that it was important that the service was on time. The focus group surveys conducted for the same study reached the conclusion that, when there is interchange, reliability is seen as extremely important. MORI (1995), Steer Davies, Gleave (1998), Oscar Farber (2000) and Bates et all. (2001) found this aspect to be of utmost importance to public transport users and that its increase could considerably enhance personal experience of interchange9. The increase in unreliability rises total travel time, through the increase of the relative percentage of waiting time towards in-vehicle time (since reliability reflects only on waiting time). This distortion is even more ill perceived then general increase in total travel time [Rietvelt et all., 2001].

It is important to take into consideration that all the referred aspects are not independent from each other. For instance, Rietveld et all. (2001) found that reliability is even more important when frequencies are low, avoiding rise in uncertainty due to high headways. The same study defends that “most public transport travellers are rather risk-averse” since within a questionnaire to evaluate transport reliability the majority preferred the certain alternative to the faster alternative. Oscar Farber (2000) argues that a reliable and frequent service reduces uncertainty of connection, and that simply increasing frequency reduces many of the problems traditionally associated with interchange.

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8 As with frequency, the importance of travel time tends to drop as better values are offered by the public transport service although it remains a very important aspect. “[…] small time saving seem not to be valued” [Gunn, 2001]. This also has to be taken in consideration in the evaluation of the effect on demand.

9 In case the journey involves the use of two (or more) public transport means with different service reliabilities, from the costumers point of view, the most reliable should be on the first trip of that journey so that connection at the interchange point would not be put at risk.
Nevertheless it is important to notice that the positive effect of frequency increase on personal perception depends also on the existing frequency, i.e. if there are already very low headways a further rise in frequency will have limited effect.

Besides being dependent of each other, the personal perception of these aspects may also vary with personal or trip characteristics. For example, MVA (1985) study found that frequent users were more concerned with missing a connection than with waiting time, although the same study showed that the latter was generally considered as more important than the former.

Although these results are only valid within the context in which they were achieved and even though there can be no conclusion about their relative importance, these results can clearly show the importance of most of the aspects that were identified, within the former section, as being the most important aspects potentially changed by interchange introduction within public transport networks and influencing personal decision. Being so, and with exception of travel distance it is fair to conclude that the other aspects, on which interchange induces changes, are clearly of importance for public transport users. The question about their relative importance remains and can only be answered for real situations, through the use of surveys. For these to produce the most real image of the truth, special care must be given to its construction so that all relevant aspects are analysed.

Surveys are than the ideal way of defining the relative importance of the aspects influencing individual perception of interchange for different local circumstances. They should also evaluate relative importance of the potential improvements interchange introduction may produce on each aspect. Nevertheless, knowledge of personal importance of each of the aspects changed by interchange introduction is not enough to correctly define a prediction for the impact on demand that interchange may produce. For this there must also be information about the operator’s strategy on interchange, especially on the degree of change operators will introduce on each referred aspect. Being so, operators indirectly influence the effect interchange has on demand through decisions of use of transport resources saved because of interchange introduction. Both stakeholders, operators and individuals, have an important influence on transport demand results, with the public transport operator being the potential decision maker.
Figure 2.5: Mutual influence of individual and operator stakeholders

In this context, public transport operators have the power to calibrate their transport strategies in respect to expected demand. These decisions can be made by “trial and error” or be informed decisions. In the first case the operator may try different changes in the transport system within interchange and evaluate results on demand, making small adjustments to its strategy along time, until the optimum is achieved. Although this is widely used by public transport companies, mainly for slight changes, it bares the risk of uncontrolled effect on demand for changes as considerable as the implementation of an interchange. On the other hand, operators may base their transport strategy, with interchange, on predictions of costumer reactions, being able to make informed decisions. This may be attained through the construction of demand models relating changes in public transport service with personal perception towards these changes and the consequent reflex on demand. The construction of these models, although time and money consuming, can be of extreme use for the public transport operator to test the effect of its transport strategies on demand and therefore be able to identify the best strategy. This knowledge can provide operators with efficient tools in maximizing their benefits through interchange introduction.

As has been discussed, interchange must be analysed within the network it creates. “[…] the quantitative research has tended to concentrate on a relatively small number of measurable attributes such as walking time and waiting time, and the interchange penalty itself […]” this “[…] clearly leaves many gaps” [Oscar Farber, 2000]. From the network attributes that are changed by interchange introduction those presented in Figure 2.6 are the most relevant influencing personal travel decision. These should be the characteristics used for the production of an effective model for travel demand
prediction. This model must be calibrated for local personal perception of each of these attributes. It is important to refer that this calibration must be a continuous process, i.e. personal perceptions vary, not only with local condition, but also with time; being so, there must be continuous adjustment of the coefficients through periodical surveys.

![Diagram](image)

**Figure 2.6:** Relevant network attributes influencing personal travel decisions with interchange

For there to be a guarantee of positive effect on demand, the decision maker – the operator – must seek to clearly understand the trade-off between the optimization of network resources through interchange introduction and the reinvestment of these resources.

### 2.6. The effect of interchange on Urban Mobility

Having analysed the effects of interchange introduction from the perspective of both urban mobility stakeholder and their mutual influence, an analysis of the effect on urban mobility is required. Their are potential gains and losses for each stakeholder due to interchange introduction and although they can potentially benefit from interchange, if from the individual perspective losses are higher than gains, interchange, as a contribution for the solutions of urban mobility problems, is condemned to failure. In case of a negative balance between advantages and disadvantages introduced by interchange in public transport service, a consequent demand decrease is expected. This is necessarily negative for public transport operators, within the context of public service (although it could still mean a raise in profit). Consequently, the expected modal
shift towards public transport would have failed, without which interchange introduction would be responsible for a negative effect, on urban mobility since problems would only have been aggravated. Being so, it is of the utmost importance to grant a positive balance for the individual perspective and this must be considerable for there to be positive effect on demand of public transport. In case there is only a slight positive balance the positive effect expected for urban mobility may be extremely limited.

The individual is the key level of analysis of the success of interchange introduction. It is the balance between the advantages and disadvantages, introduced by interchange in public transport service that will define the global positive or negative effect of interchange for every urban mobility stakeholder considered for the analysis of this thesis and for urban mobility itself. Although the individual is the key element in the integration process, the decision maker of interchange introduction is the operator\textsuperscript{10}. Passengers react to the changes in public transport service but these are decided by the public transport operators. Their transport strategies together with individual perceptions of them will dictate the success or failure of integration objectives. Being so, it is of the utmost importance that transport strategies are based on the knowledge of individual perception which can be acquired through large scale surveys. Within the scope of this thesis (see Figure 1.2) the most relevant network features influencing personal travel decision with interchange are those presented in Figure 2.6. These should be taken in consideration, jointly with individual perception of them, by operators in the definition of their transport strategies. To be able to define an informed transport strategy, operators can resort to demand models, based on the characteristics presented above.

The analysis developed in this chapter clearly shows that interchange presents many potentialities, besides the well known limitations. It should therefore, not simply be regarded as the need to transfer (with extra effort, waiting time and walking time) but be analysed within network efficiency gains, knowing that these changes can have positive effect for costumers and operators and contribute for the solution of current mobility

\textsuperscript{10} In case local transport authorities exist, these will also have considerable responsibility in decision making in regard to interchange introduction and consequent transport strategy.
problems. This chapter shows the existence of potential advantages of interchange for all stakeholders, when public transport strategies are well defined.

The first barrier to overcome is the general ignorance of these potential advantages. If interchange is to be successfully implemented, stakeholders must firstly understand their potential gains and losses, to be able to correctly perceive public transport changes. Only then can higher acceptability be expected from operators and individuals. Even so, this is no guarantee interchange will be successfully implemented.

Macário (2004b) argues that considerable initial effort is demanded from public transport operators, which is why they do not usually take the initiative of interchange implementation in spite of expected gains\(^{11}\). Being so, there is need for an initiative from the global or local authorities.

\(^{11}\) For operators to take initiative of interchange introduction in their public transport network, they would have considerable cost in, for example, construction of interchange facilities, new ticketing systems, integrated information systems, etc.
Chapter 3

Case Study

Although knowing the importance of interchange for urban transport system integration as a potential contribution for the solution of urban mobility problems, it is reasonable to believe that there is a preference for direct journeys. Nevertheless, statistics show considerable variability in the use of interchange within urban journeys, for example Munich and London present almost 50% of passenger journeys with at least one interchange while Manchester and Porto, for instance, present less then 10% [GUIDE, 2000; INE, 2000]. These figures indicate that, although believed to have low acceptability, interchange can still be highly used within urban transport systems. Interchange should even be regarded as an opportunity within urban mobility, knowing of the existence of successful examples of urban transport integration and their potential benefits.

It is therefore essential to understand personal perceptions of, and attitudes towards interchange within public transport. The former numbers show clearly that the proportion of passengers interchanging during a journey vary considerably according to local conditions, therefore, it is reasonable to believe that so does personal perceptions of, and attitudes towards interchange. Being so, case studies are essential to examine local conditions for interchange.
In the last years several case studies have been conducted by initiative of urban transport operators. Unfortunately most reports have limited public access or are restricted to company use. Although some interesting studies have been conducted there is limited information exchange making it difficult to reach broader conclusions about this issue. There is also a lack of scientific studies.

The case study presented in this chapter, besides being very important for the public transport operator involved, strives to be a contribution for this study area. The aim is to study personal perceptions of, and attitudes towards interchange within a particular case of public transport and discuss how these should influence operators’ decisions on transport service in order to take advantage of interchange potentialities.

This case study was of the initiative of the public transport operator STCP. It was ordered to the consultant TIS.pt (“Transportes, Inovação e Sistemas, S.A.”). I offered my cooperation in this project, having worked under the coordination of Faustino Gomes (TIS.pt). The surveys were carried out by the firm “2ii Informática & Informação Lda”, under the coordination of Francisco Ourique.

![Diagram](image)

**Figure 3.1:** Research Project Team

### 3.1. The case study

This case study took place in Porto, the second largest city of Portugal, the most occidental country of Europe. It is the central city of the Metropolitan Area of Porto (MAP) composed by nine municipalities (represented in Figure 3.2) with a total area of 815 km² and 1256 million people.
Figure 3.2: Europe, Portugal, Metropolitan Area of Porto

This case study centres on the evaluation of passengers’ perception of interchange, before and after interchange introduction onto a bus route, and of their attitudes towards the introduction of interchange. It involves a simple case of interchange within mode and within operator (having no particular need for coordination of service or management issues). The public bus operator is the STCP (Sociedade de Transportes Colectivos do Porto, STCP, S.A.) which is the public road transport company of Porto. This operator served a total of over 200 million people in 2003, in 6 of the 9 municipalities of the MAP, with a total network length of almost 500 km having a high network density in the central city; this density is considerably lower in the 5 surrounding municipalities that the operator serves.

3.1.1. Relevance of the case study

In recent years public transport has suffered considerable market share losses within the MAP, which in the last decade reached 20% [STCP, 2004]. The metropolitan area and its inner city have shown considerable reduction in public transport modal share from 1991 to 2001, although these have been higher in the metropolitan area than in Porto.
Figure 3.3: Public transport modal share for Porto and its metropolitan area in 1991 and 2001.

According to STCP (2004), several aspects have contributed for this situation, as for example:

- Motorization growth;
- Lack of coordination and planning of the transport system;
- Drop in commercial speed;
- Lack of articulation between operators;
- Excessive number of public transport operators (three public operators and 24 private operators).

The MAP is currently facing important changes within its mobility system because of two main factors, the creation of the Metropolitan Transports Authority (MTA) and the introduction of a new public transport mode – the light rail. The MTA is expected to coordinate the different transport modes in the MAP, managing urban transport integration. The light rail is introducing a revolution in the urban transport system of this metropolitan area being a structuring project for the urban transportation system. A functional rearrangement of the existing transport modes is required, within the new context of integrated transport system. This change within the public transport system is expected to provide higher service quality, economic efficiency and benefits for urban mobility.
The MAP public transport system is constituted by three subsystems (see Figure 3.4):

- Road public transport: public operator – STCP; private operators (a total of 24 operators);
- Heavy rail: public operator – CP (USGP);

**Figure 3.4**: Public transport public operators of the MAP.
The routes of the public operators are represented in Figure 3.4. The private operators transport routes are spread throughout all metropolitan territory. There is a generalized excessive competition within public transport operators and lack of cooperation [CMP, 2002].

The light rail service is not yet fully operational. Only the east-west route was opened until now. The rest of the routes are expected to be operational until the first semester of 2006. The routes presented in Figure 3.4 are only those of the first stage of the light rail system. A second stage is already planed, which will include more municipalities of the MAP.

As all other public transport operators STCP will have to adapt to the new public transport structure, preparing for transport integration. Therefore STCP has started a process of structural adjustment, in order to be prepared for the new challenge of integration. This operator expects a demand reduction due to light rail operation and for that reason started a process of network restructuring in 2003 with the following aims: higher frequencies; integration with the new light rail network; higher rationalization of the network [STCP, 2004].

Besides the need for network restructuring, all public transport operators will have to prepare for new operating conditions, as for example, a new and global ticketing system, coordination of service and timetables and complementary service instead of competition. Within the several studies and measures taken by STCP, the present case study was ordered with the objective of evaluating the effect of the introduction of interchange on its network, with special attention to the consequences on demand.

The present case study involves solely some routes of the STCP network, as described in the next section.

3.1.2. The routes

This thesis case study involves interchange within the same mode (Intramodal Interchange within public transport), the bus, and within the same operator, the STCP. The routes proposed for this case study were routes number 38 and 14. As represented
in Figure 3.5, these routes share part of their course between the Hospital “S. João” (HSJ) and “Sª da Hora” (SRH).

![Figure 3.5: Routes number 14 and 38](image)

Information Source: STCP

Route 14 operates between “S. Pedro da Cova” (SPC) in the municipality of Gondomar and “Rotunda do Castelo do Queijo” (RCQ) at the coast site of Porto. Its course has an important length along “Circunvalação”, which is a ring road involving Porto from the northern and eastern side. It is a very long route with approximately 19 km. “Castelo do Queijo” is near the beach and the urban park of Porto. It is therefore an important tourist and leisure destination. “S. Pedro da Cova” is essentially and urban residential area.

Route 38 operates between “Campanhã” (CAM) and “Srª da Hora” (SRH), passing through “Hospital de S. João” (HSJ), like route 14. These are three important centers of the MAP. “Campanhã” is the most important rail road station in Porto, where all rail traffic concentrates. It is therefore a very important interchange point between heavy rail, light rail, bus and individual transport in Porto. In “Srª da Hora” it is possible to find a variety of different land uses from residential use to industrial, warehouses and large commercial areas. It has also one of the major light rail stations, were three routes diverge. “Hospital de S. João” is placed within one of the Porto University Campus. Besides several Universities and Faculties of Porto University it holds also the largest hospital of the northern region of Portugal and presents a fast growing residential use. It also presents a large bus stop facility used by several routes (from the STCP and other private operators).

Figure 3.5 shows a clear duplication of operational effort along the overlapped course, between HSJ and SRH. Interchange was used to end this duplication, cutting route 38 at HSJ and leaving only its southern part. Being so, it is now necessary to interchange at HSJ transferring from route 38 to 14 or vice versa in order to travel between CAM and
SRH. Figure 3.6 and Figure 3.7 show a schematic representation of routes 14 and 38 before and after the introduction of interchange. Route 38, was cut at HSJ leaving only the course between CAM to HSJ. For route 14 to substitute route 38 between HSJ and SRH, a detour of its original course was necessary (for it to pass SRH). Route 14 was also cut at “Lidador” (LDD), reaching RCQ only during summertime. Besides the reduction in length, route 38 was also given higher frequencies of bus service, increasing from one bus each 20 minutes to one bus each 12 minutes at peak traffic hour (for off-peak traffic hour the frequencies remained equal).

**Figure 3.6:** Before introduction of interchange  

**Figure 3.7:** After introduction of interchange

At this point, it is important to refer some passenger statistics of route 38, which is the only route were direct service is lost and, therefore, the route were direct effect on demand can be measured. The total number of passengers of route 38 has been increasing in the last few years. There is higher rate of passengers of route 38 on the section between CAM and HSJ than on the section between HSJ and SRH, but this difference has been decreasing in the last years. The number of passengers passing HSJ has also been increasing jointly with the total passenger growth, keeping a percentage between 10 and 20% of total passengers on route 38. As HSJ is the chosen interchange point only this rate of passengers can be negatively affected by this change. For the remaining passengers transport service will be improved due to frequency gains.

It is important to notice that this case study did not have the need for especial efforts for network coordination because the operator involved in both routes is the same, neither for through ticketing because STCP had already been implementing a new ticket system, based on zones and not on entry and exit of a particularly route or bus. This way, clients would not have to pay a new ticket to change bus at HSJ.
A simple analysis of the STCP network helped identify two other routes that should be taken into account for this case study because of its course similarities to route 38. These routes are number 6 and 88, which are presented in addition to routes 14 and 38 in Figure 3.8.

![Map of the routes involved in the case study](image)

Information Source: STCP

**Figure 3.8:** Map of the routes involved in the case study

As route 88 is overlapped with route 14 in the section in which route 14 will substitute route 38 this would make the choice between these two routes indifferent for former users of route 38, were it not for:

- the different ticketing system used by route 88 (that will, even so, be accepted as through ticketing by route 38);
- the fact that the bus stop for route 88 at HSJ, in direction SRH, is on the opposite side of that for route 14 and of the arrival stop of route 38 coming from CAM (see Figure 3.10);
- the fact that route 88 does not have a detour to grant transport to SRH.

Route 6 was included in the case study since a major part of its course is coincident with that of route 38 from CAM to HSJ. Being so, many users of route 38 could change to route 6. This was already possible before route 38 was cut at HSJ but knowing that costumers were now obliged to transfer at HSJ to continue their journey to somewhere
between HSJ and SRH, there was higher probability for former users of route 38 to choose route 6, because now in both routes their would have to be an interruption in the journey.

As a result of the former evaluation, the routes analyses for this case study were routes 6, 14, 38 and 88. No other STCP route had sufficient similarities with any part of the route 38 between CAM and SRH that was worth studying.

The interchange point

The analysis of the interchange point is essential to understand interchange conditions in HSJ. Figure 3.9 shows a picture of the interchange facility at HSJ (viewed from the southern side). Figure 3.10 shows a scheme of the same interchange facility with a representation of the points of interchange of each route involved in this study and the necessary interchange walking distances.

**Figure 3.9:** Picture of HSJ interchange point

This is a large “on-street” interchange facility, having several bus stops, mainly from the public operator – STCP – and some from private operators. This interchange facility allows interchange within the bus service (Intramodal Interchange), be it within or
between operators, and access to the bus network. With the expansion of the light rail network this interchange will also enable intermodal interchange.

The major part of this interchange is located between the avenue “Circunvalação” and the Hospital of “S. João”. Buses travelling in direction east-west pass the interchange facility on the southern side, those with the opposite direction pass the interchange facility through the “Circunvalação”. There is also a smaller interchange facility (a simple bus stop) on the east-west direction of the “Circunvalação”. This bus stop serves routes with direction east-west and continuing on the “Circunvalação” after this bus stop, this way buses do not have to make a detour around the interchange in order to stop on the southern side of the HSJ interchange facility. This bus stop is only used by few routes; one of them is route 88 in direction towards RCQ.

![Diagram of interchange facility of HSJ](image)

**Legend:**
- Red circle: Bus stop for departures of passengers of route 38; and number of route
- Blue circle: Bus stop for arrivals of passengers of route 38; and number of route
- Red square: Arrival and waiting site of buses of route 38
- Black square: Pedestrian crossing with traffic lights
- Red arrow: Direction of traffic movement
- Blue arrow: Transfer movements for costumers of route 38 in direction CAM
- Pink arrow: Transfer movements for costumers of route 38 in direction SRH

**Figure 3.10:** Scheme of the interchange facility of HSJ

Figure 3.10 presents bus stops for arrival and departure of former users of route 38 in blue and pink, respectively. Arrivals and departures can be divided into those passengers coming from or going to CAM (routes 6 and 38) and those coming from or going to SRH (routes 14 and 88).
Interchange conditions at HSJ are not ideal. Figure 3.10 shows that arrival and departure are always distant from each other. For example, when arriving from SRH with route 14 or 88, passengers have to cross more than half of the interchange facility to get to the departure bus stop of route 6 or 38. This walking distance is of about 45m. When travelling in the opposite direction the situation is even worse, mainly because passengers can not chose to get the first bus that arrives (between route 14 and 88) because the bus stop of route 88 is on the other side of “Circunvalação” and the bus stop of route 14 is on the southern side of the HSJ interchange facility, and therefore someone waiting at the interchange point of one route would never be able to reach the bus stop of the other route if this bus arrives earlier. Costumers can not really choose the first arriving bus; they have to previously decide on which side to wait. Although walking distance is not long for those interchanging with route 14 it is dangerous for those choosing to interchange with route 88 because of the need to cross an avenue with high traffic flows. For those going to SRH only route 14 is available since route 88 does have no detour to pass there. In regard to all this aspects, although route 88 is an alternative to route 14, for former users of route 38 in making the journey from HSJ to SRH, it is not a real alternative, presenting many limitations to its use for this purpose.

Between route 6 and 38 the differences in interchange condition are not relevant, the major difference is in their courses since route 6 is not entirely overlapped with route 38 (route overlap reaches approximately 70% of route 38).

Characterization of the involved routes

The routes involved in this study have lengths between 14 and 22 km, the smallest of which is route 38 (see Table 3.1). The four routes present headways between 10 and 20 minutes for peak traffic hour and between 15 and 20 minutes for off-peak traffic hour. Route 6 presents the highest frequencies while route 38 has the lowest service level.

For the introduction of interchange the operator chose to change the total length of both routes directly involved (routes 14 and 38). In case of route 38 the length is reduced to approximately half of its value before interchange was introduced. The total length of route 14 was extended because of the detour to pass SRH, but only during the summertime. For the rest of the year it does no longer reach RCQ having been cut at
“Lidador” (LDD), near SRH, slightly reducing its length in comparison with its original value. Besides changes in total route length, the operator decided to improve the headway of the remaining section of route 38 during the peak traffic period, from 20 to 12 minutes.

**Table 3.1:** Some operational characteristics of routes involved in the case study, before and after interchange introduction

<table>
<thead>
<tr>
<th>Route</th>
<th>6</th>
<th>14</th>
<th>38</th>
<th>88</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before introduction of interchange</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak traffic hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headway (min)</td>
<td>12</td>
<td>10</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Average number of vehicles</td>
<td>6</td>
<td>12</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Off-peak traffic hour</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headway (min)</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Average number of vehicles</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Length (km)</td>
<td>14,524</td>
<td>20,827</td>
<td>13,975</td>
<td>21,665</td>
</tr>
<tr>
<td><strong>Changes with the introduction of interchange</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headway (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak traffic hour</td>
<td>-</td>
<td>-</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>Off-Peak traffic hour</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>Length (km)</td>
<td>-</td>
<td>23,340*</td>
<td>6,409</td>
<td>-</td>
</tr>
</tbody>
</table>

*During the summertime the routes continues reaching RCQ with a total length of 23,340km, during the rest of the year the route ends at “Lidador” (LDD) with a total length of 20,175km.

Information source: STCP

**Theoretical analysis of interchange introduction for this case study**

This theoretical analysis will simply be an application of the model developed in section 2.2 to the present case study; further analyses of the case study will be developed in the third section of this chapter.

This is a very simple case study of interchange introduction. No routes are detoured to reach the interchange point and only two routes are directly involved, route 14 and 38, although others can benefit and be indirectly involved. Being so, this theoretical analysis will be limited to routes 38 and 14 which were the only routes that suffered considerable changes: variation of route length and frequency.

This case study will be theoretically analysed within the same assumptions defined for the theoretical model developed in section 2.2.
Figure 3.11: Main routes characteristics before and after introduction of interchange (for the peak traffic hour)

The variation of the main variables, defined for network analysis of the theoretical model, is presented in the following table. Scenario 1 refers to the minimum headway and maximum frequency within constant total number of vehicles ($N_T$ Constant = 19 vehicles, with $N_T$ being the sum of the number of vehicles for both routes); Scenario 2 refers to the minimum total number of vehicles within constant values of frequency and headway for each of the routes.

General assumptions:

- Circulation speed is constant on each route before and after interchange introduction;
- Route 14 must maintain the service level presented before interchange introduction (headway and frequency are constant).
### Table 3.2: Network analysis – during the year

<table>
<thead>
<tr>
<th></th>
<th>Route 14</th>
<th>Original</th>
<th>Scenario 1 / 2</th>
<th>Route 38</th>
<th>Original</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>During the year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L [km]</td>
<td>20.8</td>
<td>20.2</td>
<td>14</td>
<td>6.4</td>
<td>6.4</td>
<td>6 (ΔL = -7.6 km)</td>
<td>6 (ΔL = -7.6 km)</td>
</tr>
<tr>
<td>N</td>
<td>12</td>
<td>12*</td>
<td>7</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H [min]</td>
<td>10</td>
<td>10*</td>
<td>20</td>
<td>10 (9,1; ΔH = -10.9 min; -55%)</td>
<td>20*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F [1/h]</td>
<td>6</td>
<td>6*</td>
<td>3</td>
<td>6 (6,56; ΔF = 3,56 /h; +118%)</td>
<td>3*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T [h]</td>
<td>2</td>
<td>1.94</td>
<td>2.33</td>
<td>1.07</td>
<td>1.07</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>V [km/h]</td>
<td>20.8</td>
<td>20.8*</td>
<td>12</td>
<td>12*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Summertime</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L [km]</td>
<td>20.8</td>
<td>23.3</td>
<td>14</td>
<td>6.4</td>
<td>6.4</td>
<td>6 (ΔL = -7.6 km)</td>
<td>6 (ΔL = -7.6 km)</td>
</tr>
<tr>
<td>N</td>
<td>12</td>
<td>14</td>
<td>7</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H [min]</td>
<td>10</td>
<td>10*</td>
<td>20</td>
<td>15 (13.8; ΔH = -6.2 min; -31%)</td>
<td>20*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F [1/h]</td>
<td>6</td>
<td>6*</td>
<td>3</td>
<td>4 (4,7; ΔF = 1,7 /h; +57%)</td>
<td>3*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T [h]</td>
<td>2</td>
<td>2.24</td>
<td>2.33</td>
<td>1.07</td>
<td>1.07</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>V [km/h]</td>
<td>20.8</td>
<td>20.8*</td>
<td>12</td>
<td>12*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Values that are kept constant relatively to its original value (before interchange introduction)

**Note:** The direct results obtained through equation 3.1 to 3.4 for the determination of headway and frequency are presented in brackets. Although the values between brackets present maximum increases or decrease for each variable, an approximate value is also presented (outside brackets) as being the most suitable for use in a real situation.

With,

\[ F = \frac{1}{H} \]  \[3.1\]

\[ V = \frac{2L \times F}{N} \]  \[3.2\]

\[ T = \frac{2L}{V} \]  \[3.3\]

\[ F = \frac{N}{T} \]  \[3.4\]
Table 3.3: Global variation of network length and necessary vehicles

<table>
<thead>
<tr>
<th></th>
<th>Total Length</th>
<th>Number of vehicles (scenario 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>34,8km</td>
<td>19</td>
</tr>
<tr>
<td>During the year</td>
<td>26,6km</td>
<td>16</td>
</tr>
<tr>
<td>Variation</td>
<td>-8,2km (-24%)</td>
<td>-3 (-16%)</td>
</tr>
<tr>
<td>Summertime</td>
<td>29,7km</td>
<td>18</td>
</tr>
<tr>
<td>Variation</td>
<td>-5,1km (-15%)</td>
<td>-1 (-5%)</td>
</tr>
</tbody>
</table>

For the first scenario (N - constant) and within constant circulation speed, it is possible to verify that, without an extra cost, the public transport operator could increase service frequency of route 38 in 57% during summertime and in 118% during the rest of the year (i.e. more than twice the original service frequency). This corresponds to a considerable reduction in headway for route 38 and a consequent improvement of its transport service levels. For the second scenario (F and H constant) and within constant circulation speed, a reduction of 16% of the necessary vehicles is possible, for the same service level in both routes, for most of the year. During summertime this reduction is of only 1 in 19 necessary vehicles. The introduction of interchange reduces total route length in approximately 5km, during summertime, and more than 8 km (24%) during the rest of the year.

The solution adopted by STCP was a new headway of 12 minutes for route 38 for which are needed approximately 6 vehicles\textsuperscript{12}. Being so, STCP opted for a combined solution between scenario 1 and 2, during the year with exception of summertime. The public transport operator chose a gain of 1 bus (decrease of 5% in necessary vehicles) and still provides a better transport service for route 38 (increase of its frequency in 66% and decrease of its headway in 40%). During summertime the solution implemented by STCP requires an increase in resources. To have 6 vehicles on route 38 the total number of vehicles rises to 20 which represents a 5% increase in necessary vehicle resources after interchange introduction. Because of the considerable increase in length of route 14 with the detour through SRH, for this route to maintain the entire course few transport service improvements can be introduced onto route 38 through network

\textsuperscript{12} STCP chose to keep all 7 vehicles on this route although the frequency only increased from 20 to 12 minutes. Consequence of this, two to three vehicles can be found waiting at the HSJ interchange point for their departure schedule. STCP is considering reducing one bus (maintaining the frequency).
optimization with interchange. STCP could only offer a headway of 15 minutes in stead of the 12 minutes currently in use on route 38. Being so, during summertime, the public transport operator has an extra cost to provide the defined transport service level\textsuperscript{13}.

For the theoretical evaluation of interchange introduction from the costumers perspective travel distance will be considered approximately constant. In vehicle time will also be considered constant (approximately 1 hour for the longest journey). Since travel distance is the same, in-vehicle time will be considered equal on route 38 and 14 for the same course\textsuperscript{14}. Being so, and from the aspects analysed for the theoretical model in section 2.2, only waiting time will suffer considerable changes. Since waiting time was considered as approximately half of the headway it would be of 10 minutes before the introduction of interchange. With the integration of route 38 on route 14 for the course between HSJ and SRH, former passengers of route 38 have now two waiting times. Being so, the total waiting time is equivalent to the sum of half of each of the routes headways. During summer time total waiting time would be of 12,5 minutes for the first scenario, and of 15 minutes for the second scenario. For the rest of the year these values would be of 10 and 15 minutes, respectively. In the second scenario, there is a growth in total waiting time in spite of a considerable reduction of headway on the section between HSJ and SRH, with the use of route 14. In the first scenario, total waiting time is theoretically maintained. Knowing that in this case study the public transport operator reduced the headway of route 38 to 12 minutes, theoretical total waiting time will be of 11 minutes; only 1 minute higher than before interchange introduction.

3.2. Methodology

With the construction of a light rail system in the MAP, public transport will suffer considerable structural changes. These will involve a full integration of STCP’s

\textsuperscript{13} It important to take into account that the extra effort to provide a 12 minutes headway during the summertime and the cut of the course section between LDD and RCQ, of route 14, are measures that are not imputed to interchange introduction and that therefore, can slightly deviate results of this case study.

\textsuperscript{14} Although average travel velocity is considerably different between route 14 and 38 it is evident that on the course on which these route overlap travel velocity must be similar to both routes. Being so, travel in-vehicle time for users of route 38 will be approximately the same before and after interchange introduction.
transport system with the new metro system. In order to evaluate the consequences of integration, STCP ordered this project with the objective of “studying the effects of the introduction of interchange on one of its routes in order to define its consequences on demand, within a reduced evaluation scale” [TIS.pt, 2003; free translation]. The objectives of the case study for this thesis have a wider scope. These will be presented in the following section.

3.2.1. Case study objectives

In order to complement the theoretical analysis of interchange introduction, conducted during the third chapter, the general objective of this thesis for the present case study is the comprehension of personal perception and attitudes towards interchange (for a particular situation) within the specific conditions of road public transport.

To achieve this objective two operational objectives were defined for this case study:

- **Operational Objective 1:** Evaluation of the relative importance and satisfaction level of several network features changed through interchange introduction.
- **Operational Objective 2:** Evaluation of the effect of interchange introduction on demand (forecasted and real).

Personal perception was analysed through the evaluation of the relative importance and the satisfaction level of several aspects of transport service. The latter brings understanding over the perception of transport service level of satisfaction and their evolution, comparing these with the real evolution of transport service features with interchange introduction. As has been discussed in section 2.5, the importance of each of the aspects changed by interchange introduction and that influence travel decision, from the individual perspective, can only be completely analysed within a real situation. This evaluation was made through questionnaires conducted to costumers but unfortunately did not evaluate the relative importance of all five aspect identified in Chapter 2, since these were identified subsequently to the design of the questionnaire (which occurred in a very early stage of this thesis).

To better understand personal attitudes towards interchange, an evaluation of the effect on demand was carried out. The prediction of the effect of interchange on demand was
evaluated through the gathering of stated preferences from current costumers. The real effect of interchange introduction was estimated based on some data variation of demand and the results of the surveys.

### 3.2.2. Chronogram

As has been referred, this thesis’ case study was part of a real study project from the initiative of STCP. Being so, Table 3.4 presents the chronogram of the main tasks of the study project.

This study project was ordered by STCP in August 2003. My cooperation started in October of the same year. The project started only in the beginning of the following year with a meeting of the study team with the public transport operator.

#### Table 3.4: Chronogram of the case study main tasks

<table>
<thead>
<tr>
<th>Tasks*</th>
<th>AUG</th>
<th>SET</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
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<th>MAR</th>
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<th>JUN</th>
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<td>□</td>
<td>□</td>
<td>□</td>
<td>Aug-2004</td>
</tr>
</tbody>
</table>

* Tasks:

1. Study ordered to TIS.pt by STCP
2. Beginning of my cooperation in the study
3. Meeting with the STCP to launch the study
4. Construction of the survey for the first phase (before interchange introduction)
5. Test of the Survey of the first phase
6. Surveys and count of passengers – 1<sup>st</sup> phase
7. Introduction of interchange and consequent changes
8. Construction of the survey for the second phase (after interchange introduction)
9. Surveys and count of passengers – 2<sup>nd</sup> phase
10. Statistical analyses of the data gather through both surveys
11. Construction of the final report for STCP
The main data gathering was carried out during the months from January to May. This was mainly based on surveys and direct passenger count. Two different surveys were developed for two different phases of the project, one to be conducted before the introduction of interchange – 1st phase – and the other to be conducted after interchange was implemented – 2nd phase. Both surveys were only for custumers of route 38\textsuperscript{15}. The introduction of interchange on route 38 and the consequent integration in route 14 was put in practice on the 28\textsuperscript{th} of February 2004.

The analyses of statistical data obtained from the surveys were done during the months of June and July of the same year, followed by the construction of the final report.

My main cooperation in this research project was in the construction of the surveys (which will be further presented in the following section) and the analyses of its results.

\textbf{3.2.3. Survey and data collection}

The main information for this study project was gathered through surveys. The surveys for both phases were defined so as to give answer to the two operational objectives defined for this thesis case study and the objective of the public transport operator.

The survey conducted before interchange introduction evaluates the importance and satisfaction level of several of the aspects identified in Chapter 2 as being changes by interchange introduction and influencing personal travel decision. This survey also includes an evaluation of stated preference of interchange and interchange time with regard to some compensation that the network effect of interchange introduction could produce.

The second survey, conducted after interchange introduction, evaluates interchange conditions and satisfaction level of several of the aspects identified in Chapter 2 as being changes by interchange introduction and influencing personal travel decision.

Both surveys allow an evaluation of the results in respect to several personal and travel characteristics (for example, sex, age, availability of private car, etc). It is of utmost

\textsuperscript{15} After interchange was introduced surveys were conducted to those who were former users of route 38 and that now were obliged to interchange with another route.
importance, for public transport operators, to understand this variability in order to give an appropriate answer to individual travel needs. Public transport can no longer consider costumers as being a homogenous mass with undifferentiated needs.

The first phase of surveys was conducted inside the buses of route 38. The second phase was conducted at the interchange facility – HSJ. As the objective of this study is to evaluate interchange effect, only former users of route 38 that pass HSJ (and now need to interchange), were inquired in this phase. Being so, the surveys were conducted at the departure bus stops of routes 6, 14, 38 and 88, at the interchange facility of HSJ. The interviewees were divided into eight groups depending on the routes used for their journey and the direction of the journey but only for journeys for which they used to use route 38 (see survey “After Interchange Implementation” in Annex B).

The second phase of surveys was conducted on two separate days although only one day had been planned, because from the first day resulted only a small number of answers. Being so, the study project team ordered a second day of surveys. On this day a small extra questionnaire was conducted, on board of route 38, in order to identify new costumers, their reasons for having started to use route 38 and their departure and arrival bus stop for this route. This extra questionnaire aimed to fill a gap left by the survey which ignored the potential positive network effect of interchange introduction since only former costumers of route 38 were interviewed.

The information gathered by survey was complemented with the count of passengers conducted on the same days as the surveys. Besides this, a reconnaissance of all bus stops of route 38 and of the interchange facility at HSJ was carried out with some detail.

### 3.3. Discussion of the main results

The main results of this case study were obtained through surveys and the count of passengers conducted on the same days as the surveys. These results will be analysed for each of the operational objectives defined for this cases study.
3.3.1. Personal perception of interchange – importance and satisfaction  
(Operational Objective 1)

In order to give answer to the first operational objective of this case study, this section presents the main results of the surveys conducted to passengers of route 38 before and after interchange introduction and evaluating personal perception of importance and satisfaction of several transport service features.

3.3.1.1 Before interchange introduction

Importance of some transport service features (question B.1 and B.1.1)

As has been referred in section 3.2.1, only some of the aspects identified in section 2.5, as being changed by interchange introduction that influence travel decision, were evaluated in this case study with regard to relative importance. The analysed aspects were: reliability, travel time, waiting time and the need to transfer (in other words, the importance of having directs service).

![Figure 3.12: Importance of some transport service aspects (question B.1)](image)

Figure 3.12 shows that each of the analysed features was considered by more than 50% of the inquired costumers as very important. Reliability presents the highest rate for this classification, with almost 2/3 of answers being very important. Wardman et al. (2001) also identified this to be the most important feature for its case study.

Answers considering features less than important represent fewer than 10% for each of the analysed features.

From the observation of Figure 3.12 it is evident that all of the analysed aspects are very important within transport service, for this case study, but variability within different
travel and personal characteristics must be considered to fully understand personal
importance.

It is interesting to notice that Reliability is considerably higher valued by young
people (less than 18 years old) with almost 75% of them classifying it as very
important. This classification presents the lowest rate for the elderly (more than 65
years old).

Variability of evaluation of importance can also be found in the remaining three
features. For instance, for travel time, costumers with availability of car use find travel
time less important than those that do not. As for reliability, elderly consider travel time
less important.

Waiting time is considered more important by people for which travel reason is
shopping or leisure. Women were also found to consider waiting time more important
than men. Once more, elderly consider waiting time less important.

In what concerns the importance of direct service it is less important for young people
(less than 18 years old) and for the travel reason of going to school, which are related to
each other. It is interesting to notice that those with accessibility to car use give far more
importance to this aspect. Being so, these passengers have higher propensity to shift to
private car use if transfer is required.

The relative importance of the four analysed aspects is shown in Figure 3.13. This
figure presents the percentage of answers that classified each aspect as the fist (1),
second (2), third (3) or fourth (4) most important aspects and the classification of
relative importance for each of the features. It is evident that reliability is the most
important aspect. This was already predictable from the analyses of Figure 3.12. Direct
service was considered as the less important aspect, considerably less than the other
three. Within time, waiting time is more important than travel time, although their
relative importance is not very different.
Figure 3.13: Relative importance of some transport service aspects (question B.1.1)

Satisfaction level of some transport service features (question B.2)

In order to understand how customers perceive transport service satisfaction levels before interchange introduction, the survey inquired about some relevant features: reliability, travel time, waiting time, and availability of seats. As three of these were evaluated on importance, these results can be combined for the identification of those features with urgent need of improvements. Figure 3.14 presents the results of classification of satisfaction level of these features in a scale from very bad to very good.

From the analysed features, availability of seats presented the highest rate of answers classifying it as at least good (more than 90%). The worst satisfaction level is shown by waiting time with less than 70% of answers of at least good and with the highest share of passengers considering it very bad (approximately 5%) or at least bad (more than 30%). This is especially
relevant since this aspect was considered the second most important feature of transport service for this case study (within the analysed features).

Route 38 was generally considered to have a good satisfaction level, within the analysed aspects. The worst aspect was waiting time which was predictable since this route’s headway was of 20 minutes, which originates a theoretical average waiting time of approximately 10 minutes. Being so, special attention should be given to this aspect when developing the new transport service strategy within interchange.

### 3.3.1.2 After interchange introduction

Perceived waiting time at the interchange point (question B.2)

As interchange could involve one of the four routes 6, 14, 38 and 88 its theoretical average waiting times varies with its headways (see Figure 3.15). More than 90% of passenger perceived a waiting time of less than 15 minutes which is the theoretical maximum waiting time for any of the 4 routes involved in this case study. The majority of passengers perceive a waiting time between 5 and 15 minutes. Very few passengers perceive less than 5 minutes waiting time although average theoretical waiting times are only a little higher than this. Being so, time perceptions seem to be slightly inflated. On the other hand, it could be argued that headways may not be followed and average waiting times may be higher than expected.

![Pie chart](image)

**Figure 3.15:** Perceived and theoretical average waiting time at interchange

<table>
<thead>
<tr>
<th>Route</th>
<th>Headway (min)</th>
<th>Theoretical average waiting time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>38</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>88</td>
<td>15</td>
<td>7.5</td>
</tr>
</tbody>
</table>
Satisfaction level of some transfer conditions at the interchange point (question B.3)

In order to understand how costumers perceived interchange conditions they were asked to classify waiting conditions, reliability of the second bus, interchange walking distance and waiting time and security as very bad, bad, good or very good.

All of the analysed interchange aspects were considered as very bad by 13% to 25% of costumers. The rate of respondents considering aspects as very good is considerably lower than those considering it very bad. With exception of waiting time personal perception of interchange conditions is more positive than negative (with a positive rate slightly over 50%). The results clearly show that the interchange conditions analysed (although in most cases presenting a positive result) are not well perceived by costumers.

Waiting time presents the lowest satisfaction level of the analysed interchange features. More than 45% of respondents perceive waiting times higher than 10 minutes, which is considerably high in comparison to theoretical average waiting times. This negative satisfaction level is especially relevant since it was classified as the second most important feature (within the analysed features of the survey of the first phase) and knowing that waiting time was the aspect presenting the worst satisfaction level before interchange introduction. Being so, the transport operator should seriously consider the introduction of changes on these interchange features.

In what concerns interchange walking distance, although this feature presents the best results (within the analysed features) it is still ill perceived by more than 40% of passengers. This aspect had already been referred to in section 3.1.2 during the discussion of the interchange point (see Figure 3.10 and Figure 3.9). Passengers are obliged to cross more than half of the interchange facility in order to interchange (a distance of approximately 45m). This feature could be improved through a simple
rearrangement of the layout of the interchange facility, contributing for a considerable enhancement of the perceived satisfaction level of this transfer condition. For other features like waiting conditions and security, which fall out of this thesis study scope, further research, through special designed surveys, is recommended to better understand additional passenger needs.

**Satisfaction level of some transport service features for both courses resulting from the former route 38 (question C.1)**

As before interchange introduction, the satisfaction level was evaluated for reliability, availability of seats, travel time and waiting time. Although, with interchange, costumers have two waiting times only waiting time at origin was analysed\(^\text{16}\). Additionally, frequency was included in the analysis of satisfaction level. This analysis was performed for both sides of the former route 38. On the remaining course these aspects were analysed for route 38 and 6, on the course where route 38 was cut and is now served by routes 14 and 88, these were evaluated. The main results are presented in Figure 3.17 and Figure 3.18.

---

**Figure 3.17:** Satisfaction level of transport service between SRH and HSJ

**Figure 3.18:** Satisfaction level of transport service between CAM and HSJ

\(^{16}\) Satisfaction level of waiting time at the interchange was already evaluated through question B.3.
In general it is possible to say that all analysed aspects have very similar satisfaction levels. Approximately 60% of current costumers consider these transport service aspects as at least good and approximately 7% consider them very good.

The aspect presenting the best satisfaction level is frequency, for both sides of former route 38, followed by travel time in the course between SRH and HSJ and by availability of seats in the course between CAM and HSJ.

It is interesting to verify that in general satisfaction level ratings have decreases with interchange introduction. Comparing Figure 3.14 (before interchange introduction) with Figure 3.17 and Figure 3.18 (after interchange introduction) this is easily verified. Independent of the real variation in the analysed aspects and of the perception of this evolution, people have a more negative perception of transport service features and this decrease is very considerable.

**Evolution of the satisfaction level of some transport service features (question C.2)**

The features analysed previously for their satisfaction level after interchange introduction were also analysed for personal perception of their evolution (see Figure 3.19).

![Graph showing the evolution of satisfaction levels](image-url)

**Figure 3.19:** Perceived evolution of the satisfaction level of transport service features
Major perceived satisfaction level gains were found for frequency, approximately 40% of costumers consider this feature to have at least got better. This aspects presented a real increase reaching almost double of the original value.

For all aspects the highest rate of costumers perceived no evolution. It is interesting to notice that, although reliability presents an higher rate of people considering that it has at least got better than those considering that it has at least got worse, the comparison of Figure 3.14 with Figure 3.17 and Figure 3.18 shows that its perceived satisfaction level has deteriorated. The same could be said for waiting time at origin and availability of seats. In case of waiting time at origin its theoretical average value has decrease to almost half and even so a high percentage of costumers can be found considering that it has become worse, and satisfaction level perception of this feature has dropped.

The theoretical value for travel time and total waiting time has increased. For these two features the percentage of costumers perceiving that they are at least worse is higher than those perceiving that they are at least better.

Global evolution of the transport service (question C.3)

Besides evaluating personal perception about the satisfaction level and evolution of several features of transport service, a final free answer question was proposed by the survey. For this, interviewees were asked to give their perception of global evolution of transport service with the introduction of interchange and to identify the main reasons for a positive or negative evolution.

The majority (51%) of interviewed people considered that globally the transport service had worsened with interchange introduction. Even so, almost 49% considered that the transport service had improved. As only former costumers of route 38 were interviewed this answer ignores possible new costumers and those who might have left the route because of the introduced changes.

Considerable variability can be found for this evaluation with reference to travel reason. For instance, from those travelling in service, 70% believe transport service to have improved, while from those going to work this rate drops to 30%. Occasional users of route 38 have a slightly better opinion on transport service evolution. Only 35% of the
elderly think transport service has become worse, on the other hand, 70% of young people (less than 18 years old) perceived a worsening in global transport service. Women are also slightly more negative than men about the global evolution of the transport service, although these were those who gave less importance to direct service (see analysis of question B.1 of the first phase survey).

**Table 3.5: Reasons given for global transport service improvement**

<table>
<thead>
<tr>
<th>Why better?</th>
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<tbody>
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<td>Higher frequency</td>
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<tr>
<td>Decrease of total travel time</td>
<td>17.56</td>
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<tr>
<td>Higher number of possible destinations</td>
<td>7.63</td>
</tr>
<tr>
<td>Remains equal</td>
<td>4.58</td>
</tr>
<tr>
<td>Decrease of wait time</td>
<td>3.82</td>
</tr>
<tr>
<td>Higher reliability</td>
<td>3.82</td>
</tr>
<tr>
<td>Interchange is inconvenient</td>
<td>3.05</td>
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<tr>
<td>More information</td>
<td>2.29</td>
</tr>
<tr>
<td>It if fine like this</td>
<td>1.53</td>
</tr>
<tr>
<td>Lack of information</td>
<td>1.53</td>
</tr>
<tr>
<td>Increase of wait time</td>
<td>0.76</td>
</tr>
<tr>
<td>Route 14 should continue reaching RCQ</td>
<td>0.76</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Within the referred reasons for a positive evolution of transport service, higher service frequency was found more than 50% of the times. This is the most relevant reason for passenger satisfaction with interchange introduction. It was also identified as the aspect with the best perception of satisfaction level evolution within the several transport service features analysed. The enhancement of frequency was a considerable network improvement given in exchange for interchange introduction (with a headway reduction to almost half of its original value). This is in accordance with the idea defended by Oscar Farber (2000), stating that “[…] increasing frequency reduces many of the problems traditionally associated with interchange”.

The second most referred reason for service improvement was the decrease of total travel time (with almost 18%), although in theory this time remained approximately equal (with a slight rise of approximately 1 minute). It is interesting to notice that (the increase of) total travel time was also the second most referred reason for the
deterioration of transport service (with very similar percentages). Two explanations are possible for this phenomenon. First, different sections could have presented different variations in travel time and thus for some have increased and for other decreased. Second, personal perception of travel time was influenced by the evolution of other features for which personal importance (and therefore influence) can vary with travel and personal characteristics. The third reason given for improvement of transport service was higher number of possible destinations (with almost 8% of the given answers). One possible reason could be that as HSJ is an interchange where many different routes cross, several costumers considered it an advantage, although this possibility already existed before interchange was introduced but as they did not have to stop at HSJ they must not have realized the potential of interchanging at this facility. Being so, the simple introduction of interchange may induce other interchange movements and show people the alternative travel option and their advantages and disadvantages. Increase in reliability was only mentioned by 4%, which means that it did not occur or that it was not perceived. This is especially negative since this was the most important aspects identified through the results of the first survey (within the analysed aspects). Although 30% admit this aspect has improved (see Figure 3.19) it has not been recognised as being a reason for overall service improvement.

Table 3.6: Reasons given for global transport service deterioration

<table>
<thead>
<tr>
<th>Why worse?</th>
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<tbody>
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<tr>
<td>Increase of total travel time</td>
<td>16.55</td>
</tr>
<tr>
<td>Increase of wait time</td>
<td>9.66</td>
</tr>
<tr>
<td>Interchange time is high</td>
<td>9.66</td>
</tr>
<tr>
<td>Interchange is inconvenient with bad weather</td>
<td>4.83</td>
</tr>
<tr>
<td>Schedules are not integrated</td>
<td>4.14</td>
</tr>
<tr>
<td>Lack of information</td>
<td>2.76</td>
</tr>
<tr>
<td>Lower frequency</td>
<td>2.76</td>
</tr>
<tr>
<td>Busses are not on schedule</td>
<td>2.07</td>
</tr>
<tr>
<td>Remains equal</td>
<td>2.07</td>
</tr>
<tr>
<td>Exposure to whether conditions</td>
<td>1.38</td>
</tr>
<tr>
<td>Higher frequency</td>
<td>0.69</td>
</tr>
<tr>
<td>Lack of seats</td>
<td>0.69</td>
</tr>
<tr>
<td>Low frequency</td>
<td>0.69</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
</tr>
</tbody>
</table>
The most referred reason for the worsening of global transport service was the inconvenience of interchange with 42% of responses (including reasons like, “it is unpractical”, “preferred direct service”, “transfer is unnecessary”). Being so, lack of direct service, itself, is clearly the major negative aspect of all changes in transport service features produced by interchange introduction. Other potentially negative effects like uncertainty and increase in time are not quite as relevant. As has been referred, increase in travel time, although being the second most referred reason for worse transport service, was only mentioned by 17%.

Within relevant reasons for the deterioration of global transport service, it is possible to find the increase of waiting time and the high interchange time (both with 10% of total negative answers). It is important to bear in mind that waiting time was found to be a very important feature and that the interchange time was the interchange features with the lowest satisfaction level (within the analysed interchange features).

Knowing that increase in frequency was mentioned by more than half of those perceiving a transport service improvement, this could be the necessary feature to balance disadvantages introduced by interchange.

3.3.2. Forecasted and real effect of interchange on demand
(Operational Objective 2)

This section presents the analyses of the statistical data of stated preference regarding interchange introduction, enabling the comparison of the predictable evolution of demand with its real evolution, which will be estimated through some passenger counts and survey results.

Stated Preference relating to interchange

This kind of stated preference questionnaires should be used to compare different transport strategies that combined with interchange introduction could produce the most positive effect on demand. Therefore, several possible scenarios and combinations of the five aspects identified in section 2.5, as being changed by interchange introduction that influence travel decision, should be tested in order to enable the identification of the balance between potential advantages and disadvantages of interchange. This
methodology would give transport operators a tool to better define transport strategies to be used with interchange in order to grant demand increase, or at least avoid decreases. These questionnaires can also be used to define demand models (referred to in section 2.5).

Although section 2.5 discussed the importance of the use of stated preference surveys for the definition of the transport strategy to be combined with interchange introduction, in this case study, the transport strategy had already been defined by the transport operator before the design of the survey. Being so, stated preference questions of the survey conducted before interchange introduction were of no use for the study project ordered by STCP. Even so, a simple stated preference question was included in order to enable the comparison between its predictions of the effect on demand and the real effect. This would allow an evaluation of their level of reliability for strategy definition.

Being so, the stated preference question in this survey evaluated the predictable effect on demand of the transport strategy that would be used after interchange introduction. This question evaluates the predictable effect on demand of interchange introduction with a consequent increase in reliability or frequency, and the variation of this effect with potential extra waiting time at the interchange point. As travel time was believed to be constant (within constant travel condition) and knowing the changes that would be introduced with interchange introduction on route 38, this question should evaluate the predictable effect on demand and the subsequent trade-off between gains and losses of interchange introduction. The potential gains were, higher reliability (which could be consequence of a considerable decrease in the length of route 38) and higher frequency (with an increase from 3 to 6 buses per hour). The potential losses were the need to transfer/uncertainty and waiting time.

Figure 3.20 shows that 75% of costumers would accept interchange in exchange of a gain in reliability (an indeterminate gain) and this although more than 80% considered this feature’s satisfaction level as at least good. On the other hand this was considered

\footnote{The improvement of frequency offered in exchange of interchange introduction in the survey was slightly higher than the real improvement given by the transport operator since the research team was only informed of the exact future transport strategy after the first phase of surveys had been conducted.}
as the most important of the analysed aspects so gains would always have a positive
effect on interchange acceptability.

![Figure 3.20: Interchange acceptability](image)

Although acceptability is high, it still represents a loss of passengers (of approximately 25%). This information is not complete; there is still a need to know if new passengers would be gained through reliability gains, i.e. if former users of other transport modes (for example the car) would consider using this route because of its reliability increase. This information could be gathered through stated preference questionnaires conducted to car users and other potential clients.

With regard to the increase in frequency, more than 65% of users would accept interchange introduction in exchange for a decrease of 10 minutes of the current headway (20 minutes). Although in this case, the real value of variation of the advantage, presented in exchange for interchange introduction, is known and very considerable, acceptability is lower then with an indeterminate increase of reliability. This means that this frequency gain is still not enough or that frequency is less important to users of route 38 than reliability.

Contrarily as could be expected, public transport passengers do not exclude interchange introduction as a possible travel option. These numbers show that gains in transport service can enhance interchange acceptability and maybe even turn interchange into a potential within public transport. Additionally, according to Oscar Farber (2000), “the experience was generally less worse than anticipated”.

This analysis was complemented with evaluation of the acceptability of extra waiting time at interchange (see Figure 3.21).
Figure 3.21: Acceptability of interchange with regard to maximum interchange waiting time

Even with higher reliability or frequency only 65% or 56%, respectively, would accept to wait more than 5 minutes at the interchange point (this reduces total acceptability from 75% to 49% and from 65 to 36%). For waiting times higher than 5 minutes at interchange point more than half of passengers would be lost with interchange, even with gains in reliability or frequency. This clearly shows that more gains should be given to costumers in order to enhance interchange acceptability, as for example frequency and reliability gains simultaneously, gains in total waiting time, etc.

Waiting time is clearly a vital aspect for the success of interchange introduction and should be as low as possible. For this to be achieved, high reliability and low frequencies are required.

Only 5% of those who would accept interchange in exchange for reliability or frequency gains would allow waiting times at interchange point higher than 10 minutes. Although a considerable number of costumers would be lost for waiting times higher than 5 minutes it is interesting to notice that the majority of costumers would admit 5 to 10 minutes of extra waiting time at interchange for higher reliability or frequency. This clearly shows the unexplored potential interchange constitutes. The clarification of the balance between gains and losses, related to interchange introduction, can enable the increase of public transport share.
Some interesting cases of variability were found among different journey and personal characteristics which are worth mentioning.

In case of travel reason a considerably higher acceptability was identified for costumers travelling for shopping/leisure purposes, especially in case of frequency gains (with an acceptability of 80% in stead of the medium of 67%). In case of reliability gains, acceptability of people on duty is higher than those travelling for shopping/leisure proposes. On the other hand, people returning home have a considerably lower acceptability of interchange in exchange for frequency gains. In what concerns interchange waiting time, people on their way to work expect considerably lower waiting times than the average. On the other hand, costumers travelling on duty accept considerably higher waiting times.

Variability can also be found within the frequency of use of route 38. Occasional users have higher acceptability of interchange in exchange for gains of frequency and even higher for reliability. Every day users are willing to wait longer at interchange for the referred gains (even more for reliability than for frequency) approximately 15% are willing to wait more than 10 minutes.

Costumers with availability of private car have higher acceptability of interchange in exchange for frequency and reliability. On the other hand, those who do not have a car available are willing to wait longer time at interchange.

No significant variability was found between men and women, nevertheless elderly have considerably lower acceptability of interchange independent of each of the offered gains. Knowing that these are also those who give less importance to reliability this can be easily understood. But elderly are those more willing to wait more than 10 minutes for reliability gains. This also occurs for frequency gains but in this case they present also the highest rate for less than 5 minutes waiting time.

Variation of demand on route 38

The passengers of route 38 that can negatively be affected by interchange introduction are those passing HSJ. These represent between 10 to 20% of all costumers of this route. As the remaining passengers (approximately 80%) will only be exposed to higher
service frequencies (on both sides of the interchange at HSJ) no demand decrease is expected because of interchange introduction, quite the contrary might be expected.

As passengers of route 38 are divided into four different routes (6, 14, 88 and the remaining section of route 38), it would be necessary to count all four routes before and after interchange introduction in order to establish the number of former users of route 38 in each of the other involved routes and to estimate passenger variation of route 38. The direct involvement of route 14 in the case study was only known after the first phase of surveys and passenger counts had been conducted. Being so, it was already too late to count other potentially involved routes in order to be able to predict their evolution with interchange introduction. Even if this had been known before, passenger counting on all these routes simultaneously would have required too many resources. In order to overcome this limitation the following methodology was used:

a) Evaluation of the variation of passengers passing HSJ (assuming that these are the only ones who may suffer negative effect of interchange introduction);

b) Evaluation of the percentage of new passengers in route 38 after interchange introduction;

c) Estimation of the total variation on demand of route 38.

a) Evaluation of the variation of passengers passing HSJ:

The number of passengers passing HSJ before interchange introduction was found through passenger counts conducted during the first phase of surveys (immediately before interchange was introduced). As no counting was possible after interchange introduction passengers passing HSJ were estimated based on passenger departure counts at HSJ and knowing the percentage of passengers transferring at HSJ that were waiting on the bus stop of routes 6, 14, 38 and 88 (results of the second phase surveys). The estimated decrease of passengers passing HSJ is of approximately 22%, which represents a decrease of almost 5% of total passengers of route 38.18

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18 These values (estimated by TIS.pt) refer to the time period between 7am and 8pm for the direction SRH-CAM, because these are the values available for passenger counts after interchange introduction. Although this value is only for one direction of the route, the variation of demand in percentage can be assumed as similar for both directions and for the entire course.
b) Evaluation of the percentage of new passengers in route 38 after interchange introduction:

In order to estimate new costumers of route 38 after interchange introduction and their reasons for starting to use this route, a third survey was conducted on board, on the course between CAM and HSJ (the remaining course of route 38). This survey revealed that approximately 22% of current costumers of the remaining course of route 38 had become costumers after interchange introduction.

From these new users, almost 30% are occasional riders and have therefore no particular reason for choosing this route. This jointly with new travel needs represent more than half of new costumers. Almost 25% of users have just started to use this route without a particular reason. Although this seems to be entirely disconnected to interchange introduction and consequent network effect, these new costumers may have chosen this route instead of another route or transport mode because of its improved transport service. The high frequencies and fast service are referred by 17% and 7% of new costumers as being the reason for shift to this route.

**Table 3.7:** Reason for starting to use route 38 after interchange introduction

<table>
<thead>
<tr>
<th>Why change to route 38?</th>
<th>12.20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; time</td>
<td></td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; time</td>
<td></td>
</tr>
<tr>
<td>Higher frequency</td>
<td>17.07%</td>
</tr>
<tr>
<td>Faster service</td>
<td>7.32%</td>
</tr>
<tr>
<td>New travel needs</td>
<td>21.95%</td>
</tr>
<tr>
<td>Occasionally / by chance</td>
<td>29.27%</td>
</tr>
<tr>
<td>Total</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

c) Estimation of the total variation on demand of route 38:

Knowing that due to interchange introduction 5% (4.6%) of costumers of route 38 were lost and that 22% (22.2%) of nowadays costumers<sup>19</sup> have become costumers after

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<sup>19</sup> Although this value refers only to one section of the former route 38 (the section between CAM and HSJ) the variation of demand can be assumed to be at least equal on the other section since improvements
interchange introduction, the global value of demand has grown in approximately 23% (22.6%)\textsuperscript{20}.

Comparison between the forecasted and real effect on demand

Before comparing forecasted and real effects on demand it is important to notice that many of the results of real effect on demand are estimated. These values are dependent on the assumptions and simplifications used during the evaluation.

It is also important to refer that during this evaluation the research team noticed that demand on this route has a very irregular behavior, with a very high rate of occasional passengers (mainly because of the presence of the Hospital at HSJ and of the shopping mall at SRH). Being so, a high variability is expected at a daily bases, which should have been taken into account through higher number of passenger counts disperse on several days. This must be considered when analysing these results.

Nevertheless, it is fair to say that the negative effect of interchange on demand has been less negative than the stated preference survey predicted. Interchange may only have produced a 5% passenger loss (within those having to interchange), which is far less than the predicted 30% passenger loss for frequency gains of 10 minutes in exchange for interchange introduction. It is even less than the 20% passenger loss for reliability gains in exchange for interchange introduction\textsuperscript{21}. As reliability was only perceived by few passengers as being the reason for service improvement (in spite of interchange) the stated preference question of interchange vs. frequency seems to be more similar to the real scenario.

\begin{align*}
\text{D}_1 &\quad \text{passenger demand immediately before interchange introduction} \\
\text{D}_2 &\quad \text{passenger demand during the second phase of survey} \\
\text{D}_2' &\quad \text{passenger demand during the second phase of survey that were users of route 38 before interchange introduction} \\
\text{D}_2^* &\quad \text{D}_1 \times 0.954 \\
\text{D}_1 &\quad \text{D}_2 \times (1-0.222) \\
\text{D}_1 &\quad \frac{\text{D}_2}{1.226}
\end{align*}

\textsuperscript{20} With, D\textsubscript{1}, passenger demand immediately before interchange introduction

\textsuperscript{21} Knowing that 85% perceived an interchange waiting time higher than 5 minutes (Figure 3.15), only 30% (approximately) of former costumers would be expected to remain using route 38 since interchange acceptability in exchange for frequency improvements reduces to 36% for extra waiting time higher than 5 minutes.
Additionally interchange introduction may have produced an increase of 22% of total passengers (within those not having to interchange) because of transport service improvements (within which frequency was the most mentioned). Being so, this case study confirms the idea that the real effect of interchange is generally not as bad as expected [Oscar Farber, 2000]. Estimated results have been far better than the results forecasted by stated preference surveys.

3.4. Discussion of the main findings

Having presented the main results of the case study, this section develops a discussion about the perceptions and attitudes of users of the course of the former route 38 with the introduction of interchange, with regard to importance and satisfaction level of several transport features and the effect on demand.

From the analyses of personal perception, all of the analysed aspects were found to be important, having reached the conclusion that, for this case study (and within the analysed features), reliability is the most important feature, followed by waiting time, travel time and direct service as the least important. Unfortunately, not all aspects mentioned in Chapter 2, as being those changed by interchange introduction and influencing travel choice, were evaluated for their relative importance. Even so, the analyses made of the rest of the questions induces that frequency is also a very important feature of transport service influencing travel choice. This aspect is even responsible for the majority of positive perceptions of interchange introduction for this case study.

The fact that direct service was found to be the least important of the analysed aspects is very interesting, especially since it was considered considerably less important. In addition, more than 70% of costumers were willing to exchange direct service for improvements of reliability. This may show that direct service is not as important, relatively to other network features, as is frequently believed. On the other hand it may be argued that direct service importance is undervalued as long as it is present. Even so, this may induce that lack of direct service may be compensated by improvements on
other public transport network features which have been demanded for some time now and are also considered as essential for public transport service.

All analysed transfer conditions presented very weak satisfaction levels, few more than 50% considering them at least good. Waiting time was the worst of analysed transfer conditions, being also the only one presenting a negative satisfaction level. This is especially important since it was considered the second most important features (within those analysed). In case of “interchange walking distance”, the analyses of the interchange layout (see section 3.1.2) revealed that a simple restructuring would potentially improve this features satisfaction level. For other features like waiting conditions and security, falling out of the scope of this thesis, further research and a more detailed survey would be recommended.

With regard to the satisfaction level of the analysed aspects, frequency was considered the best feature after interchange introduction. It was also the feature that presented the highest improvement of satisfaction level perception; this is easy to understand since its real improvement almost doubled its original value. Unfortunately this aspect was not evaluated in the first phase of surveys, this would have enabled the evaluation of the evolution of the ranking of the satisfaction level of this aspect with interchange.

Comparing the evolution of the perceived satisfaction level of some transport service aspects before and after interchange introduction with the perception of evolution of the aspects it becomes evident that interchange introduction changed perception of satisfaction level. Although the perception of evolution of the transport features was relatively positive, personal perception of transport service satisfaction level was considerably worse after interchange introduction (knowing that before interchange introduction all analysed aspects presented good satisfaction levels). This shows that personal perception of the satisfaction level of a certain aspect is very susceptible to change of other aspects. Being so, the simple comparison of personal satisfaction level rates within different conditions can produce misinterpretations of the evolution of personal perception of these conditions.
Figure 3.22: Comparison of perception of feature satisfaction level evolution with regard to global opinion on service evolution

The previous figure shows that customers with a negative opinion of global service evolution with interchange introduction have considerably lower perceptions about the evolution of individual aspects. The opposite occurs for those perceiving an improvement in global service satisfaction level. This is so even for frequency where considerable gains were experienced with interchange introduction. Costumers perceiving a negative evolution on transport service also tended to perceive losses in frequency satisfaction level. This corroborates the idea that the perception of transport features satisfaction level is influenced by individual importance and by the perception of satisfaction level of other features. This must be taken into account when analysing survey results and even when using them for calibration of demand models. Further research should be developed in order to improve the understanding of this phenomenon learning how to correctly interpret these results and even on how to avoid this deviation in result by improving surveys techniques.

Another possible example of satisfaction level misperception can be that of variation in total travel time presented as reason for global service improvement and deterioration. Almost the same percentage of unsatisfied and satisfied customers considered that increase and decrease of total travel time, respectively, was responsible for the variation of global service satisfaction level. As has been argued in section 3.3.1.2, two possible explanations are possible for this phenomenon. One is that different sections could have
presented different variations in travel time and thus for some have increased and for other decreased. It is also possible that the global negative or positive perception of interchange may have influenced the perception of total travel time, especially since this is an aspect that theoretically suffers a non perceivable increase (of 1 minute). It would be relevant to further research the reasons for this contradictory perception.

For the costumers that continued using the former course of route 38 after interchange introduction, a small majority considered that globally the transport service had worsened. The main reason given for this was the inconvenience of interchange (including answers like “its unpractical”, preferred direct service” or “transfer is unnecessary”). Even so, almost 49% considered that the transport service had improved, mainly because of frequency improvements. These reasons are rated considerably higher than any of the other justification given for global service improvement or deterioration.

Knowing that increase in frequency was given as reason by more than half of those perceiving a transport service improvement, this could be the necessary feature to balance disadvantages introduced by interchange (within this conditions). If we take into account that even more people were willing to interchange for reliability gains then for frequency gains, if these had occurred or if they had been perceivable, interchange introduction could have had a more positive effect on global transport service.

These trade-offs between interchange and other network features should have been evaluated in its full extent through stated preference questionnaires in order to enable a wider understanding of the optimum network strategy, minimizing negative effects of interchange implementation and even maximizing positive effects on demand. However, the discussion of the potential trade-offs between interchange and other network features was limited by the restrictive condition of this case study, in which, stated preference questions simply enabled a comparison between real and expected demand and a limited evaluation of the potential trade-offs.

Although interchange may have produced a very small immediate reduction in total demand (within those having to transfer) the present demand might be higher than before interchange introduction due to a considerable number of new costumers. Being
so, passenger demand may have increased with interchange introduction onto route 38 although, only a small part of this increase can be directly linked to interchange introduction. The results of the evaluation of the effect of interchange on demand are limited by the constrains in which they were obtained. Being so, these must be regarded with prudence. Nevertheless, as at least the negative effect of interchange on demand (passenger loss within those having to interchange) was defined for the worst case scenario it is fair to say that the real passenger loss, because of interchange introduction, was considerably lower than that forecasted by stated preference surveys for the exchange of direct service for frequency gains. Being so, this corroborates the idea that “experience is generally less worse than anticipated” [Oscar Farber, 2000]. Being so, further research would be needed to clarify the relation between real effect on demand and the effect anticipated by stated preference surveys.

For those passengers lost due to interchange introduction it would be interesting to evaluate if they continued using public transports (through another route or operator) or if they started using private transport modes (like the car). It would also be relevant to evaluate former transport modes of the new users of route 38. This would enable an evaluation of the transport mode shift interchange had produced within this conditions, knowing that its potential contribution for the solution of current urban mobility problems depends on its ability to assure modal shift from private car to public transport.

Interchange would also have been better perceived if extra waiting at interchange point would have been lower. Although theoretical waiting time at interchange varies from 5 to 7.5 minutes, perceived time is mainly between 5 and 15 minutes. Being so, almost 45% of costumers accepting interchange in exchange for frequency improvements would have been lost because of excessive waiting time. Waiting time was the interchange condition with lowest satisfaction level perception. Higher acceptability of interchange could have been achieved if waiting times at interchange had been reduced. As theoretical average waiting times depend on frequency, all routes would need considerable gains in order to lower interchange waiting times. Improvements in reliability could also help to approach real to theoretical waiting time. This is especially important since waiting time was considered the second most important feature (within
the analysed features during the first phase of surveys) and also because its satisfaction level was within the lowest. Special attention must be given to the fact that waiting time seems to be higher perceived than its real value, being so, further research is needed to clarify the difference between real and perceived waiting time.

It is also interesting to notice that although no new destinations were introduced through interchange, this was the third most frequent reason given for global improvement of the transport service. The simple fact that costumers were now obliged to change vehicle at HSJ (which is a major bus stop for many routes) may have given them the perception of having more travel alternatives. Although these already existed before interchange introduction the potential of interchange at this facility must not have been realized. Being so, the simple introduction of interchange may induce other interchange movements and show people the alternative travel option and their advantages and disadvantages.

The main finding of this case study, analysing personal perception and attitudes towards interchange within road public transport, are summarized in Table 3.8

Finally, in what concerns personal perceptions special attention must be given to the analyses of variability with regard to personal and journey characteristics. It is of utmost importance, for public transport operators, to understand this variability to better respond to individual travel needs. Public transport can no longer consider costumers as being a homogenous mass with undifferentiated needs.

This particular case study shows that interchange introduction, when combined with an effective transport service strategy can turn the negative effect of interchange into a potential. If the correct combination of advantages is offered to costumers in exchange of interchange introduction positive effects on demand can be accomplished. This balance between advantages and disadvantages from the personal perspective must be calibrated with the trade-off from the operator perspective, i.e. how much of the saved resources is the operator willing to use in order to improve transport service and therefore have positive effect on demand.
Table 3.8: Main findings of the case study

<table>
<thead>
<tr>
<th>Importance:</th>
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<tbody>
<tr>
<td>Relative importance (frequency was not evaluated):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st reliability;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd waiting time / travel time;</td>
<td></td>
<td></td>
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<tr>
<td>3rd direct service (much lower)</td>
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<thead>
<tr>
<th>Satisfaction Level:</th>
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<tr>
<td>Frequency was considered the best feature after interchange implementation (had the highest improvement of satisfaction level).</td>
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<tr>
<td>Transfer conditions presented very weak satisfaction levels (waiting time was the worst – negative satisfaction level).</td>
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<tr>
<td>Interchange introduction had a negative influence on the perception of the satisfaction level of individual features (without real deterioration of their service level).</td>
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<tr>
<td>Changes on some aspects are susceptible of changing personal perception of satisfaction level of other aspects.</td>
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<tr>
<td>A small majority considered that global transport service had worsened with interchange, mainly because of the inconvenience of interchange.</td>
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<tr>
<td>Within those considering that global transport service had improved (49%) frequency gain was presented as its main reason.</td>
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<table>
<thead>
<tr>
<th>Perception</th>
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<tr>
<td>High rates of passengers exchange direct service for gains in frequency and reliability (real effect higher than forecasted).</td>
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<tr>
<td>High waiting time at interchange considerably decreases acceptability of interchange.</td>
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<tr>
<td>Demand may have increased with interchange introduction.</td>
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<tr>
<td>Passenger loss (within those passing HSJ) was considerably lower than forecasted.</td>
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<tr>
<td>The need to transfer within an interchange facility, where several other routes stop, may show alternative travel option (inducing other interchange movements).</td>
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Chapter 4

Conclusion

According to AMAR (1999) the first conclusion of the Vienna UITP Colloquium of November 1998 was that “[...] interchange points constitute a strategic challenge for public transport”. It can even help attract new passengers by offering new journey opportunities, rising speed or even improving the overall journey [T/L, 2001]. The research developed for this thesis corroborates these statements showing that besides being acceptable, interchange can even enable the improvement of public transport service perception by enhancing network efficiency. As an immediate result, interchange may enable positive effect on public transport demand. The case study shows that direct service may be compensated by improvements on other public transport features. These can be accomplished without increase in necessary resources because of transport resource optimization made possible by interchange. The introduction of interchange in public transport routes may be transformed into a “win-win situation” for both, operators and individuals. Being so, interchange holds the potential of producing global benefits for urban mobility and for its main stakeholders.

As had been argued in Chapter 2, interchange needs to induce a modal shift from the private car towards public transport (for medium distance travel patterns) in order to assure the success of integration as a potential contribution for the solution of urban mobility problems. Within the context of public transport, the best trade-off between the gains of operator and individual (as the two main urban mobility stakeholders) must be
found in order to assure positive effect on public transport demand. Figure 2.5 clearly illustrates that the operator, as the decision maker, must define its transport strategy as the compromise between optimization of necessary transport resources (enabled by interchange introduction) and the effect on demand (consequence of individual reaction to transport strategy). This trade-off depends of the balance between advantages and disadvantages of interchange introduction, from individual perspective. These can be influenced by the operator, compensating disadvantages of interchange implementation through transport service enhancement using resources saved because of interchange.

This case study within Porto’s public transport network shows that interchange effectively enables operators to reduce necessary transport resources and to enhance transport service without extra cost (see Table 3.2) confirming the analysis developed in section 2.3. It also shows the importance of some of the transport network features identified in section 2.5 as being changed by interchange introduction and influencing personal travel decision. Within this particular case study, reliability was found to be the most important transport feature within interchange followed by time and direct service (the last, presenting considerably lower importance). Unfortunately, the relative importance of frequency was not evaluated, but the results of the stated preference question in the first phase of surveys induces that, though being very important, frequency seems to be less important than reliability in a public transport network with interchange.

This case study also enabled the identification of some potential balances between advantages and disadvantages of transport service strategy with interchange, which condition interchange acceptability and even success. The results of the stated preference question showed that a very high rate of public transport customers are willing to exchange direct service for other transport service improvements (this study evaluated increase of reliability and frequency) if these are important and significant. This high acceptability demonstrates that the improvement of certain transport features constitute advantages for network efficiency with the potential of compensating the

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22 In this case study the public transport operator chose to increase the number of used vehicles (increase used resources) although this was not necessary to enhance transport service. This transport strategy may have positively biased the effect on demand.

23 As was explained before, not all aspects were analysed through the case study because the theoretical evaluation was conducted subsequent to the first phase of surveys.
inconvenience of interchange; these improvements are enabled by interchange introduction. Being so, for interchange to contribute for sustainable urban mobility it must introduce sufficient optimization of necessary transport resources (preferentially in excess) granting enough network efficiency gains to compensate inconvenience of interchange (or even exceed the necessary compensation) without extra cost. This is the key issue of acceptability of interchange and its contribution for sustainable urban mobility.

It is also interesting to notice that interchange presents higher acceptability when compensated by reliability improvements (although its values were not specified) than when compensated by a reduction of headway to half of its original value. These results show the importance of reliability in integrated public transport networks in accordance with Wardman et all. (2001) and Oscar Farber (2000) (see Table 2.5).

The case study confirms some of the evaluation found in the literature review made in section 2.5 discussing the importance of several transport service features in compensating the inconvenience of interchange. For instance, Rietveld et all. (2001) found that reliability is even more important when frequencies are low (which is the case of this case study), avoiding rise in uncertainty due to high headways; Oscar Farber (2000) argues that simply increasing frequency reduces many of the problems traditionally associated with interchange.

This case study also shows that special attention must be given to extra waiting time at interchange, since this particular aspect had very significant influence on interchange acceptability in exchange for reliability and frequency. Being so, to maximise interchange acceptability, extra waiting time at interchange point must be minimized (ideally to less than 5 minutes). To achieve this without timetable coordination, service should be reliable and frequency must be as high as possible (ideal headway lower than 10 minutes). Nevertheless a simple increase of frequency, even if considerable, may not be enough to produce a considerable reduction of waiting time and therefore enhance interchange acceptability.

24 For example, a reduction of 10 minutes in a 30 minutes headway, although considerable produces still very high waiting times for transfer.
The effect of interchange on the public transport route of this case study is evidence of the positive balance between the disadvantage of direct service loss and the advantage of frequency gains (other aspects like reliability or waiting time were not measured) having even produced a positive effect on demand.

The loss of passenger (within those having to interchange) was considerably lower than that forecasted through the stated preference question, especially if considering that extra waiting time at interchange (as the worst interchange condition with negative satisfaction level) was perceived by the majority of clients as being very high and also considering that frequency gains in the real case were lower than those proposed for the stated preference question. This situation shows that there was higher acceptability of interchange than that identified through stated preference surveys, i.e., people are willing to accept lower transport service compensations, for the inconvenience of interchange, than forecasted.

The result of the case study show that, besides a low passenger loss (within those having to interchange) a considerable increase in demand can still be achieved. At least one quarter of new passengers of the studied route chose this route because of its transport service level. More than half of new costumers presented unclear reasons; even so these may be related to transport service improvements.

Summarizing, the main conclusion to be drawn from this research is that:

| Interchange can be acceptable and even generate positive effect on public transport demand producing global benefits for urban mobility and for its main stakeholders. |
Recommendations for further research:

Some aspects of this thesis case study need further research in order to enhance its results and interpretations:

- Further evaluation of the compensation between different advantages and disadvantages of interchange introduction using more complete stated preference surveys.
- Further study of the difference between predicted and real effect on demand aiming to calibrate correctional coefficients that would enable stated preference results to be corrected for them to be closer to real effects.
- Study of the contribution of interchange for the increase in service reliability due to route length reduction.
- Further research is needed in order to identify the transport mode from which new costumers came and to which former costumers switched in order to evaluate the effect of interchange on private car demand (and therefore on sustainability of urban mobility).
REFERENCES


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Annex A

NETWORK MODEL
This annex presents some relations within variables used in the model of section 2.2, justifying the results presented within Table 2.4. All relevant variables are determined relatively to route length for three different situations:

- **Situation 1:** General situation (for route length of “a” and frequency of “f”)
- **Situation 2:** Variation of route length (for a route length of “k a”, with “k” a constant and frequency of “f”);
- **Situation 3:** Variation of length with the same number of vehicles (for a route length of “k a”, with “k” a constant and number of vehicles of “n”).

For the last two situations, besides the determination of each variable relatively to route length, variation of the value of each variable relatively to the first situation is included.

**Situation 1:**

\[ L = a \]
\[ F = f \]
\[ N = n \]
\[ D = 2a \]
\[ T = t = 2k_1a = k_2a \]
\[ H = h = \frac{1}{f} = \frac{t}{n} = \frac{2k_1a}{n} = \frac{k_2a}{n} \]

**Situation 2:**

\[ L = k_1a \]
\[ F = f = \frac{n}{t} = \frac{n}{2k_1a} = \frac{n}{k_2a} \]
\[ N = n^* = k_3n \]
\[ D = d^* = 2L = 2k_1a = k_3d \]
\[ T = t^* = 2k_1a = k_3k_2a = k_3t \]
\[ H = h = \frac{2k_1a}{n} = \frac{k_2a}{n} \]

For constant velocity \( \Delta T = \Delta L \).
**Lemma 1**: For constant values of frequency, variation of number of necessary vehicles is proportional to variation of route length.

\[ \Delta N = \Delta L \quad \text{A.1} \]

**Situation 3:**

\[ L = k_3 a \]
\[ N = n \]
\[ F = f^* = \frac{n}{k_2 k_3 a} = \frac{1}{k_3} f \]
\[ D = d^* = 2 L = 2 k_3 a = k_3 d \]
\[ T = t^* = 2 k_3 k_1 a = k_3 k_2 a = k_3 t \]
\[ H = h^* = \frac{2 k_1 k_3 a}{n} = \frac{k_2 k_3 a}{n} = k_3 h \]

**Lemma 2**: For constant values of number of vehicles, variation of headway is proportional to variation of route length.

\[ \Delta H = \Delta L \quad \text{A.2} \]