Diana Rita da Silva Leal

RAIL CARGO ON THE LISBON-MADRID HIGH-SPEED RAIL LINE

AN ASSESSMENT OF FEASIBILITY

PhD Thesis in Doctoral Program in Transport Systems supervised by Professor Luís de Picado-Santos and Professor Bruno Filipe Santos, presented to the Department of Civil Engineering of the Faculty of Sciences and Technology of the University of Coimbra

March 2015

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Abstract

This thesis presents an application to deal with the introduction of containerized cargo on the high-speed rail line operations between Lisbon and Madrid. The future rail line is a large, rigid and complex system with a long cycle of operation. Therefore, initial design needs to be carefully planned since once it's installed it is very difficult and expensive to modify. In order to plan the infrastructure, its life cycle performance needs to be considered, given that the performance of the infrastructure depends not only on the initial project preparation and design but also on the maintenance and renewal decisions taken during the life cycle. In addition, in order to guarantee an optimal long-term result for the railway system, the effects of decisions taken should be methodically evaluated. Therefore, it is mandatory that all options (pre and post-operation) are evaluated in order to better serve demand and improve cargo investment efficiency.

For different reasons until now, cargo was never a target revenue segment considered for high-speed rail lines development. The main reasons for this are the serious maintenance and operational constraints that occur when conventional freight-rail trains are ridded in a high-speed rail line, namely in terms of the track maintenance rehabilitation and safety for passengers. The current research aims to study the inclusion of 'light rail-freight' service on the Lisbon-Madrid high-speed rail connection in the investment evaluation through the use of dedicated rolling stock to deliver cargo. The expectation is to handle the extra capacity of the line derived from the passenger's demand for introducing cargo services, aiming at a better efficiency for the investment. The analysis takes the passenger and cargo operations into consideration as well as all the impacts on the several potential stakeholders such as government, infrastructure manager, operator, other transport modes operators and society. This brings a multi-dimension into the decision process turning the analysis more complex but also more comprehensive. Stakeholders typically have different objectives and concerns. Their perspective and commitment to project varies according to these objectives and concerns. Thus, solutions need to find a compromising platform between those stakeholders in order to become implementable. As a result, a more comprehensive multi-stakeholder method is preferably used, instead a traditional cost-benefit approach. The feasibility of this method, called MATE – Multi-Attribute Tradespace Exploration, for dealing with this complex transportation issues and associated constraints is discussed and the result is positive, not only for the problem addressed but also for the recognition of its potential to be applicable to other transportation domains.

If one takes into consideration that rail-cargo activity should integrate a rail-road facility in order to turn the service commercially viable, results show the ability of the investment to integrate cargo trains in the daily routine of the line evaluated.

Resumo

A presente tese apresenta uma aplicação metodológica que lida com a introdução de carga contentorizada na operação da linha ferroviária de alta-velocidade entre Lisboa e Madrid. A futura linha ferroviária é representada por um grande e complexo sistema de transporte com um longo ciclo de operações. O planeamento eficaz da infraestrutura considera o desempenho do seu ciclo de vida, dado que o desempenho da infraestrutura não depende apenas do projeto inicial mas também das decisões de manutenção e renovação tomadas durante o ciclo de vida da infraestrutura. Além disso, a fim de garantir um resultado ótimo para o sistema ferroviário implementado, estas decisões deverão ser tomadas e avaliadas de forma metódica. Desde modo, é obrigatório que todas as opções (pré e pós-operação) sejam avaliadas, de forma a servir eficazmente a procura de passageiros e melhorar a eficácia do investimento de carga.

Por diferentes motivos, a introdução de carga em linhas de alta-velocidade não tem sido uma opção de investimento nos diferentes sistemas de alta-velocidade implementados. Os principais motivos centram-se com os custos de operação, manutenção e as restrições operacionais que decorrem da circulação destas composições, nomeadamente em termos de reabilitação da via e segurança para os passageiros. A presente investigação tem como objetivo a introdução de mercadorias 'leves' na ligação de alta-velocidade entre Lisboa e Madrid e a avaliação do investimento necessário para o transporte de carga com recurso a material circulante dedicado. A expectativa é utilizar o espaço deixado pela operação de passageiros, para a introdução dos serviços de carga, de forma a melhorar/otimizar a eficiência do investimento. A análise leva em consideração as operações de passageiros e carga, bem como os impactos sobre os potenciais grupos de interessados selecionados, tais como o Estado, o Gerente da Infraestrutura, operadores e a sociedade em geral, integrando-os numa análise muti-dimensional. Os grupos de interessados selecionados têm, por norma, diferentes objetivos e interesses em relação à avaliação que fazem do investimento em análise. A sua perspetiva e ação de compromisso variam em relação a estes objetivos e preocupações. Assim, as soluções necessitam de encontrar um ponto de compromisso entre as diferentes partes interessadas, de forma a tornarem-se exequíveis. Como resultado, é apresentado um método multi-decisor mais abrangente do que as tradicionais abordagens Custo-benefício. A viabilidade do método MATE - Multi-Attribute Tradespace Exploration, para lidar com questões relativas a sistemas de transporte complexos, é aqui discutida e os resultados demonstram a capacidade para lidar não só com o problema abordado mas também o reconhecimento para lidar com outros domínios de transporte.

Os resultados consideram um investimento em instalações de apoio rodoferroviário (plataforma logísticas) de forma a tornar comercialmente viável o serviço de transporte de carga e demonstram a capacidade do investimento para integrar o serviço de carga na rotina diária da operação da linha Lisboa-Madrid.

Recomeça...

Se puderes,

Sem angústia e sem pressa.

E os passos que deres,

Nesse caminho duro

Do futuro,

Dá-os em liberdade.

Enquanto não alcances

Não descanses.

De nenhum fruto queiras só metade.

Miguel Torga

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List of Acronyms

ADIF	Administrador de Infraestructuras Ferroviarias
€	euro
AVEP	Alta Velocidade Espanha-Portugal (High-Speed Spain-Portugal),
ARRA	American Recovery and Reinvestment Act
AVE	Alta Velicidad Espanola (Spanish High-Speed)
BRT	Bus Rapid Transit
BVWP	Bundesverkehrswegeplan (Federal Transport Infrastructure Plan)
Cap	Captured Demand
CBA	Cost-Benefit Analysis
CHSRA	California High-Speed Rail Authority
COTIF	International Carriage by Rail
CP	Comboios de Portugal EPE
DB	Deutsche Bahn (German Railway Company)
DVM	Design Value Matrix
EBA	Eisenbahnbundesamt (Federal Railway Authority)
EIB	European Investment Bank

ERTMS	European Rail Traffic Management System
EU	European Union
FS	Ferrovie dello Stato (Italian rail company that manages infrastructure and services)
GDP	Gross Domestic Product
GINA	Generalized Information Network Analysis
GIF	Gestor de Infraestructuras Ferroviarias (Spanish rail company that manages infrastructure and services)
HS	High-Speed
HSR	High-Speed Rail
ICE	InterCity Express
Ind	Induced Demand
INE	Instituto Nacional de Estatística (Statistics Portugal)
km	kilometer
km/h	kilometer per hour
kV	Kilovolts
LEP	Lottery Equivalent Probability
MATE	Multi-Attribute Tradespace Exploration
MATE-T	Multi-Attribute Tradespace Exploration applied to Complex Transportation Projects
MAU	Multi-Attribute Utility
MAUT	Multi-Attribute Utility Theory
MCA	Multi-Criteria Analysis

MIT	Massachusetts Institute of Technology
NPV	Net Present Value
NST	Nomenclature Statistique des Transports
PGT	Piano Generale dei Trasporti e della Logistica (Plan for Transport and Logistics)
pkm	Passenger-kilometer: 1 passenger transported a distance of 1 kilometer
PPP	Public-Private Partnership
Pt	Portugal
RAVE	Rede Ferroviária de Alta Velocidade (High-Speed Infrastructure Company)
REFER	Rede Ferroviaria Nacional EPE (Portuguese Rail Infrastructure Manager)
RENFE	Red Nacional de los Ferrocarriles Españoles (Spanish Operator)
RFF	Reseau Ferre de France (French National Railway)
RFI	Rete Ferroviaria (Italian Rail Company)
RS	Regional High-Speed
SEAri	Systems Engineering Advancement Research Initiative (MIT)
SNCF	Societe Nationale des Chemins de Fer de France (French Rail Company)
Sp	Spain
t	tonne = 1000 kilograms
TEN-T	Trans-European Transport Network
TERFFs	Trans-European Rail Freight Freeways
TEU	Twenty-foot Equivalent Unit
TGV	Train à Grand Vitesse (French High-Speed Rail)

TINA	Transport Infrastructure Needs Assessment
tkm	Tonne-kilometer: 1 tonne transported a distance of 1 kilometer
TSI	Technical Specification for Interoperability
UIC	International Union of Railways
US / USA	United States of America
VAT	Value Added Tax

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Rail Cargo on the Lisbon-Madrid High-Speed Rail Line

An Assessment of Feasibility

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1 INTRODUCTION

1.1 Context and Objectives

In the modern society, the transport infrastructures are seen as generators of the economic development and competitiveness of the economy. The permanent development and innovation of transportation system makes the movement of people, goods and information possible, which is usually called mobility. Even within this definition mobility is still one of the most decisive economic factors, and seen as an economic engine (Savelsberg, 2008).

The economic development of a country is mainly driven by the level of investment, trade and consumption. As a means of enabling trade, transport is assumed to be a key factor of the economic level achieved by a country. A good transport network has an important role to play, moving towards the objectives of a balanced competition, social and spatial cohesion, and environmental objectives. A high quality network is a crucial element to ensure regional development objectives, social inclusion and territorial cohesion.

However, transport is a major consumer of resources and a pollution producer. In fact, concerns about the externalities of road transport such as environmental impacts, influence on the quality of life and congestion have influenced the panorama of transports. Transportation policies are usually defined to identify challenges, evaluate options, manage goals, detect constrains, engage stakeholders and establish success criteria. This way, as a general trend, these policies aim to reduce road traffic and promote sustainable mobility.

The relationship between transportation and economic activity has been the object of several studies and is fairly established that historically the growth of transport infrastructures has led the economic growth of regions. However the scale and objectives of each study imply different approaches and therefore different methods, models and variables. The main issue is on whether there are additional investment benefits risen by the economic development (Banister and Berechman, 2001). Economic development and economic growth are linked to the transportation investment and play a high value in the direct transport benefits. Related to the transport investment type, in developed countries, the infrastructure might not result on its own in economic growth. Nevertheless, the transport investment is specifically located in order to have the potential to raise the effects on local economies. Consequently, the economic growth measurement must take place at the local level. A three-dimensional framework is preset by several authors in order to identify the scale of the analysis, the type of variables used to assess the investment and its impacts. Additionally the relationship between the types of measurement at national, regional and local level (Banister and Berechman, 2004, 2001; Ribeiro, 2008; Rietveld and Bruinsma, 1998). At a national level it is expectable to have an infrastructure that can compete at an international level in new global markets and at the same time that public investment and the private can support the expectable growth. The infrastructure at a regional level is seen as an accessibility concept. That is, the investment results in a redistribution of employment or the creation of new activities, which is usually defined as economic growth. Finally, at a local level the problems are related to congestion, or in the way that the new infrastructure might influence the urban territory.

A demand-led approach has been followed by heavy investment in the network to meet expected growth. This approach has been modified through management based policies – as traffic management or demand management – but even here inefficiencies increasingly occurred as a demand that continues to grow and congestion created. New strategies are required in order to mix both the physical and the financial options in combination with opportunities to develop strategies with transportation management policies.

The factors that influence the development of transport systems have changed over the time. In the past, the speed increase in transport was a huge milestone. Then the transport infrastructure expansion allowed the mobility within wider areas, increasing the average transport distance of passengers and goods. The economy of scale, translated by the time-cost related to transport and the increase in the efficiency of transport terminals allowed a reduction of transport time and costs, increasing the capacity and the reliability of the transport systems.

When defining new developments, it is important to evaluate new links, particularly the strategic ones at different levels. Besides, it is also important to perform a wider evaluation of links and networks in a way that the supporting means – finance, regulation, competition, organizational factors, communications, etc. – are also included. The dynamic of the processes turns to be interesting and informative, as the use of networks changes radically. The major changes are the decision making process used by all interested parties at different decision levels. Consequently, the investment in transport infrastructures has a significant impact on economic development. The reasons are connected to the relationship between transport investment and economic development. In developed countries, the massive investment in transport infrastructures has little impact on the economy and territorial development. In this case, the investment is more related to where it is made and what it incorporates in the existing network. Therefore, the investment appraisal regarding a transport infrastructure has to be done in a careful manner. An analysis is required not only for the immediate and direct effects, but also to integrate the investment in the context of the infrastructure's life cycle and in the context of the involved regions.

To keep competitiveness of their transport systems, European countries are allocating large amounts of money in the field of transport infrastructures and logistic terminals. This means that it is important to evaluate the future investments given the economic environment and expectations regarding the growth of mobility. On the other hand, it is also interesting to characterize the passenger and freight sector, including existing infrastructure and flows in order to promote a more equitable distribution of different transport modes.

The Lisbon-Madrid high-speed rail connection is part of the Trans-European Network Projects and the main object of this thesis. The goal is to link the two Iberian Peninsula capitals and enhance the revitalization of surrounding regions. Hence, the connection provides a high-quality alternative that directly competes with air transport and private vehicles. At the same time, it promotes a higher cohesion and territorial integration for Alentejo (Portugal) and Extremadura (Spain). As an additional goal, and in line with the current White Paper on Transport (European Commission, 2011a), the high-speed rail connection contributes to a more sustainable mobility by reducing greenhouse effects and energy consumption full costs. Besides, there is a significant time saving expectation related to high-speed rail even when compared with the regular air operation (considering the door-to-door duration), which might increase mobility and simultaneously promote a reduction of road traffic and accidents.

The European high-speed railway lines link populated regions which induce high levels of demand. The Lisbon-Madrid high-speed rail line, although not primarily planned for freight transport like many other European high-speed rail lines, has a low level of passenger demand that enables the use for passenger and freight-rail trains. The Lisbon-Madrid link is connected to major freight routes, which are integrated and interoperated in the Trans-European network. Thus, regarding freight-rail transport, the new line may be used to enhance intermodal solutions and increase rail market share. The logistic systems in both countries may benefit from such investment, straightening their strategic position in the European market.

The future high-speed rail network can thus contribute to a better modal distribution, both for passenger and freight, changing the current hegemony of roads in the Iberian Peninsula, mainly for the Portuguese side. The reaction could be the increase in mobility and competitiveness of the ports, airports and logistic systems together with the new high-speed rail line acting as the backbone of transport services.

1.1.1 High-Speed Rail (R) evolution

Rail transport is enjoying a resurge due to the technological advances in the latter part of the twentieth century. In passenger transport high-speed rail systems are a breakthrough in speed. High-speed gives rail a huge competitive advantage over road transport and even over with air transport of over short and medium distances.

Since the 1960s, when commercial operations began, high-speed rail has been introduced as a story of success regarding demand and revenues. In many countries, high-speed rail has been seen as a key factor for passenger traffic revival, a declined business that had lost its momentum due to the aggressive competition of road and air transport (Rus et al., 2009).

Development high-speed rail corridors can involve a large long-time investment. High-speed rail is a complex system that besides speed innovation includes infrastructures, adapted rolling stock, signaling system, maintenance system, stations, operation management, financing and a roll of legal aspects among other components. The initial investments are high due to the construction of rail tracks and provision of expensive rolling stock. Railway network is affected by topography given the lack of capacity of locomotives to mount gradient. As result, railways avoid important natural barriers or overcome them by costly engineering solutions.

There are many technical differences between conventional and high-speed trains that go beyond speed. Conventional and high-speed railways can coexist in the same network depending on how the infrastructure and the market are organized. Different countries adopt different exploitation models for these two types of train operations. In Japan, for example, high-speed rail runs on exclusive tracks. In France, high-speed rail uses upgraded conventional tracks for final approaches into city centers. The Spanish infrastructure enables conventional trains to use high-speed rail tracks. Other models, like a particular one in German, allows for freight to use spare capacity of the high-speed tracks during night-time slots.

The chosen model determines the service that the new high-speed rail will provide. This decision affects not only the overall construction and operating costs but also the benefits received from the operations of the service and also from added traffic restrictions. The decision to implement a new high-speed rail service or choosing a particular exploitation model should not be solely based on costs. The decision should be based on whether the economic and social benefits gained from such system are high enough to compensate its infrastructure and operating costs. Besides, in this decision a multi-dimensional evaluation should also be undertaken in order to evaluate the ambitions of the group of decision-makers involved (users, non-users, managers, operators, etc.) which are not usually enrolled in the process but are determinant regarding the life cycle success of the project.

As with any transport infrastructure project, when an entity is looking into the possibility of developing a high-speed corridor it is necessary to evaluate which financing mechanism is available. There are several business models that can be applied. These range from purely public, public-private partnerships, to purely private. Literature suggests that given the specific characteristics of transport infrastructure projects the involvement of the public sector is always required (Rutzen and Walton, 2011). The public sector interest goes beyond financial gain to take social-economic benefits into account.

High-speed rail is well studied regarding the ability to perform in terms of market shares in corridors of 400 to 600 kilometers but other characteristics are under great discussion and further research is needed. Given the high investment, maintenance and operation costs involved, high-speed rail projects need to be associated to the capacity of changing modal split between big trip generation regions and to the potentiality of generating major economic and social benefits. A mix of arguments, besides time saving – strategic considerations, environmental effects, regional development, and so forth – has often been used with inadequate evidence to support the building decision (Rus, 2009; Rus and Nash, 2007). Given the recent economic constraints the opportunity cost raised by the high-speed railway clashes with the society's willingness to support the huge investment. However, several studies performed in the last twenty years report to the economic vision against the political ambition regarding the construction of high-speed rail lines (Levinson et al., 1997; Nash, 2010; Rus and Nash, 2007; Rus and Nombela, 2007).

1.1.2 Evaluation Framework and Modelling Assumptions

In order to devote funds to new transport infrastructure projects, such as the high-speed rail project, the significant effect on 'economic development' is sometimes used as an argument, either at a national or regional level. However, there is no firm understanding of what 'economic development' really means or what is its real significance into the project appraisal (OECD, 2002a). However, some studies have already evaluated the social and economic impact of high-speed rail as a tool for regional development (UIC, 2011). Taking this into account, it becomes mandatory to evaluate the transport investment contribution in the economic structure and analyze the impacts that should be handled in the project appraisal evaluation.

The main instrument used by decision-makers in the appraisal of transport investment is a cost-benefit analysis. The framework aims to estimate the costs and the benefits of a given project in monetary terms. Then, one can establish which limited resources are being allocated efficiently with the aim of maximizing the welfare of society as a whole. This appraisal method varies somewhat from country to country. The evaluation of projects using the traditional cost-benefits analysis does not justify the socio-economic interest of the public or private sectors because it does not adequately take into account the regional impacts that arise from the investment (OECD, 2002a). Consequently, there is no universal agreement on the extent to which cost and benefits should be disaggregated, which impacts should be included and how they should be monetarily quantified.

Facing increased constraints in financing transport infrastructure, many countries are willing to allocate their resources in a way that maximizes their net return to society (OECD, 2002a). An investment in the rail sector implies a huge amount of financial resources and represents cost and benefits for a wide variety of institutions, companies and individuals (European Investment Bank, 2005). The rail investment involves a large variety of activities, actors and resources which infer a certain degree of technological as well as organizational complexity. The decisions taken are rarely based on one single perspective because different stakeholders are usually involved in different decision-processes, which increases the complexity of the analysis.

Several attempts are made in order to evaluate transport studies using a common framework. The difficulty in comparing them is notorious since the evaluation framework or the regional impacts differ significantly from one study to another. Usually, evaluations are based only on one transport mode, avoiding more complex questions of multimodality or intermodality of transport projects. Thus, it is also related to the definition and size of the impact's area considered and the stakeholders involved.

Besides the methodology involved, there is often a lack of consistent and reliable data. The lack of information makes quantitative evaluation difficult. Travel time, vehicle operation and accessibility are common variables. These are considered and compared in order to identify the impacts. However there are several variables that are not always taken into account. These variables could analyze back-up measures taken by the state, or by managers or operators or even by non-direct users, in order to reinforce the beneficial effect of the new infrastructures and tackle the negative impact. The evaluation can be optimized adding information about the relationship to other transport modes, since improvements on one transport mode can have an impact on other modes. Information about the quality and level of service is also important (comfort, usefulness, frequency, etc.) The reliability of the service as well as environmental impact are important attributes to take into account. All these issues need a more broader and effective analysis framework.

1.2 Research Objectives and Methodology

Decision problems in the public domain are very complex and involve multiple conflicting objectives, nebulous types of non-repeatable uncertainties, costs and benefits accruing to various individuals, businesses, groups, and other organizations (Keeney and Raiffa, 1993). A purely objective analysis might fall on providing guidelines for decision making that the output of the analysis may not pass the threshold of relevancy. A complex problem – and for that matter a complex transportation problem – demands the consideration of subjective values and tradeoffs. The main issue is not whether subjective elements should be considered, but whether they should be articulated and incorporated into a formal analysis.

It is often said that formal analysis is incomplete for complex problems, since these problems require subjective evaluations in order to quantify the unquantifiable. The trouble with formal analysis is not that subjective evaluation cannot be accommodated into the framework but that there is a demand for too many subjective inputs. On the other hand, decision-makers argue for inclusion of subjective evaluations even if they are reluctant to write these evaluations down.

Portugal and Spain are still debating the plan for the implementation of a rail network as part of the Trans-European Network. The future infrastructure integrates Portugal and Spain into a fully interoperable Trans-European high-speed rail network. During the past years, the future network was seen as a way to increase rail share regarding international freight and to improve connections between southern and northern Europe (IMTT, 2008). REFER – *Rede Ferroviária Nacional, EPE*, as the Portuguese infrastructure rail manager (at that time), has carried out most of the rail infrastructure investment with the enrolment of the private sector (in both construction and operation) (REFER, 2013).

Given the economic constraints, the high-speed rail project, as initially planned, changed during the last years. The strategic transport planning was reorganized and took into account the investment needs in order to balance the financial scale. Thus some measures from the initial plans were reviewed. The number of links was rescaled and the emphasis was the international connections. The decision took into account the politics of sustainable mobility, promoting social and territorial cohesion as well as economic development (European Commission, 2014). Hence, the future projects should promote the connection between the conventional line, logistic platforms and sea ports. Regarding the Lisbon-Madrid connection, besides the passenger service, it is expected that the line promotes an interoperable link for freight between Évora and Caia and a direct connection to Sines sea port is also in debate. The new solution aims to increase the Iberian attractiveness and extend the Madrid hinterland.

For different reasons, cargo is not, until now, a target revenue segment for high-speed rail lines. The main reasons for this are the serious maintenance and operational constraints that occur when conventional freight-rail trains are ridden in a high-speed rail line, namely in terms of the track maintenance rehabilitation and safety for passengers. The present research aims to include the delivering of 'light rail-freight' on the Lisbon-Madrid high-speed rail connection in the investment evaluation through the use of passenger rolling stock to deliver cargo. The expectation is to handle the extra capacity of the line derived of the passenger demand for introducing cargo services, aiming at a better efficiency of the investment.

The main research objective is to consolidate an evaluation system of the feasibility of the investment in complex transport infrastructures through by the study analysis of the Lisbon-Madrid high-speed rail connection case. The analysis takes the passenger and cargo operations into consideration as well as all the impacts on the several potential stakeholders such as government, infrastructure manager, operator, other transport modes operators and society).

The final goal is to find the solution(s) that have the highest utility (best judgment for someone in the context of a certain reality) for the main stakeholders involved. To deal with the combination of stakeholders, costs and utilities, one applies the MATE (Multi-Attribute Tradespace Exploration), a method developed by SEAri-MIT (SEAri, 2009). This method was already applied to several aerospace case studies with good results (Ross, 2006). However, MATE is recognized to have the potential to be applicable to other domains (Nickel, 2010). As a result, due to the complexity involved, transportation is certainly one of those domains and this study does the first attempt to use the method in this field.

1.3 Structure and Scope

This thesis is organized in 6 chapters. The present chapter (1) gives an overview of the problem, defines the research questions to answer and appoints the methodology to be used, concluding with the description of the structure of the thesis.

Chapter 2 presents the state-of-the-art of the present document. Different high-speed rail project case studies are presented as well as the most common forms of investment appraisal. A deep insight is given to rail-freight transport and its capability to become a reality in a high-speed rail infrastructure.

Chapter 3 supports the methodology. The effects of the evaluation with several stakeholders are clarified, as well as the estimation of the expected financial transfers between them and their role in the decision making process. The process takes advantage of information that is usually available for the traditional cost-benefit analysis and uses other detailed data provided by the agency that dealt with the project (just for passengers) on the Portuguese side. The information related effects and stakeholders, summarizes the main economic and financial implications of the project, the transfer between stakeholder and the distribution of costs and benefits. It also integrates non-monetized effects and overall indicators of the investment profitability. The evaluation system used is an application to the transport sector of the tool developed by Seari-lab at MIT called MATE - Multi-Attribute Tradespace Exploration (SEAri, 2009).

Chapter 4 presents a general overview of the Lisbon-Madrid line, as well as the investment and the decisions taken by different studies.

Chapter 5 presents all the results achieved from with Chapter 3 and Chapter 4 data. The results concern the feasibility of the cargo service together with passenger service, in the operation of the Lisbon-Madrid high-speed rail line. The results translate the stakeholder expectation regarding the project solution and suggest that light cargo should be considered as new target revenue for this transport segment, using the infrastructure applied for passengers and leading to a new way of high-value goods delivery.

Chapter 6 presents the main conclusions of the research and describes the main assumptions that can be made and implemented. It also indicates the path that should be followed in order to validate the current appraisal system.

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2 HIGH-SPEED RAIL CONTEXT

2.1 Introduction

High-speed rail is a transport system that has become more and more popular world-wide. Currently there are high-speed established systems of different ages in different European and Asian countries. In recent decades, one of the main railway activities in Europe has been the construction of new infrastructures specially designed for high-speed rail running (López-Pita et al., 2008). At the same time, there are other countries looking into building new routes, like the United States.

Many reasons can be pointed out to understand why a country might wish to construct a high-speed rail line. From congestion in existing transport modes to the desire to reduce dependency on fuels, the fundamental purpose of a high-speed rail system turns out to be moving people and being accessible (UIC, 2012).

High-speed rail should not be regarded as an element but as a complex system that includes infrastructure, rolling stock, signaling system, maintenance system, stations, operation management, financing and other components among legal aspects. It is not a unique system and its implementation needs to be adapted to take the different settings in each location into account such as commercial and operational features.

The design, construction and operation of a new high-speed rail line is a complex task which is influenced by many stakeholders, requirements, challenges and objectives which must all be carried about. A high-speed rail system ideally connects populations and economic centers, providing an additional mode to compete with airlines and private vehicles. As a result additional transport capacity is combined with to the additional routes. High-speed rail system is mainly designed and built with the intention of moving people in a faster, safe manner and enhancing environmental gains. To meet this purpose, there must be rigorous technical requirements that the system must comply with regarding design, construction and operation (UIC, 2012).

High-speed rail is often seen as an isolated system and simply as advantageous or disadvantageous as compared to other transport systems. However, the international experience tell us that high-speed rail has the effect of generating re-examinations on how other modes will meet future transport, economic development and policy objectives. Considering this, high-speed rail should support transport service as a complement. Other benefits relate to the decrease of congestion. One of the high-speed rail benefits is to provide an opportunity to reallocate and improve capacity on the existing systems. This provides an opportunity to make way for new commute or freight services. Thus, high-speed rail projects can benefit freight operations by creating capacity and optimize infrastructure performance. As a result, high-speed rail project represents an opportunity to transform cities and regions and stimulate regional development.

This chapter presents an overview over the high-speed rail history around the world. The main insights relate to different approaches regarding economic evaluation and decisions taken. Cargo-rail is also being debated and evaluated with several attempts being studied on a European level.

2.2 High-Speed Rail Definition

After the World War II, Japan and European countries emphasized the need for rebuilding their railway network. The development of the Japanese network, the oldest high-speed rail network in operation implemented since 1960, benefits the regional and national economy. European Union followed this success and since the 1990s has adopted the Trans-European Transport Network plan. Trans-European Transport Network aims at the integration and interoperability of all its member states and coordinates improvements on roads, railways, inland waterways, airports, seaports and traffic management systems.

During this time, the United States of America was focusing on improvements on roads and airports. Due to a lower population density and a more automobile-oriented culture promoted by its easier access, passenger rail is not as competitive in the United States as in other parts of the world (Rutzen and Walton, 2011). However, a similar approach made to the European Union is being followed by the United States federal government in order to designate future high-speed rail corridors.

Although high-speed rail shares the same basic principles as conventional rail, several differences can be established between the two systems. The main difference is the commercial speed in which each system operates. High-speed train operates at a speed above 200 km/h and has been tested up to 515km/h (Ellwanger and Wilckens, 1994; Whitelegg and Holzapfel, 1993). The speed performance requires trains to operate in tracks with special geometrical characteristics such as curve radius. Considering this, the high-speed rail system requires the use of appropriate rolling stock that enables it to reach those higher-speeds. Another significant difference between conventional and high-speed rail is the signaling systems. Traffic on conventional tracks is controlled by external electronic signals together with automated signaling systems, whereas signaling between high-speed trains and blocks of tracks are usually fully in-cab integrated, eliminating the need for drivers to see line-side signals (Rus et al., 2009). There is also a difference in the electrification of the lines. High-speed lines require at least 25000 volts to achieve enough power, while conventional line may operate at lower voltages.

Nevertheless, there are many technical differences between conventional and high-speed trains that go beyond speed. These two types of railways systems can coexist in the same network depending on how the infrastructure and market are organized.

2.2.1 Economic Aspects within High-Speed Railways

The evolution of transport activity as a whole is at approximately the same rate as the evolution of the Gross Domestic Product (GDP) (Figure 2.1). During the last decades the European economy has benefited from the fact that the transportation cost carries marginal economy weight, generates wealth and employment. Transportation systems offers a highly efficient organization which all European citizens have experienced during the last decades (Savelsberg, 2008).

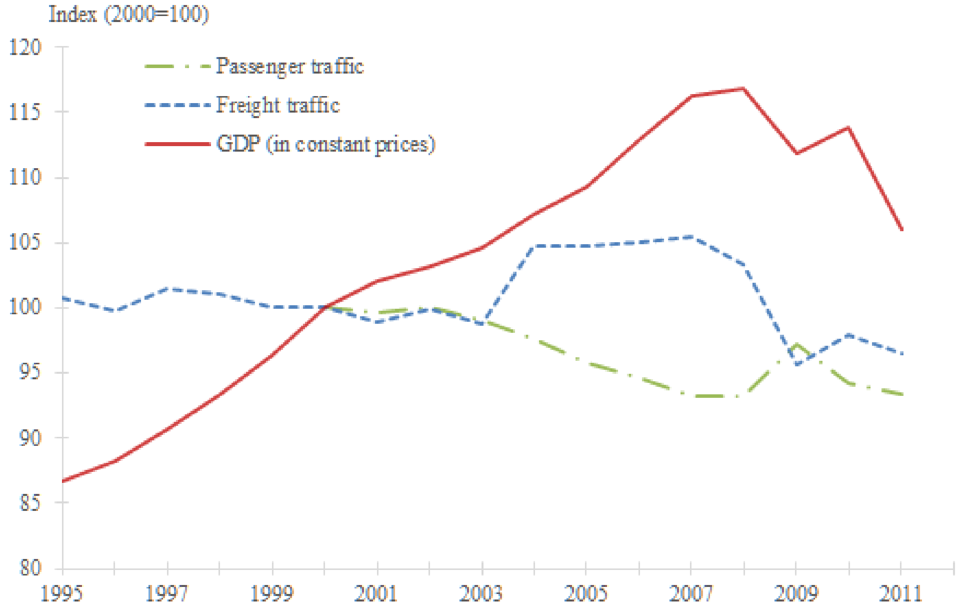

Figure 2.1 Growth of transport and Gross Domestic Product EU 27 (1995-2011). (1) Total passenger traffic (passenger-kilometer). (2) Total freight traffic (tonne-kilometer). (3) GDP at constant 2000 prices. (source: (Eurostat, 2013a))

Currently, goods and people can circulate quickly and easily between Member States. However, major efforts and investments have been implemented in order to build the missing links and remove the bottlenecks in the transport infrastructure. Quoting Jacques Barrot, Commissioner for Transport (2004-2008), the Trans-European network is a key element in the (re)launched Lisbon strategy for competitiveness and employment in Europe (European Commission, 2005).

A truthful Trans-European network (TEN-T) is vital for the economic and social cohesion of the European Union and the achievement of a single market in goods and services (European Commission, 2001a). The TEN-T program plays a vital role in financing transport infrastructure by granting support to selected European projects in all transport modes and in every European Member State, with the ultimate aim of forming a multi-modal network that allows people and goods to circulate quickly and easily in a single European transport area. TEN-T projects are also helping to build an integrated, greener and ultimately decarbonized European transport system from which all European citizens, both economically and socially will benefit (European Commission, 2012a).

European countries and its regions are moving towards an economic network, where important nodes of economic, cultural and technological progress are linked together by a well-connected infrastructure network. Particularly after the approval of the Maastricht Treaty the notions of inter-connectivity, inter-operability and inter-modality have gained much more popularity (Nijkamp, 1995). The development of high-speed rail as a new network of transport speeded in the European countries and became a key element in the TEN-T's priority (Vickerman and Ulied, 2006). Although the primary motivation for the early high-speed railway lines was to enhance capacity, the step change regarding speed and the improvement of the quality of the European infrastructure network have also been made clear.

The European railway sector follows the opportunity for competitive operations on medium and long distance. The European railway network requires a strong cooperation among railway companies. In order to emphasize the circulation of high-speed trains through the several train networks of the European Union, Member States aim to harmonize the high-speed rail system in order to create an interoperable European network. The European Council Directive 96/48 establishes three different types of lines (European Commission, 1996a):

- Specially built high-speed lines equipped for speeds generally equal to or greater than 250 km/h;
- Upgraded conventional lines, equipped for speed around 200 km/h;
- Other upgraded conventional lines with special features as a result of topographical or land-planning constrains, on which the speed must be adapted to each case.

The current technical definitions are broad enough to include all rail infrastructures capable of providing high-speed services. However, practice has shown that speed is not always the best indicator. The commercial speed is limited in many services due to the proximity to densely urbanized areas or due to viaducts or tunnels where speed must be reduced.

Numerous improvements and new technologies have been conceived in order to allow commercial exploitation of high-speed rail transport. These innovations are visible in the infrastructure, which has been modified in order to handle with the high-speed constraints. High-speed railways share the same engineering principles with conventional railways – both are based on the fact that rails provide a very smooth and hard surface on which rail wheels roll with minimum fraction and energy consumption. The technical differences play a significant role from an operational point of view. The differences are more significant on the signaling system, whereas traffic on conventional tracks is usually controlled by external signal together with automatic signaling system, the communication between a high-speed rail train and the different blocks of the track is usually fully in-cab, which eliminates the need for drivers to see line side signals. Other key difference is the electrification system considering that most high-speed railway lines require at least 25000 volts to achieve enough power, the conventional lines operate at lower voltages.

However, it is the relationship with the existing conventional services together with the use of the infrastructure that plays a more relevant role in the economic definition of high-speed services. Regarding to all this and according to Campos and Rus (Campos and de Rus, 2009) four different exploitation models can be identified as explained in Figure 2.2.

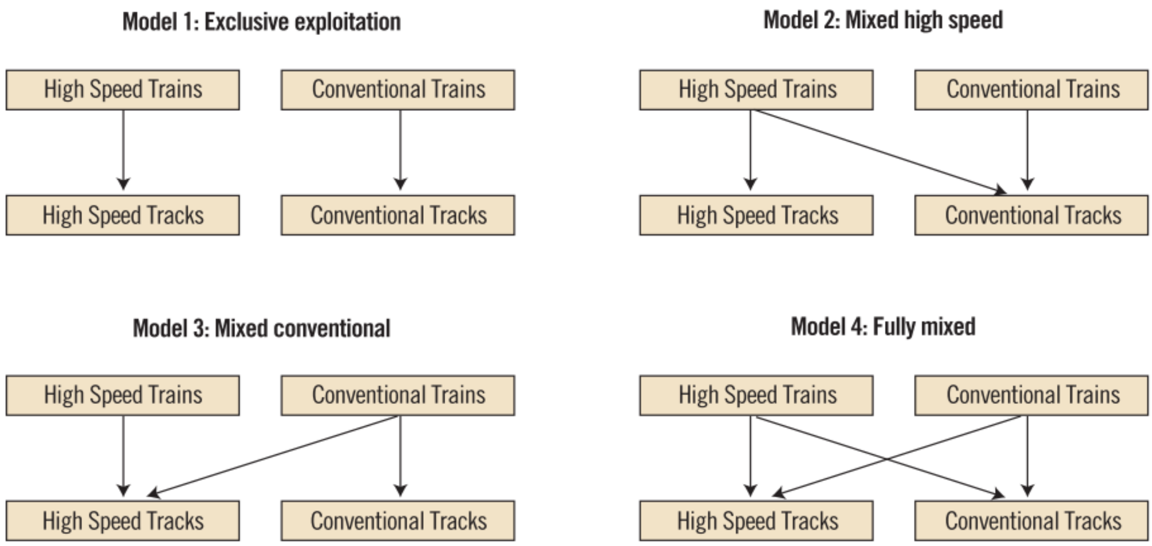

Figure 2.2 High-speed rail models according to the relationship with conventional service (source:(Rus et al., 2009))

The first one, the exclusive exploitation model is characterized by a full separation between high-speed and conventional services. The major advantage is that the market organization of both services is fully independent. This model is used in Japan where the main reason for the development of a high-speed rail system was that conventional lines had reached its capacity limits.

The second model defined in the figure is the mixed high-speed model, in which some conventional trains can operate on specifically built new lines or on upgraded segments of conventional lines, reducing construction costs. This model is followed by the French TGV (*Train à Grand Vitesse*) system. Due to the lack of space to duplicate the line the TGV trains use upgraded conventional tracks for approaches to city centers.

A third exploitation model, the mixed conventional model adopted by Spanish railway system, allows some conventional trains to run on high-speed tracks. To enable its use, a specific technology for rolling stock was developed in order to easily manage the interoperability of international services. The main advantage is the rolling stock acquisition savings and the flexibility for providing intermediate high-speed services on several routes.

The fourth model, the fully mixed model, allows the maximum flexibility. In this case both high-speed and conventional services can run at their own speeds, on each type of infrastructure. This case is represented by the German intercity trains and the Rome-Florence line in Italy. High-speed trains can use the upgraded conventional lines, and freight services might use the spare line capacity during the night. This model is more expensive regarding maintenance costs.

The reason why it is important to define the high-speed rail service it's because it infers with traffic management restrictions. The chosen model affects building costs and maintenance cost, or the cost of upgrading and maintaining the existent line (conventional line). The decision to implement high-speed rail service or choosing one exploitation model over another should not be based only on costs. The decision should also be based on the economic and social benefits gained from one system, on whether they are high enough to compensate infrastructure and operating costs.

Campos and Rus also considered three additional factors that contribute to the definition of high-speed rail in economic terms (Campos and de Rus, 2009). The first of them is rolling stock type. The rolling stock specificity needs to be adapted to the high-speed features. High-speed rail train-set is designed to run without locomotives, which means that both extremes of the train can be used as the initial one, with minimum oscillation on curves with higher radial speed and without the need of tilting compensation for the centrifugal push. The second reason relates to the public support. High-speed rail, particularly in Europe, undertakes the public support. National governments compromised a significant amount of funds regarding the development of high-speed networks. Moreover, the European strategy aims to revitalize the railways as a meaning for shifting the balance between modes (European Commission, 2001b). The third reason has to do with the demand for high-speed rail services. The high-speed rail service began to be claimed as a different mode of transport, with a dedicated infrastructure and with a more specialized and technological advanced rolling stock. It provides an improvement over traditional rail transport which increases the added value for the passenger or cargo to be delivered.

Several research studies point out the relevant characteristics of a high-speed rail in order to become commercially viable. High-speed rail is dependent on high demand and also on shortening the distance between two cities. Results from G. De Rus and Nash (Rus and Nash, 2007) suggest that, given the usual rail demand values in Europe, investment in high-speed rail infrastructure on a single corridor can rarely be justified on the basis of time savings and the net willingness to pay off generated traffic alone. However the high-speed investment can be justified by a combination of factors: the need of bypass bottleneck sections, the existence of network benefits arising from serving a variety of traffic flows with a single link, and the presence of congestion or environmental problems in competing transport modes. According to Vickerman, depending on construction costs, a high-speed rail line needs to generate, at least, 12-15 million passengers a year to became viable (Vickerman, 1997).

In the available literature on the matter, it’s possible to find researches describing the main benefits related to high-speed rail investment. The direct benefits are: passenger time saving, increase of comfort, reduction in number of accidents, and shortening of environmental externalities. Time saving benefits are dependent on the door-to-door travel time for the available modes compared to the difference achieved on high-speed rail. Time saving also depends on how time is valued by the user (if it is work-related or leisure). The increase in comfort is in terms of space, noise, acceleration and any number of services that can be provided by the operator such as catering service, bar, use of electronic devices, etc.

Additional capacity benefits are only relevant if the demand exceeds the capacity of the existing modes (Rus et al., 2009). The British railway leaded out a study which suggested that about 50 percent of the new high-speed rail line traffic is diverted from other modes, mainly car and air. The remaining value are new trips (Atkins, 2002). The diversion of traffic causes reduction in congestion and decreases delays in road and airports. High-speed rail might offer a higher capacity of transport of 400000 passengers per day (UIC, 2009).

High-speed rail is seen as the safest transport mode, in terms of passenger fatalities. The amount of accidents involving high-speed trains is reduced and only few of these reported fatalities. High-speed rail is usually recognized to be a less polluting mode, when compared to air and road transport. Nevertheless, the quantity of polluting gases generated to power a high-speed train depend on the amount of energy consumed and the air pollution generated from the electricity plant that produces such energy (Rus et al., 2009; Rutzen and Walton, 2011).

The current development on high-speed systems shows that investments should not be based and supported on expectations regarding economic development benefits. The reason for investment must be seen as a change in transport mode and the capacity to serve the railway market better than before and also compete with air mode. There is no doubt that high-speed rail can provide for socio-economic benefits and mostly improve the accessibility of the cities that are served (Givoni, 2006). In order to increase benefits, the new links should serve many cities and include many stops. However, more stations in a high-speed railway line mean a lower average speed and a lower capacity on the route which lead to an increase on travel time. From an European Union perspective, the difficulty is to determine the added value of the networks, both from the key cross-border elements and from the key linkages between cities within member states (Vickerman, 2006).

2.2.2 Financing a High-Speed Rail Project

The idea of embarking on a high-speed line project may stem from requirement's expresses – the overall transport service not in line with real travel needs, or from the political determination to develop and enhance the national territory. This way, the project owner needs to evaluate which financing mechanism should be used. At this stage the project owner does not need to be a government authority, it may be from a public or a private sector. However, it is advisable for the project-owner to have sufficient financial resources at its disposal in order to handle the project cost. Other alternative is to be well supported by a group of co-founders.

A large number of the current European high-speed railway lines were financed by the public sector. The projects were supported at a national level, with the European Union's help through the budget allocated to the Structural Funds and Cohesion Fund. In addition, the European Investment Bank also contributed towards the development of the new rail network by conceding loans (European Commission, 2010a).

The Structural Fund plays a substantial role to help and support the European regions by building research and innovation capacities corresponding to their situation and priorities. Regions and Member States can use the Structural Funds in a flexible manner to help meeting their specific needs and exploiting the synergies with the Framework Program and other Community instruments (European Commission, 2010b).

The Cohesion Fund is a structural instrument that helps member states reduce economic and social disparities and stabilize their economies. Since 1994, the Cohesion Fund financed up to 85 percent of eligible expenditure of major projects involving the environment and transport infrastructure (Furst et al., 2011). The European Union establishes that a member state is eligible for Cohesion Funds if the per capita gross domestic product (GDP), measured in purchasing power parities is less than 90 percent of the European Union average and also if the national program follows the economic convergence conditions of the Article 104c of the treaty establishing the European Community regarding the avoidance of excessive government deficit (Laissy, 2008). The Cohesion Fund support is conditional and could be suspended if the country fails to comply with the convergence program for economic and money union.

There are several business models that might be applied for the development of high-speed railway corridors. These range from public, public-private partnership, to purely private. Recent research suggests that due to specific characteristic of transport infrastructure projects, the involvement of the public sector whose interest goes beyond financial gain and takes social-economic benefits into account must always be required (Rutzen and Walton, 2011). The long-term return of the investment and the risk that is common to rail infrastructure project turn the investment in a less attractive deal for the private sector (Fischer et al., 2006).

Developing high-speed rail corridors can involve long-term investment. The huge initial investment cost and long construction period are combined with a slow ramp-up period in order to increase revenues. This cash flow situation makes the investment opportunity less attractive for private investors and justifies the need for some kind of public sector contribution (Roll and Verbeke, 1998). For an infrastructure project such as a high-speed rail to be attractive to a private investor, it needs to have some sort of public sector participation, as a public-private partnership (PPP). The public-private partnership might vary from project to project depending on the specific characteristics and the legal framework followed (Rutzen and Walton, 2011). On the other hand, due to the lack of funding resources, many public entities have promoted the use of PPP as a way to finance infrastructure projects. Private investors are being invited to participate in the infrastructure projects as stakeholders, creditors or holder of bonds. The public sector roles might serve as a regulator or might have more participation in the investment. Thus, public sector can provide grants, loans and guarantees for a percentage of the investment in order to lower the risk and make it more attractive for the private sector (Rutzen and Walton, 2011). The major public-private partnership's benefit is the sharing of the business and commercial risk involved in each project.

Public-private partnerships are risk-sharing relationships between a public agency and a private sector, with the aim of carrying out infrastructure projects or providing services for the public. The PPP can offer an attractive option for the investment success and accelerate the TEN-T project implementation. Therefore, it is important that all financing opportunities are exploited to create a basis for the execution of as many infrastructure projects as possible. Three types of public-private partnership are identified as the most common to trans-European network projects: joint ventures, concessions and hybrid types. Joint ventures are investments shared between the public and the private sector. Concessions refer to an investment which is fully undertaken by the private sector and the hybrid types mean that the project is split in several project components with a public special purpose vehicle in control of the overall projects.

The European Commission wishes that public-private partnership plays a major role in the development of TEN-T. The Commission prepares regulatory framework for public-private partnerships in the area of public procurement law. Furthermore, the TEN-T Financial Regulation includes instruments for promoting public-private partnership in which the European Investment Bank is a risk-sharing partner for PPPs infrastructures such as railway investment. The European Investment Bank regulation provides a common framework for the appraisal of railway projects across the European Union and is the result of a harmonization exercise carried out under TINA – Transport Infrastructures Needs Assessment for transport projects (European Investment Bank, 2005).

Eurostat has issued guidelines on the national accounting treatment of infrastructures funding under public-private partnership (Eurostat, 2010). The guidance made clear that to achieve the balance sheet treatment the government unit must be responsible for the provision of infrastructure. The government must have autonomy in the decision making process. Moreover, when a government unit or controlled entity is directly involved with the provision of the infrastructure, at least half of the revenues must be derived from market sources rather than government subsidies. However, when a private sector contractor is involved with the infrastructure provision, the contractor must bear with the construction risk and either demand or availability risk.

2.3 High-Speed Rail Case Studies

The spread of the high-speed rail around the world is relatively slow. Despite the success of the Japanese line, it took seventeen years to be introduced outside Japan – in France – and another seven years for the second European high-speed rail to begin service in Italy.

All over the world, governments with different political orientations are investing in high-speed rail infrastructure (Rus, 2012). The high-speed system covers much of Japan and Europe, and is starting to be introduced in the Far East. There is no single pattern and some countries are more enthusiastic than others. Some countries have chosen alternative ways to improve the intercity rail. For example, United Kingdom and Sweden, upgraded their conventional network, increasing speeds on existing tracks and using tilting trains because of the curvature of the tracks (Nash, 2010). The different international corridors are evaluated in terms of organizational structure, operations, service level, development, type of funding, financial models, private sector involvement, and competition with other modes, as well as socio-economic characteristics. The organizational structure of all the evaluated cases has separated agencies into infrastructure and operations responsibilities. The division follows the idea of promoting competitiveness and efficiency and at the same time maintaining a tight regulation in terms of rail development.

The history of high-speed rail development reveals a recurring tension between economic analysis and political pressure. The first high-speed rail line in a country is usually built in a location where investment makes the most sense economically speaking, in terms of population density and travel demand (Peterman et al., 2012). The identification of the priority corridors has been a key factor in the development success of high-speed rail in the different countries. The success is measured in terms of passenger demand, revenue and economic development. Usually, all the systems had a previous rail system in place. The decision to upgrade the technology in place has been driven by national governments and with the support of the agencies responsible for rail infrastructure and rail operation. Governmental policies and regulators have an important role regarding the success of the high-speed rail over other modes of transport.

High-speed rail common design features do not imply that all projects become similar (Rus, 2012). In fact, it is quite the opposite. The cost comparison between projects is difficult once the technical solutions adopted in each case differ widely. The following is a brief overview of the most relevant high-speed rail models, its performance and organizational model.

2.3.1 The Japanese Experience

Japan may be the ideal country, geographically speaking for high-speed rail. Its main island is relatively long and narrow and the largest population is concentrated in cities arrayed along a corridor. Japan opened its first high-speed rail line, between Tokyo and Osaka, in 1964 (Central Japan Railway Company, 2012). The line was built to overcome the lack of capacity of the narrow gauge corridor. The success of the Tokyo-Osaka line encouraged expansion, and the Japanese government supported construction of other high-speed lines (Figure 2.3). The Shinkansen line has a very high frequency of trains – every ten minutes – and provides a capacity of over 1600 seats per train (Campos and de Rus, 2009).

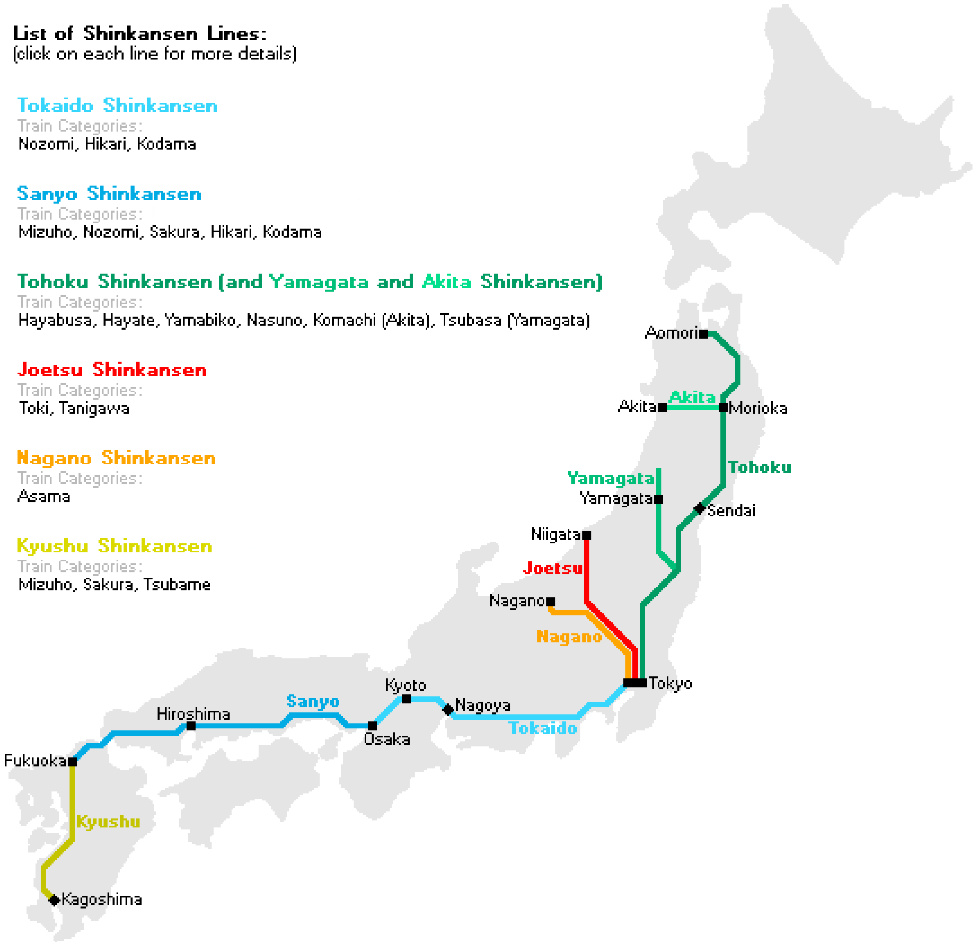

Figure 2.3 Japanese Shinkansen high-speed rail line (source: (Japan-guide, 2013))

The approach adopted in Japan is a combination of a financial and economic impact appraisal, which takes national interests and the technological development into account. However, wider economic objectives have not been fully achieved, in particular objectives related to the development of new cities (Steer Davies Gleave, 2004). The report conducted by *Steer Davies Gleave* for the Ministry of Finance in Japan states that cost benefit analysis might not be sufficient as a decision making basis. The reason, according to the report, is that it is not possible to put monetary values to all impacts that influence the appraisal.

Japan rejects the idea of carrying out formal economic appraisal because the political decision cannot be substituted. The criteria used for this political decision are difficult to quantify based on objectively comparable issues. From the limited information available, the appraisal emphasizes economic effects of transport projects and also includes regeneration effects. Moreover, it considers but not explicitly includes the technological advance and national pride regarding the technological index. However, the main factors influencing the decision making process have been time saving and service improvement.

Since 1987, when the government privatized Japan National Railways, private companies have operated all high-speed lines. Current information on the profitability of individual lines is not available, but the more recent railway lines have lower ridership than the heavily travels Tokyo-Osaka line (Peterman et al., 2012).

2.3.2 USA vision

After more than 50 years of investigation on road and aviation systems, the United States (US) are moving towards a new transport vision for the nation, in order to respond to the economic and environmental challenges. US administration has proposed the integration of a high-speed rail system to the current transportation network as a way to attend current and future passenger and freight demands. In 2009 federal government assigned funds in order to develop the high-speed rail project under the coordination of American Recovery and Reinvestment Act (ARRA) (Cameron, 2009; Peterman et al., 2012).

The amounts of the federal high-speed rail funding made available over the last years have been allocated to several projects. These projects entail upgrading the existing lines owned and operated by freight railways to allow somewhat faster passenger trains speeds than the ones currently possible. Moreover, federal government initiatives have always been interested in the potential benefits of high-speed rail. The first high-speed rail act, in 1965, contributed to the establishment of the nation's fastest rail services, the Metroliner, on the Washington DC to New York City when that line was under private ownership (Peterman et al., 2012). In 1970 the ownership was transferred to Amtrak, a government-controlled company. At the same time several major infrastructure improvements were done in the Northeast Corridor. In 1990, the new Acela *Express* tilting train was purchased for Amtrak to link Washington DC to Boston (Amtrak, 2012). The *Express* service has a top speed of 250 km/h and runs on a completely separated grade and with dedicated tracks. This type of service intends to relieve air and road capacity constraints. Although *Express* services do not fall under the category of 'true' high-speed, the intention is the same: providing intercity passengers with a superior transport system that fulfils the current economic and environmental needs (Federal Railroad Administration, 2009).

The federal government has also supported the research into various high-speed rail technologies and studies of potential new high-speed rail corridors outside the Northeast Corridor (Figure 2.4).

Figure 2.4 High-Speed Intercity Passenger Rail Program: Federal Investment - 1 mph ≈ 1.609 km/h (source: (Peterman et al., 2012))

United States of America (USA) is now closer to build a high-speed rail infrastructure, however there has been reluctance to give the final approval due to the cost of the evaluation of its economic and financial viability. Until now several new corridors across the USA have been designed for high-speed rail operations, but the construction's beginning seems to be far away.

Chicago is the center of a number of high-speed rail projects and proposals in the Midwest. This includes improvements to passenger rail service between Chicago and St. Louis. The line is owned and operated by four different freight rail companies and consists of one track with sidings to allow trains to pass. Although the long-term goal is to double-track and provide speed up to 350 km/h, the funds are being used to upgrade much of the existing single track in order to increase maximum passenger train speed (Peterman et al., 2012). The improvements also include new sidings, new signals, upgrade stations and new trains for passenger use.

The California corridor is the one at the most advanced planning stages (Amtrak, 2011). The California High-Speed Rail Authority (CHSRA) proposed to build a rail line that can reach speeds up to 320 km/h. California is moving forward with the creation of a nation's first genuine high-speed rail system and Amtrak is seeking to involve private investors in its plans to bring the high-speed rail to these busy corridor (Dutzik et al., 2011).

There is a significant difference in the structure of the rail industry in countries with high-speed rail history compared to the United States. The current debate in the US is centered on the Amtrak future, the passenger rail company and the level of subsidies.

2.3.3 Australia

Nowadays there are high-speed rail running in all continents except for Australia. Since 2002 the Department of Transport and Regional Studies has been evaluating the high-speed connections on the east coast in order to connect Melbourne, Canberra, Sidney and Brisbane (Figure 2.5). The evaluation performed shows that the east coast connection would be too expensive and almost 80 percent of the funding needs to be provided by public money (Givoni, 2006). However, many states have extensive suburban rail networks. There is also an interurban and rural network that is primarily used for freight and also covers some passenger traffic.

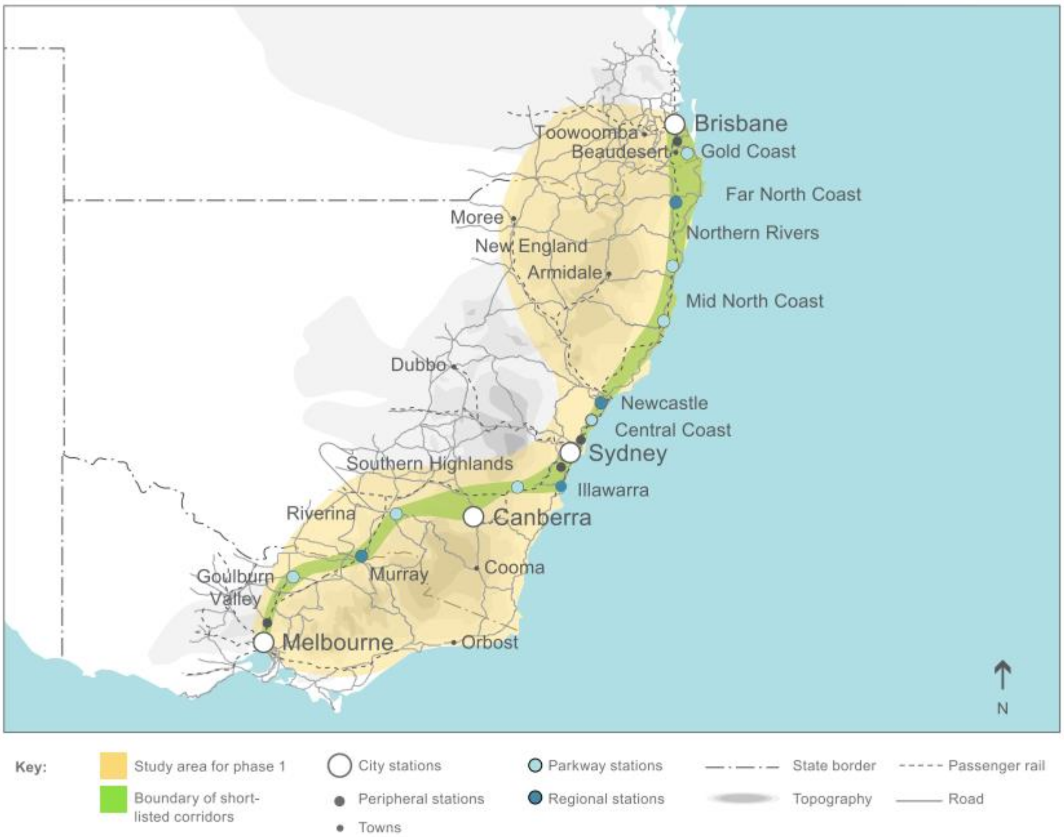

Figure 2.5 Proposed East Coast High-Speed Rail Alignment (source: (AECOM et al., 2011))

In 2011, the Australian government published a report focused on the definition of preferred routes, assessing the likelihood of costs for these routes and estimating the potential future market demand for high-speed rail (AECOM et al., 2011). However, the report did not explicitly examine the financial feasibility of the east coast high-speed rail and did not include a benefit versus cost analysis. The benefits are quantified by a relative base and compared among alternative corridors. In 2012, a second report examines the financial feasibility of high-speed rail in order to identify an optimum route alignment, refine investment, cost estimation and search for potential financial options (Edwards, 2012). However, until now any further decision took place regarding the construction of the East Coast high-speed rail connection.

2.3.4 The European Masterplan

In the early 1990s, the Maastricht Treaty defined the implementation of the Trans-European Transport Network policy and the development of guidelines in order to improve the establishment of a single, multimodal network covering traditional infrastructure and equipment as well as the organization of innovative and intelligent transport system to enable safe, efficient and sustainable traffic.

The declared objectives of the TEN-T intend to *enable citizens of the Union, economic operators and regional and local communities to derive full benefits from the setting up of an area without internal frontiers, the Community shall contribute to the establishment and development of trans-European networks in the area of transport. The Community shall aim at promoting the interconnection and interoperability of national networks as well as access to such networks* (article 129b; European Commission 1992).

During the European Council in June 1994, the European Commission agreed on a first list of eleven TEN-T priority projects. This list not only emphasized the concept of removing cross-border bottlenecks to facilitate traffic flows, but also the tendency of member states to prioritize projects of national importance(European Commission, 2010c). During the Essen European Council later that year, the project list was endorsed and extended to fourteen projects known as the Essen Projects (Furst et al., 2011). In 2004, the list of priority projects was revised to cover the new member states and extended to thirty projects, as presented in Figure 2.6. The effectiveness of the Maastricht Treaty had become operative with the proposal for TEN-T guidelines. The plan comprises a network of 70000 kilometers of track, including 22000 kilometers of new and upgraded track for high-speed trains, 58000 kilometers of roads, corridors and terminals for combined transport, 267 airports and networks of inland waterways and seaports (European Commission, 1995; Sichelschmidt, 1999). Other TEN-T projects relate to telecommunication and energy networks. The projects selected show a clear tendency for investment on the railway sector. The share of rail infrastructures – including combined transport projects – reflects the Commission’s intention to bring a new discussion about modal shift and the improvement on avoiding environmental effects of transport (European Commission, 1995; Sichelschmidt, 1999).

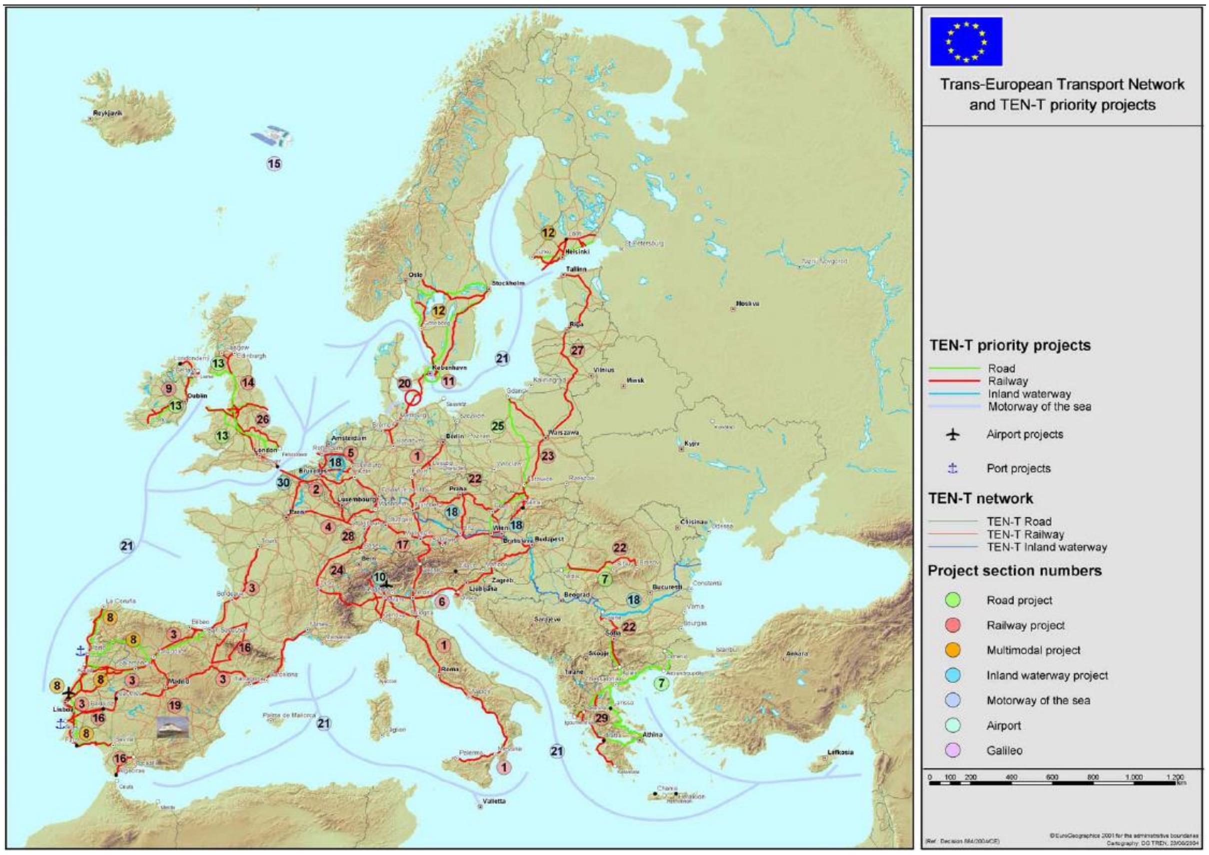

Figure 2.6 Priority axes and projects of TEN-T (source: (European Commission, 2009))

Besides the TEN-T projects it is absolutely crucial to think about the availability of financial means. The financial perspective of the European Commission emphasizes the idea of ‘private-public partnerships’ in financing TEN-T (Kinnock, 1998). However, commercial investment has rarely flowed into transport infrastructure and the European Commission (1995) had to acknowledge that *in most cases public financing may account for the lion’s share of investment* (Johnson and Turner, 1997). The reason for the reluctance of private investors to participate in transport projects might be related with the high capital intensity which implies an high debt service being paid for a single investment, the length of construction periods without project-generated revenues, the length of payoff periods as well as uncertainties of the forecasted traffic volumes (Johnson and Turner, 1997; Sichelschmidt, 1999).

High-speed rail in Europe has had a thirty-year development period since the beginning of the first French TGV (*Train à Grand Vitesse*) service between Paris and Lyon in September 1981. The success of this line led to the expansion of the high-speed rail network. The history of high-speed rail network development in Europe can be examined in the most documented experiences in countries such as France, German, Spain and Italy. These four key cases are the most representative of the European evolution. Thus, they are also the ones which have enough information to record results and to draw several conclusions.

2.3.5 The French TGV

France was the first European country to construct a high-speed railway line system, which opened in 1981 to connect Paris to Lyon. The first line – with the *Train à Grand Vitesse* - was conceived in the 1970's primarily for political and strategic reasons, and also because of capacity constraints that had occurred on the existing passenger rail lines between Paris, Dijon, and Lyon. Due to the relatively low population density of France and the central role of Paris, the French high-speed rail network has been radiating spokes outward from Paris (Peterman et al., 2012).

The French high-speed rail line resembles the Japanese Shinkansen in purpose, but differs in the design philosophy (Givoni, 2006). The most significant difference is the operation in European standard gauge (UIC), which allows the French high-speed trains to use the existing rail lines to approach the city centers, leading to significant cost savings. This strategic decision was based on an intensive economic and technical research. Consequently, high-speed train can serve regions with no high-speed infrastructure or serve the network where current demand is not enough to justify the construction of a dedicated line (Bouley, 1986). The current railway line outline is shown in Figure 2.7.

Figure 2.7 French high-speed rail network (source:(SNCF, 2012))

The success of the first line brought forth political justification for the following projects. The policy was to invest only in profitable lines. The French high-speed network was developed under a state-directed policy that insisted on cost containment and commercial viability (Dunn and Perl, 1994). The priority had been given to economic objectives in order to prove that a public enterprise can make money from operating the system (Albalate and Bel, 2010). In 1982, the transport legislation *Loi d'Organisation sur les Transports Intérieurs* (LOTI) (Loi n° 82-1153, 1982) stated that all huge infrastructure projects should be appraised with consistent criteria, and evaluations should take construction costs and direct as well as indirect social and environmental costs into account. The policy implemented at a regional level involves the development and improvement of the regional services that serve the nodes with high-speed railway stations so those benefits can be widely spread and overall accessibility improved. This strategy has resulted in a higher incidence of traffic than expected.

The formal social-economic appraisal is now required in the French assessment process. The first TGV projects was appraised based on financial evaluations and then approved based on political and strategic judgment, rather than resulting from an economic cost-benefit analysis (Steer Davies Gleave, 2004). The detailed economic appraisal that is now required is defined in two documents, the *Circulaire Idrac* (1995), which is the official appraisal document for all public projects, including high-speed rail; and the *Boiteux* report (2001) which is an updated guidance for transport projects. Appraisal is based on cost-benefits principles and the monetary values are as many as possible, even though the political decision considers other issues such as economic and regional development. The result of the cost-benefit analysis is an assessment of the social rate of return from the project compared with the reference case (if there is any other project) (Steer Davies Gleave, 2004). Therefore, even if the project appears to have positive evaluation regarding all appraisal criteria, there is no guarantee that it will receive funding, because the cost-benefit analysis is intended to inform, however it does not replace the political decision. Although multi-criteria analysis has not formally been used in France, the projects that have been led were based on multiple criteria evaluation such as national pride and technological development. Thereby, appraisal documents include non-quantitative explanations of the key benefits. These key benefits are not included in the cost benefit analysis.

The main operator of passenger service is the SNCF (*Societe Nationale des Chemins de Fer de France*), a state owned company. Eurostar and Thalys also operate on international long-distance high-speed rail services in partnership with SNCF. The rail infrastructure is owned by RFF (*Réseau Ferré de France*). RFF is a state owned company, which was founded to comply with the European Union legislation on the separation of infrastructure and operations. RFF acts as the owner of the infrastructure but hires the operation and maintenance safety system from SNCF (Rutzen and Walton, 2011).

The rail-freight market in France has been operating since April 2006 and its access is regulated by national law. The business unit SNCF *Geodis* (freight and logistic) encompasses all activities of SNCF freight (*Fret* SNCF) together with all European rail-freight subsidiaries (Sippel and Mayer, 2012).

2.3.6 German, the InterCity Express

German opened its first high-speed railway line in 1991 and its high-speed rail trains are called InterCity Express (ICE). German railway line varies significantly from the neighboring countries rail line. The German rail line service was developed to connect many hubs instead of centering in a single city. Germany puts more emphasis on the upgrading existing railway lines to accommodate higher speed services, and less emphasis on building entirely new lines (Peterman et al., 2012). The first lines were built to accommodate both passenger and freight trains. This decision increased construction costs given the required gradients to accommodate both services. As a result the high-speed lines were designed for lower speeds compared to other European lines (Figure 2.8).

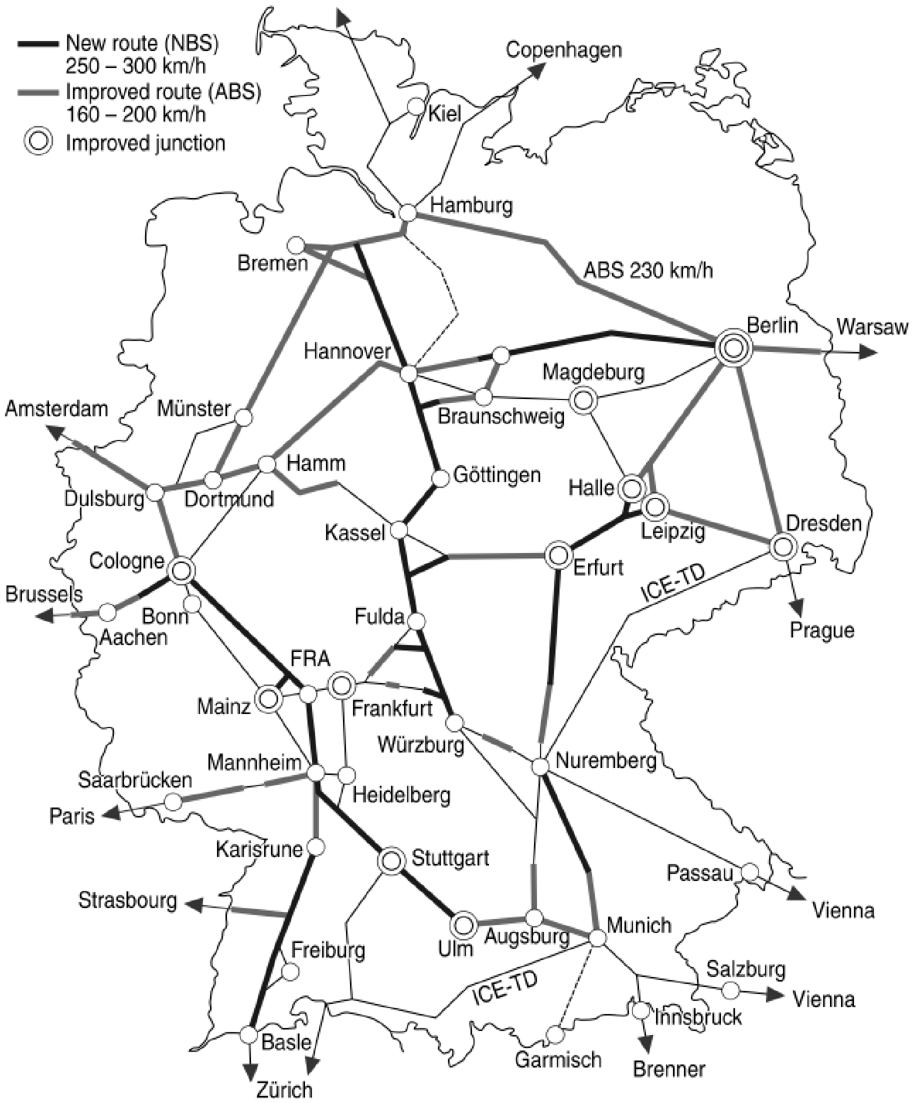

Figure 2.8 German High-Speed Network (source: (Ebeling, 2005))

The high-speed rail decision is preceded by a time-consuming discussion in order to evaluate whether new lines should be dedicated only to passenger transport (following the Japanese and French model) or adopting a mixed-use line. The mixed-used means the line is used for both passenger and freight transport. The goal was to solve congestion problems in some corridors and to improve the freight traffic. The mixed-use feature turned out to be a disadvantage since it led to an increase in construction and operation costs given that to support the higher loads of freight trains, it is necessary to limit gradients and install passing places. The disadvantage can also be seen in the low use of the lines since it is impossible to create a reasonable timetable for daytime freight due to the large speed differences between passenger and freight traffic (Albalate and Bel, 2010; Ebeling, 2005; Gutiérrez, 2004).

The German multi-purpose high-speed railway system which shares high-speed and conventional passenger trains together with freight-rail is conceived to spread benefits. In *High-Speed Trains in Germany* (Heinisch, 1992) states that the primary consideration for the new railway lines is not the passenger traffic speed but the profitability on the overnight freight-rail traffic. The freight transport has become more important since it has contributed more to the turnover than the passenger rail traffic case. The main difference regarding the French TGV is that the German rail system is heavier, wider and more expensive to run, but offers a higher flexibility (Dunn and Perl, 1994).

The operation of passengers and freight services and also the railway infrastructure maintenance of the rail infrastructure are controlled by the *Deutsch Bahn* (DB). DB is a private joint stock company, established in 1994. DB joins the state owned *Deutsch Bundesbahn* of West German and *Royal Rieschbahn* of East Germany, bringing together different departments responsible for diverse railway services. DB Bahn manages the passenger railway service within Germany, including ticketing and servicing and performs all intercity rail services and international rail services. DB Netze is responsible for the rail infrastructure, including construction and maintenance. DB Schenker is the freight division. Some private operators also have concessions to provide local and regional freight services (Deutsche Bahn, 2012). In 2008 the DB was supposed to change from private joint stock to public stock but this process has been delayed due to market conditions. DB currently remains under state control (Jordan, 2009).

The German government defined the basis of the high-speed rail programme - as well as other infrastructure modes program - according to the BVWP (*Bundesverkehrswegeplan*) the Federal Construction Plan Law. Following the approval of this law, DB requests for planning and construction permission to Eisenbahnbundesamt (EBA), the federal railway office and rail regulator. The federal railway office and rail regulator determines whether the financial agreement between the government and DB is reasonable. The development of the BVWP is a process that can take up to ten years and requires a feasibility study. The latest multi-criteria studies include a cost-benefit analysis, an environmental risk assessment and a spatial impact assessment (Rutzen and Walton, 2011). The German appraisal guidance gives an explicit weighting to be applied to the result of the multi-criteria study in order to draw an appraisal outcome. Although the analysis of the factors are not included in the cost-benefit analysis, the multi-criteria analysis uses a scoring system to determine the combined cost-benefit in relation to the spatial impact evaluation (Steer Davies Gleave, 2004). The goal of multi-criteria analysis is to ensure that items with no monetary values are not ignored by decision-makers. In addition, it defines a standard process that can be used for evaluation across all projects, and reduces the flexible interpretation of non-quantifiable results. The environmental risk assessment is also a numerical value but it is considered separately from the combined result of the cost-benefit analysis and from the spatial impact assessment.

2.3.7 Spain

The first high-speed railway line in Spain, or AVE (*Alta Velocidad Española*) as it is commonly known, started in 1992 connecting the capital of Madrid to the southern city of Seville. The Spanish government chose this route over the most obvious one – connecting Madrid to Barcelona, the second largest Spanish city, because Seville hosted the World Expo in 1992 (Figure 2.9).

Figure 2.9 High-Speed Rail Lines in Spain (source: (ADIF, 2013a))

According to a study, by Steer Davies Gleave, 2004, there is no clear evidence that an economic appraisal has been made to justify the Madrid-Seville project. Several studies point to a political strategy to promote economic development in the country's poorer regions in order to favor cohesion. The territorial equity was the main reason pointed out for the choice of this line. The railway line represented a high social cost to the economic system (Sala-i-Martín, 1997). The high-speed railway line has been successful since the opening of the service. Travel times were reduced by 60 percent compared to the conventional rail line and 99.8 percent of the trains arrive within three minutes of the predicted arrival time schedule (Steer Davies Gleave, 2004).

The Madrid-Seville line was the first Spanish high-speed rail line to be constructed with the European standard gauge (1.435mm). With the construction of the new railway line Spain now has two different gauge types. The Spanish conventional network has the Iberian standard gauge (1.668mm) that is wider than the international standard. Many trains have special equipment to allow them to operate on both networks. The new line is reserved only for passengers traffic due to the lack of interest from freight traffic operators in an 'isolated' line (Teixeira et al., 2008).

The high-speed rail network is seen as a way of improving mobility with less environmental impact than automobile or air travel. Besides, the line is a way of promoting the development of Spain's regions, as well as to promote transportation-related employment (Peterman et al., 2012). The state-owned company *Red Nacional de los Ferrocarriles Españoles* (RENFE) is the national railway passenger operator and the main freight operator. ADIF (*Administrador de Infraestructuras Ferroviarias*), another state-owned company, is in charge of the construction and maintenance of the rail infrastructure. Prior to the European legislation that required the separation between infrastructure and operation, RENFE was also responsible for the construction and maintenance of the rail infrastructure. A third state owned company, GIF (*Gestor de Infraestructuras Ferroviarias*) is responsible for the development of the high-speed rail lines, together with ADIF (Rutzen and Walton, 2011; Steer Davies Gleave, 2004).

Initially, the rolling stock technology adopted was from the French Alston TGV and then the Simems Velaro ICE from German. The French and then the German technology provided the necessary mechanisms to reach the desired speeds (España Exportación e Inversiones, 2009). A joint venture between Bombardier (France), CAF and Talgo (both from Spain), began to develop the 'tilting' trains. The tilting technology detects the track curves and allows the conventional trains to travel at higher speeds. The developed system allows the automatic gauge-switching exchange to move people and goods beyond borders. RENFE offers three types of service: long distance (AVE), long-distance/dual gauge (ALVIA) and medium-distance (AVANT).

Historically, Spain's rail market share is the lowest in European member states, largely due to the poor quality of its conventional railway network. When the Madrid-Seville high-speed rail line opened the Spanish airline, Iberia, it was under state control. This allowed RENFE to enter into a competition agreement with the airline, taking a significant amount of its market share for that route (Jordan, 2009).

The Spanish government is committed to provide high-speed connections to all regions within a radius of four hours from Madrid and six hours from Barcelona. As a result, the new connections might reduce travel times up to 70 percent compared to the current conventional railway travel times. The high-speed rail is seen as a structural element for country development that promotes country homogenization, country image and railway sector modernization (AT Kearney, 2003).

The development of the high-speed railway line in Spain starts with an analysis by the Ministry of Public Works in order to determine where the investment yields the highest value. This is followed by a more detailed study by the Ministry of Public Works and GIF on how the operations should be delivered. An economic analysis is also conducted for each project. The analysis follows the guidelines established by the European Commission Directorate General for Regional Policy since a large share of the funding comes from European Union regional development funds. Value of time is not specified in the guidelines and can vary between projects. High-speed rail project assessments also include financial and multi-criteria analysis (Steer Davies Gleave, 2004). Shadow prices and conversion factors are used in the project assessment, following the *Guide to Cost-Benefit Analysis for Investment Projects*. However, economic assessment is only conducted as a means to prioritize rather than to determine if the project should be implemented.

The AVE is considered a symbol of modernity for Spanish people (Rus and Román, 2006). Currently, high-speed rail in Spain reverses the long-term decline in rail transportation with a new product that has become commercially profitable and able to cover all operating and maintenance expenses.

Freight is not a target revenue segment for high-speed rail. The Spanish high-speed rail sacrificed the rail-freight business because its high operating costs discouraged the entry of potential competitors (Campos, 2008).

2.3.8 Italy

Italy has taken its first step towards construction of dedicated high-speed line with the Diretissima between Rome-Florence in 1981 (Nash, 2009a, 2009b). During the last 30 years, the investments carried out in high-speed rail resulted in a network up to 900 kilometers long (Ben-Akiva et al., 2010). The high-speed railway line is the answer to the very poor quality of the conventional rail network. Currently there are five high-speed railway lines in operation in Italy, connecting the country's major cities, such as Rome, Florence, Milan, Naples, Bologna, and Turin (Figure 2.10).

Figure 2.10 Rail Connections in Italy (source: (eurail, 2012))

The state railway, FS (*Ferrovie dello Stato*), in 1992, was converted into a private company with the Ministry of Economy and Finance as the only shareholder. Lately, and according to 1997 EU Directive, the railway infrastructure and operation was separated into different sections under the FS Group. RFI (*Rete Ferroviaria*) manages the existing rail infrastructure, including tracks, stations and installation. The operating company, *Trenitalia*, manages both freight and passenger railway services (Rutzen and Walton, 2011).

Rail infrastructure in Italy is completely mixed. All railway services can use the high-speed or the conventional system as well as freight trains. This configuration allows trains using conventional lines to approach city centers and allows freight train to use the spare line capacity during the night. Two types of high-speed trains are used in Italy: tilting trains and non-tilting trains. Tilting train technology allows high-speed trains to operate on non-straight tracks minimizing the need to build new rail infrastructure and also allowing trains to operate at higher speeds on existing tracks. On approach to curve the train tilts to reduce centrifugal force on passengers while maintaining its high-speed (Valenti, 1998). In Italy, tilting trains are designed to operate on the sinuous route along the coastal area and the mountainous area with the Alpine system (Railway Technology).

The main motivation for high-speed investment was the low market share of rail traffic in mobility statistics (Albalate and Bel, 2010). Thus, the objective was to raise the Italian rail infrastructure to the highest European standards and improve its capacities. High-speed rail has become more competitive given capacity constraints on the conventional lines which shifted passengers to the new lines, especially for long distance travels. On the other hand, the emergence of low cost airlines resulted in competition between rail and air modes (Rutzen and Walton, 2011).

The Italian government prepares a general transportation plan every five to ten years. This plan, called *Piano Generale dei Trasporti e Della Logistica* (PGT), sets the guidelines for transportation infrastructure projects and lists projects to be implemented. If a project is not included in the PGT, it cannot be undertaken. However, the inclusion of a project does not lead to construction within the timeframe defined. RFI developed a specific rail infrastructure plan that is consistent with PGT. This plan, the *Piano Prioritario degli Investimenti* (PPI), includes an evaluation of all rail infrastructure projects, as well as a prioritized list of rail projects to be developed (Steer Davies Gleave, 2004). Again, the project inclusion does not automatically guarantee its construction.

Several guidelines are used to prioritize rail infrastructures projects. The Italian guidelines are related to safety, legal requirements, efficiency, productivity improvement and solving capacity constraints. The new project will provide better quality of service, benefits the development of freight network and benefits the underdeveloped southern regions. The PGT requires the RFI to consider as many criteria as possible. In addition RFI evaluates the financial viability of the proposed railway project and assesses the effects on the overall railway network. However, the key decision-making is still undertaken by the government, and then RFI might or might not proceed to the construction of the high-speed rail line (Steer Davies Gleave, 2004).

2.3.9 Portugal

In order to revive rail efficiency and promote rail competitiveness and sustainability, the European Union envisioned the development of the Trans-European Transportation Network. Given this, it becomes necessary to develop new railway services and infrastructures in Portugal where railway services have not been a priority to enhance accessibility and promote mobility. To be part of the European railway network there is a demand for a socially public investment which produces several types of benefits such as passenger time savings, increase in comfort, generation of new trips, reduction in congestion and in accidents and release in capacity in roads and conventional lines as well as in airports, and wider economic benefits including the development of the less developed regions.

Portugal and Spain are developing a strategic plan to integrate the high-speed railway network foreseen as component of the TEN-T (Figure 2.11).

Figure 2.11 Priority axis and connections (source: (Eurostat, 2013b))

Priority axes aim to link the major cities on the Iberian Peninsula with France by rail. The new connection allows traveling by high-speed railway, from Madrid to the French border in less than four hours. The priority axis also considers a high-capacity line that will link the Sines and Algeciras container terminal ports with the Spanish and French railway network. The future infrastructure makes way for the integration between Portugal and Spain into a fully interoperable Trans-European high-speed rail network. Besides, the high-speed rail network will increase rail market share regarding international freight and improve connections between southern and northern Europe (IMTT, 2008).

The Portuguese project started with three priority connections, Lisbon-Porto, Porto-Vigo (Spain) and Lisbon-Madrid with an estimated length of 650 km and a planned investment of 8 billion euro. The planned investment included civil structures, such as the Tagus River Crossing and would allow the connection to a large number of major cities and border connections by high-speed rail, as presented in Figure 2.12.

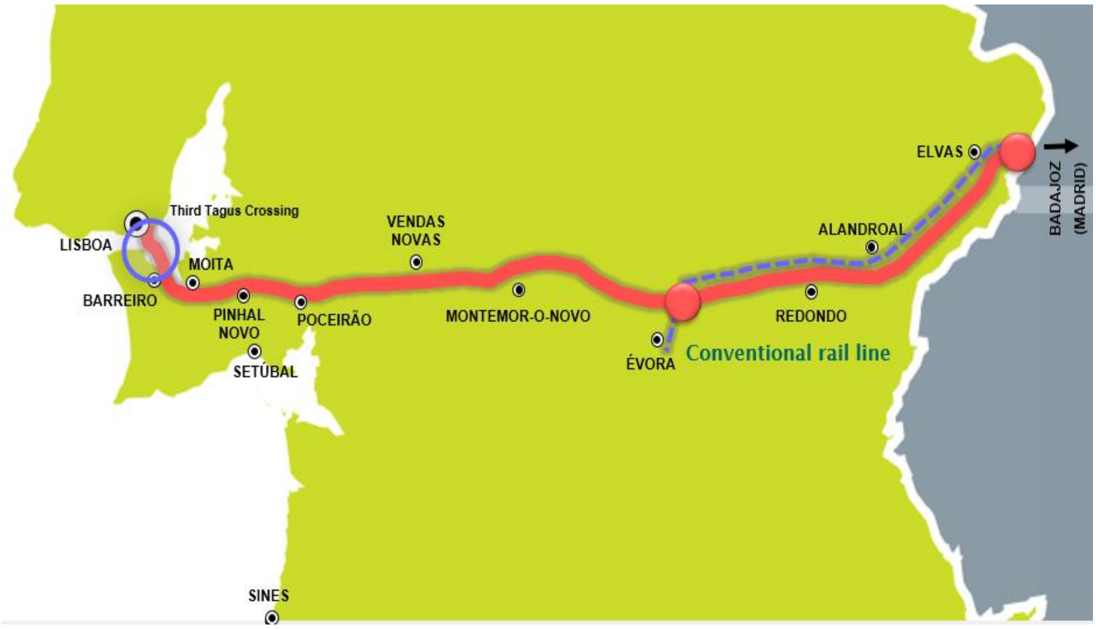

Figure 2.12 Lisbon-Madrid rail connection (source: adapted from (RAVE, 2011))

In recent years the combinations of the public transport companies' debt, the lack of structural reforms in transport and the financial situation of the country led all the projects to be pulled back. The conditions imposed by the International Monetary Fund and by the European Union determined that the PPP projects that included the high-speed railway network were suspended. This led to the reformulation of the initial project. The new design only includes the rail link between Lisbon-Madrid with few network revisions and excludes the Tagus River Crossing. The rail line will include freight connections to the sea ports of Sines/Lisbon and Setubal and connection to the logistic platform of Poceirão. This way, freight rail traffic would be also linked to Madrid and to the rest of Europe, ensuring an interoperable railway link (Ministério da Economia e do Emprego, 2011).

The main objective aims to enable a modern, sustainable and efficient transport system in order to reduce the country's peripheral position and connect Portugal to Europe. The new rail connection would contribute to the competitiveness of the Atlantic south-west front and the speeding up of the economic and technological development at a regional level. The final objective is not only contribute to a better modal distribution, both passenger and freight, but also increase mobility and competitiveness of the ports, airports and logistic platform using the high-speed rail network as the backbone of the future transport network, as presented in Figure 2.13.

Figure 2.13 Portuguese transport network (source: adapted (RAVE, 2012))

To coordinate the development of the high-speed rail network, the Portuguese government set up RAVE – *Rede Ferroviária de Alta Velocidade, S.A*. RAVE was a public limited company owned 60 percent by the government and 40 percent by REFER – *Rede Ferroviária Nacional, EPE* . REFER is the state rail manager and carries out most of the rail infrastructure's investment (Jordan, 2009).

RAVE was recently dismantled due to the Portuguese financial crisis. Still, RAVE started in 2000 and spent years planning and conducting preliminary studies and environmental review in order to develop a business plan for the high-speed rail project. In 2007, RAVE proposed a business model based on public-private partnerships in order to sustain the viability of the rail link. The studies performed provide information on the financial plan, construction plan and operation plan of the high-speed rail network. Regarding the procurement, RAVE divided the network into six different public-private partnership projects in order to ensure that each package is attractive to the market. Five of the PPP packages are sections of rail infrastructure (for the design, financing and maintenance), and the sixth is a signaling and telecommunication PPP covering the entire network (Figure 2.14). The Public-private partnerships' choice was the subject of study by RAVE. RAVE concluded that six public-private partnership projects represent an optimum balance between public and private-sector interest while minimizing the number of interfaces between projects and contractors (KPMG, 2010).

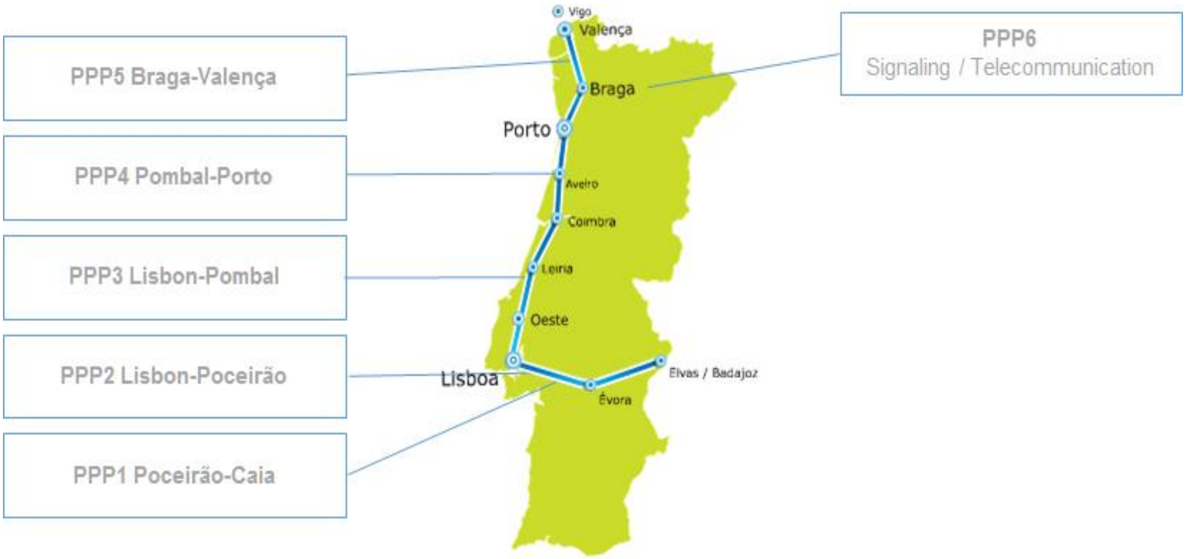

Figure 2.14 Public-private partnerships (PPP) (source: (RAVE, 2011))

The business plan was based on the structuring of incentives. The builders of each railway section will be paid back over the 40-years period of the concession through availability fees. Thus, it encourages companies to do high-quality construction and to maintain availability of the rail network over the period of time set. Furthermore, about two percent of the compensation should be tied to the amount of traffic carried on the line, providing the infrastructure company with an incentive to work closely with the operating rail service company in order to maximize traffic (Silva et al., 2010). For the first PPP segment - Poceirão-Caia the major risks and hurdles identified will be shared between the Rail Manager and the private partner. The Portuguese government will take care of the purchase of rolling-stock which will be transferred to the rail operating company in charge (Dutzik et al., 2011; Silva et al., 2011).

2.4 Rail Project Appraisal

The countries that chose to invest in high-speed systems did it for a different number of reasons. The decision to proceed with the construction of the high-speed rail line or not has not just been based on economic appraisal but also on different reasons. Different appraisal techniques are used to determine the appropriate use of a country's economic resources, based on both strategic and operational objectives. However, it is also clear that appraisal practice is converging to cost-benefit analysis, particularly in European high-speed railway projects.

Investment appraisal is where the critical decisions are taken about transport infrastructure. These have historically been determined by methods which rely on the identification of user benefits, dominated by user time savings, relief of congestion and reduction in accidents, but allowing for environmental impacts (Vickerman, 2007a). However, investment decisions based on cost-benefit type procedures depend on the accurate measurement of future demands which in turn require correct modeling of the responses of users to the new investment (Vickerman, 2007b).

The Cost-Benefit Analysis (CBA) is the technique usually applicable in public investment assessment (Musgrave and Muscrave, 1989). This analysis is normally used for planning, decision support, program evaluation, and proposal evaluation. CBA facilitates decisions that should be undertaken by investors referring to costs of project and optimal choice among different alternatives (Brzozowska, 2007). The appraisal allows the policy maker to identify and measure the scale of the difference between gains and losses. Moreover, not only an individual project can be appraised as useful or not, but also alternative projects can also be ranked (Vickerman, 2007a). CBA estimates and totals up the equivalent money value of the benefits and costs establishing whether they are worth it or not. This means that all benefits and costs of a project should be measured in terms of their equivalent money value and in time (Brzozowska, 2007).

Benefits and costs are always expressed in terms of money and only money. However, the validations of non-market or intangible effects - that are not usually conceived of in money terms - should be based on one from three possible methods: direct valuation; indirect market value and social values. These types of consequences are known as externalities (alternative terms are spillovers, external effects, or social effects), and may be recreational, social, and political (Brzozowska, 2007). Several authors sum up the cost-benefit analysis in three main steps. The first step is the identification of all factors - profitable and negative – in relation to the project. The second step is the financial valuation of cost and benefit. Finally, the choice of the best alternative according to net social benefits, which represents the surplus of total benefits on total costs.

The economic magnitude of high-speed rail investment is not always in accordance with the research reported in the economic literature (Campos and de Rus, 2009). Nowadays, the decision to build or plan high-speed railway lines are only considered if the investment generate returns on a commercial basis supported by the strategic and political objectives. Besides this, the project design must take into consideration the specific characteristics of the urban patterns and economic structure of the country such as traffic patterns given the importance of a country's mobility. The fixed costs of high-speed rail investment are huge. The cost consideration is critical in relation to design choice and implementation (Albalate and Bel, 2010).

Another appraisal process involves the comparison of a set of options. It is necessary to be clear about the base case and ensure that the available range of options is verified. Generally, a 'do minimum' is chosen as case base and as an alternative investment called 'do something'. These alternatives are compared on an incremental basis to see which particular option is better than the base case (Nash, 2009b). In the case of high-speed rail, the 'base case' should include the necessary investments to keep the existing service running, and consider how to deal with the future traffic growth, the investment in rolling stock or with the fares applied. The alternative 'do something' should include infrastructure upgrading, the purchasing of the trains, and the construction of an additional line or additional road/airport. Other options should also be considered, such as how far to extend the line, the service frequency to be considered or the price policy to be adopted. As a result, it is necessary to examine as many alternatives as possible which makes the appraisal a difficult task due to the huge potential range of options. At the same time, the timing of investment should be considered.

Several methods have been developed based on the CBA method. They intended to capture the conflicts of interests of all parties involved and affected by the project. Multi-criteria analysis (MCA) is a method to trigger the trade-off between objectives (e.g. transport efficiency, improve equity, or reduce environmental externalities) in order to enable decision makers to make rational and systematic choices regarding the preferred project (Berechman, 2009). The MCA allows each decision-maker to manage its own set of criteria, to measure the score and to generate a system of relative weights specific for the given context.

The difference between MCA and CBA are mainly two. MCA has no limits in the forms of criteria in the sense that MCA allows intangible elements and does not require price use. MCA makes use of weight and scores – however prices might be used to derive the overall scores. The MCA method is used with a less consistency. Some countries have formally used this analysis but others only present a non-quantitative explanation of the key benefits of the project that are not included within the scope of the quantified cost-benefit analysis as key part of the appraisal process (Steer Davies Gleave, 2004). From the studied countries, only Germany assigns numerical scores to the multi-criteria analysis that are added to the result of the cost-benefit analysis to give a combined appraisal score.

2.4.1 The Spatial Impacts

One of the basic relationships of transportation involves the amount of space that can be overcome within a given amount of time. Thus, the faster the mode, the greater the distance that can be overcome in the same amount of time. Improvements in transport systems changed the relationship between time and space. Significant regional and continental gains were achieved during the eighteenth and nineteenth centuries with the establishment of national and continental railways systems as well as the growth of maritime shipping. In the twentieth century the growth process continued with air and road transport systems.

High-speed rail is considered a technical concept related to the maximum speed trains can reach in a particular track segment (Campos and de Rus, 2009; Rus et al., 2009). By changing the relative accessibility of places, high-speed creates a different social and economic space. Spiekermann and Wegener (1994) illustrate the possible impact using time-space maps of European railway network which represent the true European ambition in what shortening travel time is concerned. The elements of a time-space map are organized in such way that the distances between them are not proportional to their physical distance as in topographic maps, but proportional to the travel times between them.

Figure 2.15 shows the shorter travel times, between two points, closer together on the map and the most distant points represent longer travel times. The scale of the map is no longer in spatial but in temporal units (Spiekermann and Wegener, 1994, 1996; Vickerman et al., 1999). The map on the left represents Europe based on travel times in 1990s; the map on the right is a representation of how Europe will be in 2020 if the TEN-T outline plans are all implemented. The full 'space-eating' effect of high-speed rail becomes visible: in 2020 the continent will shrink in time-space (ESPON, 2004; Spiekermann and Wegener, 1994). At that time, the impact caused by the high-speed rail projects will be even greater.

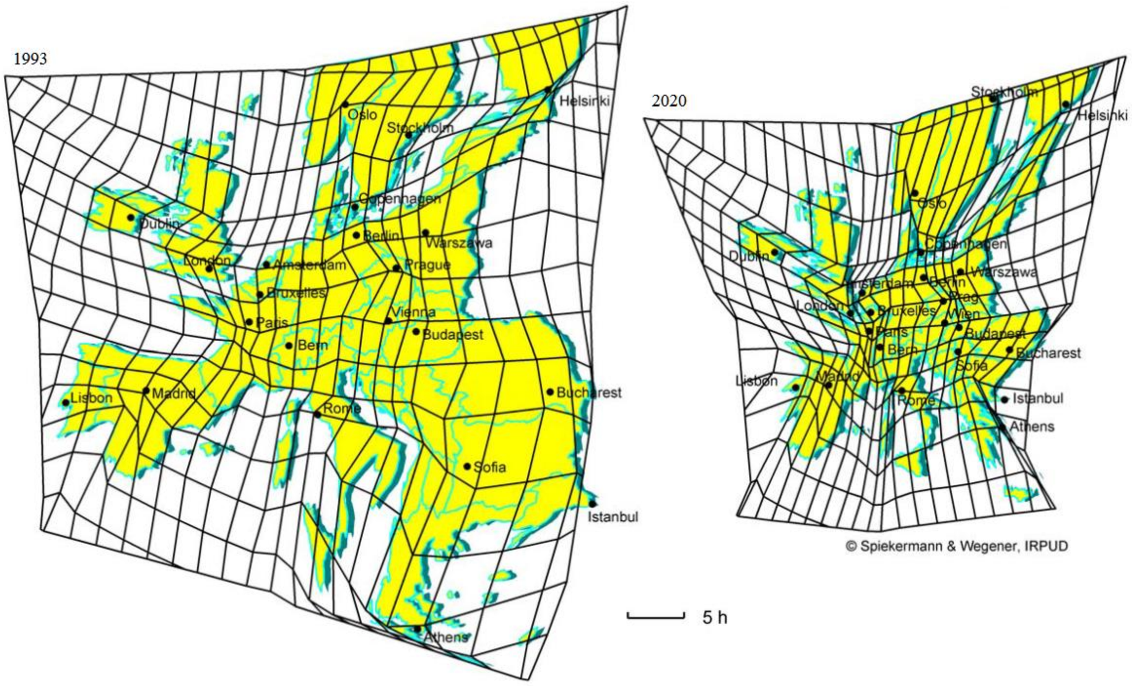

Figure 2.15 Time-space maps of rail travel times 1993 (left) and 2020 (right) (source: (ESPON, 2004))

The time-space maps are well fit to visualize travel time reductions for the most accessible nodes achieved by trans-European networks. The introduction of high-speed rail may lead to intermediate stops being served by slower trains, providing that travel times increase without being displayed on the time-space map. A time-space map is also unable to show that in some cases more distant high-speed rail destinations can be reached in a shorter time than the nearest locations (Vickerman et al., 1999). The shorter travel times offered by high-speed services near the cities connected to high-speed network, increase its connectivity, and also lead to an increase in socio-economic impacts.

High-speed rail lines allow fast trips. However, the advantages and disadvantages should be balanced according to the distance performed. The following Figure 2.16 shows the competitive advantages of the high-speed rail lines compared to conventional rail and air services. The range of travel in which the high-speed railway is competitive, in terms of travel time, is related to the time required to access the station to check-in. The rail market advantage is also dependent on speed and reliability of service –particularly around 300 km/h. Thus, to travel less than a distance of 150 kilometers, high-speed railway offers little advantage over conventional rail and becomes dependent on the location of stations that are usually less well located for passengers. From 150 to 400 kilometers of travel distance, rail can be faster than air travel, even without dedicated high-speed lines. For more than 400 kilometers, the high-speed railway system is the quickest mode and makes significant changes possible. If the travel distance is higher than 800 kilometers, even if high-speed rail infrastructure is available, air travel is faster.

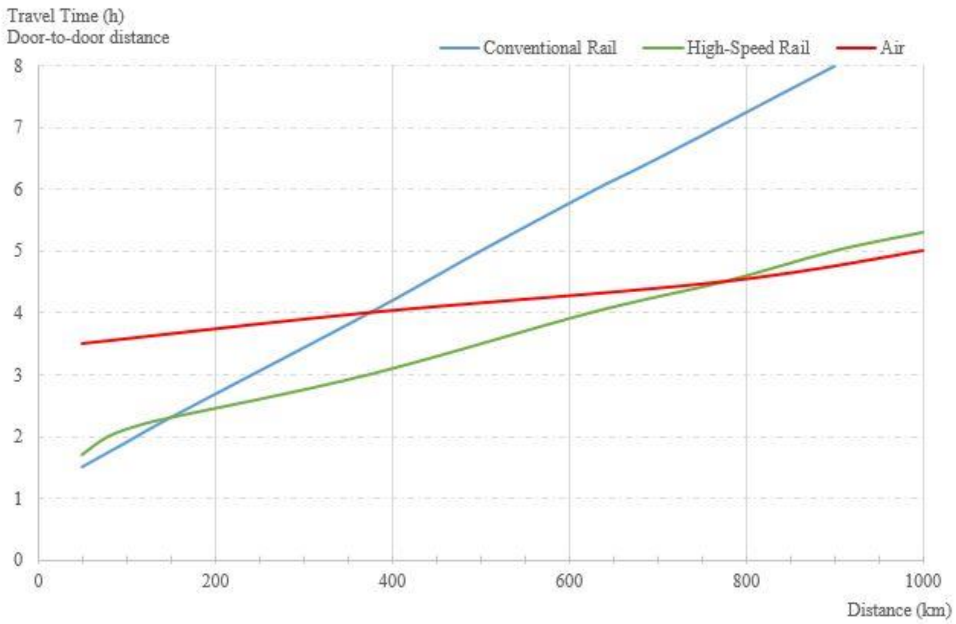

Figure 2.16 Competitive advantages of the high-speed rail lines

2.4.2 The Economic Importance

Transport is an economic factor that provides market accessibility by linking producers and consumers. An efficient transport system favors many economic changes. Some major impacts are related to the improvements in transportation and communication enabled by the geographical specialization that increases productivity and spatial interaction. In addition, an efficient transport system offers cost, time and reliability advantages which allow goods to be further delivered. The just-in-time concept has expanded the productivity of production and distribution in a large-scale production. Moreover, when a transport system is efficient, the potential market for a given product tends to reduce prices and promote quality and innovation. As a result, the land near or served by a good transport service increases value due to its higher utility. Consequently, transport also contributes to the economic development through job creation, since there is a large amount of direct and indirect activities associated to transport.

When economic impacts are applied to a new high-speed rail line the evaluation results should be considered as improvements, since the new infrastructure can anticipate a change in the generalized costs of rail travel in corridors where conventional rail, air or road transport are complements or substitutes. Investing in a high-speed rail line requires a minimum level of demand in the first year of operation. This minimum demand threshold required for a positive net present value becomes higher, the lower the value of time, the average time saving per passenger, the proportion of generated traffic, the overtime on growth or benefits, the project life and the cost savings in alternative modes. On the other hand, the investment, maintenance and operating costs, and the social discount rate also become higher. The economic rationale of spending public funds in high-speed new lines depends more on its capacity to relieve road and airport congestion and to release capacity for conventional rail where saturation exists, than in the pure direct benefits of time savings and the net willingness to pay regarding generated traffic. Therefore, the justification of investment in high-speed rail is highly dependent on local conditions concerning airport capacity, rail and road network situation, and existing volumes of demand. The economic evaluation of a new technology has to compare these local conditions regarding the introducing of the new alternative of transport (Rus, 2008).

2.4.3 Cohesion

Cohesion is considered one of the main policy goals regarding European Union strategies. The creation of the trans-European networks is considered one of the policy instruments to achieve the cohesion goal in order to contribute for the strengthening of economic and social cohesion (European Commission, 2011b).

In 2004, the Treaty *Establishing a Constitution for Europe* included the aim of promoting economic, social and territorial cohesion as one of the Union's objectives. Moreover, cohesion is defined as one of the areas of shared competence between the Union and the Member States. The treaty also states that particular attention shall be paid to rural areas, the ones affected by industrial transition, and regions which suffer from severe and permanent natural or demographic handicaps such as the northernmost regions with very low population density and island, cross- border and mountain regions. Finally, it is recognized and respected access to services of general economic interest in order to promote the social and territorial cohesion (López et al., 2008; OJEU, 2004).

Moreover, the third cohesion report introduces the concept of territorial cohesion. The objective of the territorial cohesion is to help achieve a more balanced development by reducing existing disparities, avoiding territorial imbalances and by making both sectorial policies with a spatial impact and regional policy more coherent (European Commission, 2004a). However, the territorial cohesion has been discussed and interpreted in different points of view from European institutions, stakeholders and public (Yang, 2012). With the new territorial challenges faced by the European Union and in order to respond to strategies and policies, the territorial cohesion concept keeps developing dynamically with changing contents. The notion of territorial cohesion is shared by official European documents and researchers as represented in Figure 2.17 (Camagni, 2009; European Union, 2011a, 2011b; Yang, 2012).

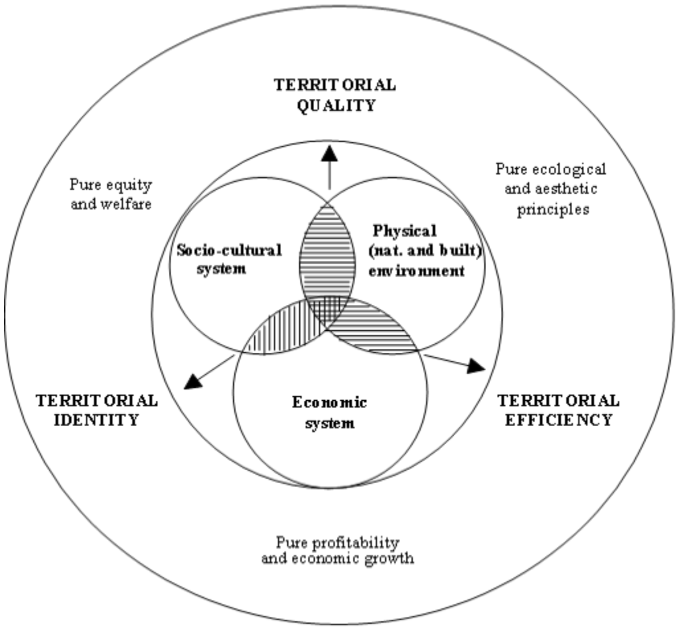

Figure 2.17 The component of territorial cohesion (source: (Camagni, 2007))

The three dimensions considered are territorial efficiency, territorial quality and territorial identity:

- Territorial efficiency relates to resource-efficiency with respect to energy, land and natural resources; competitiveness of the economic fabric and attractiveness of the local territory; internal and external accessibility.
- Territorial quality is the quality of the living and working environment; comparable living standards across territories; similar access to services of general interest and to knowledge.
- Territorial identity: presence of ‘social capital’; capability of developing shared visions of the future; local know-how and specificities, productive ‘vocations’ and competitive advantage of each territory.

The tree dimensions integrate the tree elements of sustainability in terms of economic, socio-cultural and physical environment's objectives.

2.5 Rail-Freight Transport in Europe

There are a number of reasons for the diminishing attractiveness of rail-freight transport. Historically, most rail-freight companies in Europe are state-owned companies. This model resulted in a lack of international integration and reduced the change of rail companies to offer fast, reliable and efficient international services at an European level (Wiegmans et al., 2007). In comparison to the United States, where most rail networks are private domain, the transcontinental transport is open to competitors and railway companies maintain a share of the overall freight market (European Commission, 2001b).

Currently the decrease in rail-freight transport is well known and there are many problems, such as incompatibility forms of track's electrification, differing track's gauge, and lengthy border checks (Wiegmans and Donders, 2007). The European Commission found that the average speed of international freight services has fallen to eighteen kilometers per hour and in terms of tons, almost all European Union countries have shown an increase since 1995 (Figure 2.18).

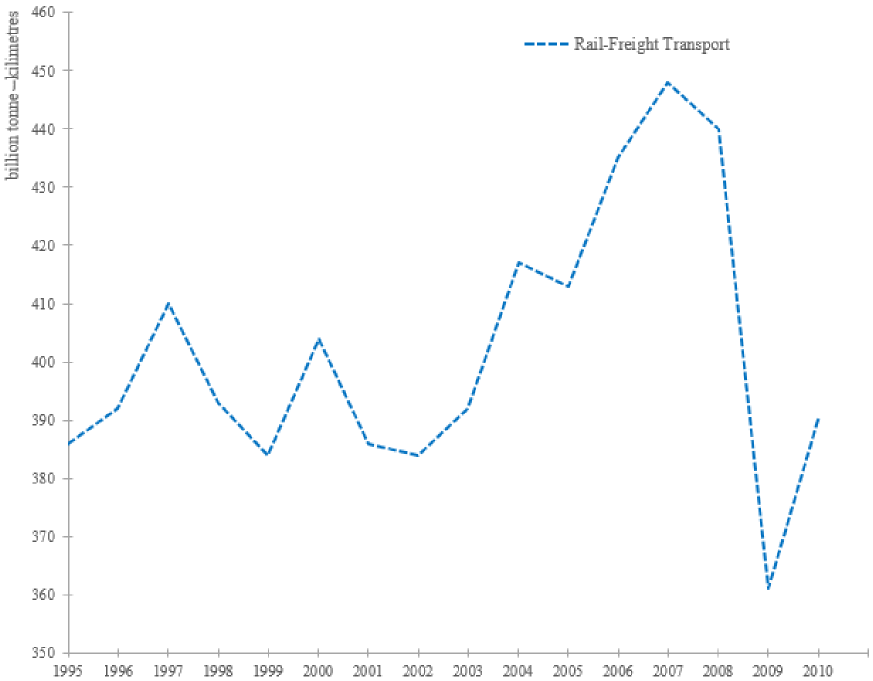

Figure 2.18 Rail-freight transport performance EU-27 (1995-2010 in billion tonne-kilometer) (source: adapted (European Commission, 2012b)

In recent years, there has been important changes in Europe in the railway transport sector mainly regarding containerization and shuttle trains (Meijer et al., 2003). However, it is still difficult to improve the competitive position of rail-freight transport. The main reasons relate to the relation between market share and the level of service offered, regarding to transit timetables and reliability of service. Significant reductions in transit times require large increases in both the number of connections and operating costs (Ferreira, 1997). Other researchers demonstrated that high train frequencies contribute to a strong rail performance as demonstrated in Austria and Switzerland (FitzRoy and Smith, 1995).

The rail-freight network has an insufficient connectivity, limit track time for extra services and policies that favor the existing technology paradigm. These disadvantages reveal that it is quite difficult to improve the competitive position of rail-freight transport and that it is urgent to develop the efficiency and effectiveness of rail operations.

One of the aims of the European Commission, translated on the transportation policies, is to implement an open and competition-oriented system of network infrastructures. This requires actions on enforcing the interoperability of such infrastructures. Improving the interoperability would allow access to the rail network and would help many transport enterprises to use the rail infrastructure. However, the non-use of the railway infrastructure is related to the lack of adequate institutional framework for international railway transport which has become an interoperability problem (Nijkamp, 1995).

The European Commission began an active involvement in rail policy in 1990, when the White Paper *Communication on a Community Railway Policy* was prepared. The ambition has been to promote efficiency and competitiveness of the railway through gradual liberalization. The directive 91/440/EEC on the Development of the Community's Railways (Council of the European Communities, 1991) requires the separation of infrastructures and operations and requires that Member States grant rail companies their independence from the government and introduce commercial management. The 1991's Directive follows the ideas proposed in the White Paper with the aim of adapting the railways to the needs of the single market and increase railway efficiency. The White Paper and the EU Directive stressed the importance of management autonomy and the necessity of using uniform accounting methods in order to induce more financial discipline and more operational competition both nationally and across borders (Butcher, 2013). The Directive created a certain access to rights, separated railway infrastructures management from the operation of the trains and simplified the use of the infrastructure by multiple users.

2.5.1 Revitalizing the Community's Railways

In 1996, the White Paper *A strategy for revitalizing the Community's railways* (European Commission, 1996b) set out suggestions for a strategy to revitalize the European rail. The Commission aims to promote a transfer of freight traffic from road to railways, ease the access to Europe's rail networks, restructure the state rail companies and move to increase rail freight, including a series of rail freight freeways (Butcher, 2013).

The policies limited the development of freight freeways. The idea of the Trans-European Rail Freight Freeways (TERFFs), introduced in the White Paper, provides a framework for voluntary co-operation between Member States, freight train operators and infrastructure managers to make international freight services more attractive to customers. The TERFFs consist of packages of prices, timetables slots and service levels involving rail infrastructure to be used by independent operators and routes (Sichelschmidt, 1999). However, this package has turned out to be ineffective, mainly due to union-led resistance. In 1998 the Commission proposed a new package of measures to ensure a more efficient use of the European railway infrastructure, in order to adjust the previous Directives. Nevertheless, in 2001 four new Directives on infrastructure and interoperability were adopted, with the aim of increasing competition. The new Directives amended the 1991 and 1995's Directives regarding the development of the European Railways and established the open access for international freight (Council of the European Union, 2001a). These Directives override policies relating to the licensing of railway infrastructures (Council of the European Union, 2001b) or allocation of rail infrastructure capacity (Council of the European Union, 2001c). Moreover, they established some guidelines on the inter-operability of the trans-European conventional rail system (Council of the European Union, 2001d).

2.5.2 European Transport Policy for 2010: Time to Decide

Besides the amended directives, in 2001 the European Commission published the White Paper *European Transport Policy for 2010: Time to Decide* (European Commission, 2001b). The main objective was to refocus the European transport policy on the demands and needs of its citizens and to place user's needs as a strategy. The White Paper proposed several measures. The first was to shift the balance between modes of transport by 2010 in order to revitalize the railway, promote maritime and inland waterway transport and link up the different modes of transport (Butcher, 2013). According to the White Paper the railway revitalization center around the opening up of the national freight markets to cabotage and to establish a high safe level for the rail network. The development of the interoperability directives on the use of high-speed and conventional railway network were also proposed. Moreover, the White Paper recommends opening the trans-frontier passenger service, in order to promote measures for the quality of services and customers' rights and create a common agency for safety and interoperability. The second measure of the rail Directives was listed by the Commission in 2002. This package includes widening access right to domestic freight and international passenger services and the development of a common approach to safety, establishing the European Railway Agency as a steering board, enhancing interoperability, and also enabling access to the *Convention Concerning International Carriage by Rail* (COTIF). The main strength of this second package is on standardization in order to make easier for railways to compete with other means of transport, and in particular to complete the liberalization of the rail freight market.

One of the measures presented is the Directive 2004/51/EC regarding the full liberalization of freight and proposition concerning the opening up of cabotage operations (Council of the European Union, 2004).

2.5.3 Railway Packages

In 2004, the European Commission published four additional proposals that focus on railways, the so-called 'Third Railway Package'. The highlight was on increasing competition in the passenger rail market, an avoided area due to its complexity. The initial package consisted of four legislative proposals related to the liberalization of passenger services and international passenger's rights and obligations. Railway freight services are set in COM(2004)139 on the development of the Community's railways that amend the 1991 Directive (European Commission, 2004b). Moreover, the COM(2004)144 regulates the compensation in cases of non-compliance with contractual quality requirement for rail freight services (European Commission, 2004c). The proposed text aims to guarantee that quality factors are systematically discussed and taken into account.

On 30 January, 2013 the European Commission published the details of the Fourth Railway Package. The package includes six new legislative proposals. The idea is to open the domestic rail market to competition and improve the operation in the EU railways system and its institutional framework (European Commission, 2013a).

2.5.4 High-Speed Rail-Freight Experiences

The freight traffic market reveals an ongoing increasing growth rate for the future. However, railway companies face a continuing need to improve their revenue and cost situation in order to cope with increased competitiveness as well as intermodal and especially with road traffic (Lloyd's Register, 2008). The positive development of the overall transport market can be a chance for rail freight segment to gain higher market shares by an improved transport quality. Besides all this, freight rail market faces new intra-modal competition (rail-rail) and inter-modal competition (rail-road, rail-vessel) and find a strategy that matches both competitor types.

However, there is no single definition for high-speed in the context of railway services. The main reference is always to passenger service and not to freight (Givoni, 2006). The new high-speed railway lines were built exclusively for passengers while the old lines promote a more efficient mobility for freight. The existing infrastructure was upgraded and the track is shared by suburban or regional passenger services and freight services. Furthermore, the location of the industry is not likely to be in the path of the (new) high-speed railway line. Other reason (pointed out by Campos and Rus, 2009) is the speed difference between high-speed passenger services and freight services, that cause massive decreases in line capacity. In some cases, the night hours of high-speed railway lines are dedicated to lower-speed lines in favor of freight traffic.

López-Pita (2001) refers that there is some misunderstanding about the practical application of the concept of mixed traffic (passengers and freight) run on high-speed lines. López-Pita also mentions that it seems advisable to define, in a more precise way, the terms *passenger* and *freight* since they may not be enough to exemplify the technical and economic viability of operating a mixed traffic line.

The operation of mixed traffic on a high-speed line is always associated to a different maximum operating speed and different train formations that could lead to higher track damages and increased maintenance costs. Given the investment in rail transport it is now possible to use a modern rolling stock design, with dynamic behavior, capable of operating at high-speed and capable of carrying passengers or goods traffic with compatible loads and power demand. However, there are several rules that need to be taken into account regarding the safety operations in a high-speed line for mixed traffic. For security reasons it is recommended that trains do not cross inside tunnels allocated to high-speed lines.

Nevertheless, the Germany experience tried to design not faster lines for passenger traffic, but lines to promote higher profitable overnight freight traffic between North Sea Port and the industrial areas and the consumer market in Southern Germany. The initial idea was to focus on the possibility of running high-speed passenger trains and operating freight trains at 200 km/h carrying wagons (López-Pita, 2001). The freight transport was deemed more important because it contributed considerably more to the turnover than passenger traffic (Albalate and Bel, 2010). Moreover, the state railway obtained a large part of their income from freight traffic doing high investments in the new infrastructure which has served freight traffic as well as passenger traffic (Ebeling, 2005). However, mixed traffic lines have been limited. Recent railway lines have been built only for passengers given the high financial cost required for the operation. During the operating time of the Kassel-Göttingen section of the Hanover-Würzburg high-speed line, the line carried similar amounts of passenger trains and freight trains. The freight trains run during most part of the night, and the passenger trains run throughout the day, so that the need to use passing tracks was not frequent. Other mixed passenger-freight experience was the Cologne-Frankfurt line. The experience from other sections showed that rail-freight traffic might only be accommodated with several restrictions (Ebeling, 2005). The first refers to the difficulty to create a reasonable timetable for daytime freight due to the large speed difference between passengers and freight-rail traffic. Secondly, the time slot required for night traffic cannot be allocated given the high levels of maintenance required which can only be done during the night. Finally, the weight difference between passenger and freight trains is another factor that favors the split of freight and passenger services. Another key issue is the incompatibility between high-speed traffic and short-distance traffic. The solution requires the separation of the two infrastructures and gives priority to high-speed rail services. However, freight is now demanding the same privileges to protect business quality, which suffers several delays to be 'pushed aside' during certain periods of the day. The main reason is the priority of commuter traffic based on social necessity.

In the mid-sixties, France started to plan new lines suitable to carry high-speed traffic with an exclusive design for passenger trains. The exception was in the vicinity of the city of Tours (TGV Atlantique) where the line was also designed for carrying freight services. The reason outlined by SNCF was the geometry adopted for the

Paris-Lyon line that would be capable to deal with the future demand. Yet, if freight services were eliminated, it would be possible to triple the capacity of the line for passenger services (López-Pita, 2001). The exception was the 17 kilometers section near Tours where the mixed passenger and freight traffic would be acceptable. Only a negligible number of trains use that section. However, since the end of 1997 some sections of both the Paris-Lyons line and the TGV Atlantique line have been used during the night by two conventional freight trains which run at a maximum speed of 160 to 200 km/h. These are made up of specially modified type of wagons with 16 tons and locomotives with an axle-load of 22.5 tons. The modification of wagons and locomotives was mandatory in order to preserve the geometric characteristics of the line for proper operation, or at least not without incurring prohibitive maintenance costs which were incompatible with traffic intensity.

In the British context, Atkins (2002) considered that, by relieving conventional lines from the fastest passenger trains, the finances of the conventional network would be seriously affected by the withdrawal of passenger traffic which is the most profitable traffic. If capacity is available, the high-speed rail line may also be used by other services such as commuter trains or even freight over some length. The high-speed line from London to the Channel Tunnel is already used by commuter services into London and freight use is expected to start soon (Nash, 2010).

In Spain, domestic freight benefited from high-speed rail lines through the freeing of capacity on conventional lines. The international freight, which shows greater potential to drive economic growth, has been hampered by the Spanish track gauge. In order to take advantage of the growth opportunities in the international freight services, the Spanish high-speed rail strategy includes development of hybrid passenger/freight lines operation on European standard gauge for routes that cross the borders (Invensys Rail, 2012). The hybrid solution involves changing the axles of the wagons. It does not take long to do it – approximately 10 minutes per wagon – but the train operation is interrupted by the numerous shunting maneuvers that need to be performed at the border station of Porbou (Spain). In order to improve international rail traffic, the Barcelona-Perpignan line is equipped with the European standard (UIC) track gauge. The list of reasons for the mixed rail line decision was pointed out by López-Pita (Teixeira et al., 2008). The first reason relates to the high-speed passenger network on the other side of the Pyrenees. The second has to do with the peripheral location of Barcelona meaning that the envisaged passenger traffic is not very high (less than 3.5 million passengers/year), and the extra capacity would allow other train types to use the line. Besides all this, running freight trains on the Barcelona-Perpignan line boosts the importance of the Barcelona port and reduces freight transport times to central Europe (López-Pita et al., 2007).

In *Economic Assessment of Railways Policies: High-Speed or High-Performance,* (Coto-Millán et al., 2012) refers that the Santander-Palencia high-speed rail line which supports the connection Santander-Madrid makes possible to deliver freight between both cities. However, by admitting the possibility of delivering freight, the infrastructure maintenance cost increases over 50 percent. The increase is justified by the data collected from the economic-financial annual report of the rail company RENFE. The report analysis the maintenance costs of the infrastructure both for AVE - used only for passenger transport, as in the case of Madrid-Seville, as well as the maintenance of the conventional infrastructures used both for passengers and freight services.

New ideas are emerging in order to improve the concept of European freight services on the existing high-speed railway network (EuroCarex, 2011a). The Carex concept uses the European high-speed rail network to carry airfreight pallets and containers over distances of between 300 and 800 kilometers (Figure 2.19), involving a modal-shift from trucks and short-/mid-range aircraft to high-speed trains wherever appropriate. Carex also uses airport-based air/rail terminals connected to high-speed rail links and tailored service to suit the logistics chains and transport plans of integration, with priority given to express freight in order to guarantee next-day delivery.

Figure 2.19 The Euro Carex network (source: (EuroCarex, 2011b))

The Carex service anticipates the customer needs and aims to be an answer to their expectations in terms of speed and efficiency. At the same time, Carex provides a response to the night flights' restrictions and the increase regulatory and cost constraints that are applied to road transport.

2.6 Planning a High-Speed Rail Shared Line

With some exceptions, such as buses and pipelines, most transport modes are developed to handle both freight and passenger traffic. The sharing of space between freight and passengers raises some difficulties. The difficulties are, for example, the congestion caused by trucks in urban areas or by passenger transport users. Regarding railway services, the poor performance is seen as the outcome of freight and passenger rail services needing to share routes. The advantages of joint operations are related to the high investment cost and the maintenance costs that can be spread over a wide base and also the track sources that can be used both for freight and passengers. On the other hand, the main disadvantage of joint operations is related to the location of demand, since origin/destination of freight is usually distant spatially from passenger traffic. Other disadvantage is the difference between demand frequencies. Passengers need a higher frequency service than freight. Besides, timing of service is different for passengers – which has specific peak-times during the day – rather than for freight, which tends to be more spread throughout the day. The reliability of the service – freight traffic increasingly demands quality service and delays in passenger service are not acceptable. Route sharing favors passenger traffic, as passenger trains have priority and trucks can be excluded from urban areas during a certain time of the day. Passenger and freight services require different procedures regarding the operation and security measures.

2.6.1 Line Planning

The planning process always starts with the definition of the routes and lines of the railway network. Besides, it is required to attract customers to have a regular service and proper connections between stations. Even with the new rail system the problem is the same since the early ages. Given the increasing mobility and congestion on roads, railways need to expand and find new markets. On the other hand, freight transport by rail needs to face the road flexibility regarding transport management and price challenges.

The investment in high-speed rail network makes it possible to plan from scratch and introduce new stations, capacity extension and reduce the existing railway network. The transport companies offer several solutions in order to meet costumer’s requirements. The set of stations where the train should stop has to be selected and that decision should be based on technical constraints as well as economic analysis (Bussieck et al., 1998).

The planning of railway passenger transport model requires passenger demand data. A conventional and useful process is the origin-destination matrix. There is also a hierarchy of planning. The generation of the origin-destination matrix is followed by a line planning. Line planning is followed by train schedule generation, which is followed by scheduling rolling stock and staff. Line planning concerns the line optimization problem in order to operate the line with a frequency that serves passenger demand and some defined objectives. Besides, line planning needs to minimize any inconvenient for passengers of direct connections (Bussieck et al., 1998)

Train schedule consists in finding a regular periodic schedule based on a line plan and reacting to fixed frequencies. The arrivals and departures of the train have to satisfy regulations and conditions. The objective is to minimize the total transit time for passengers, and the time spent by the passenger in the system, including travel and waiting time (Caprara et al., 2002). In addition, train schedule needs to meet the necessities of the local requirements, which is an ongoing project (Bussieck et al., 1998). Difficulties in scheduling rolling stock are also related to the material, the maintenance and the depot location. All trains need to be equipped with a rail-crew that includes a driver and rail-staff.

2.6.2 Cargo-Rail Transport

Cargo on high-speed rail networks is usually seen as a secondary option. However, for strategic reasons it can become an important requirement. To consider cargo it is necessary to understand that the reliability of service is as important as time. Adding cargo in high-speed rail lines can help to justify the investment when passenger traffic demand is not enough. Hence, cargo revenues should compensate the extra investment performed to accommodate mixed traffic. With the introduction of high-speed rail service the need to take full advantage of the possibilities offered by this brand system has become increasingly evident. This, together with the design features of the high-speed trains, intended to exceed the speed authorized for conventional rolling stock (López-Pita, 2001).

New investments and research changed the way that freight transport is seen. Integrating cargo into a high-speed rail line became possible and feasible. However, several features need to be taken into account. Firstly, the design choice of the geometrical layout is determinant. This way, before the geometrical parameters selection and the choice of the maximum gradient and length of gradient the impact of the investment into the infrastructure, operating cost and graded load of freight trains should be evaluated. Secondly, the effects of mixed traffic on the deterioration of the track geometry need to be established. Operating cargo trains on a high-speed rail line may increase the track maintenance cost up to 20 or 25 percent as compared to a dedicated line for passenger traffic. Since this cost represents about 40 percent of the total cost of fixed installations – tunnels, bridges, signaling and communication, overhead equipment and power supply - the extra cost to operate a mixed traffic line would be around 10 percent. Thirdly, the repercussions of freight traffic on the line needs to be evaluated. Operating cargo-trains finds its potential where passenger demand levels are not sufficient to justify the operation. Finally, several operating criteria need to be measured, such as crossing speed of passenger trains and cargo trains, maintenance intervals and also the environmental impact of cargo trains. The traffic control systems makes it possible to regulate speeds and the use of the parking tracks along the line.

2.7 Conclusions

This chapter describes the development process of several high-speed rail services in the world together with the usual appraisal methodology of the investment. The investment required for the construction of a new railway infrastructure is obviously high, and it is necessary to ensure the proper evaluation in order to achieve an optimal result. As approached, the rationale for the investment tends to go further away from the traditional approach applied to project evaluation, dominated by strategic and political influences or regional development objectives. Every time that an investment decision has to be taken, it involves weighting costs against benefits over a large period of time.

Traditional appraisal methods such as cost-benefit analysis or multi-criteria analysis are both the most common frameworks for assessing options facing decision-makers and also trying to construct a common metric in order to compare the available options. CBA provides an advanced means of comparing different investments and outcomes by reducing them to a common monetary form, and the conclusions are often very sensitive to specific assumptions, such as discount rate or risk. However, with CBA it is difficult to balance non-quantifiable costs or benefits against quantifiable ones. On the other hand, MCA can be used to broaden the scope of analysis, and it provides a framework to enable decision-makers to overcome difficulties in handling a large amount of complex information in a consistent way. Besides, MCA established preferences between options but brings significant difficulties in terms of determining the appropriate weight of the different criteria involved. Nevertheless, MCA is a method based on CBA and capable of eliciting the trade-offs between objectives in ways that enable decision-makers to make rational and systematic choices regarding the preferred project including monetary and non-monetary options will (certainly) become an asset.

As mentioned before, high-speed rail generates more economic benefits as the volume of traffic increases (Rus and Nash, 2007) and freight services can be the solution to turn high-speed rail line investment economical profitable. There is no doubt that operating a high-speed line for freight implies an increase in track maintenance costs when compared to operating a high-speed line used exclusively for passenger traffic. The opportunity to upgrade the offered services is a key factor that increases the value of high-speed services. The ability to use rail to differentiate services has become a strategic weapon rather than an operational tool in the new competitive rail environment. Improving service quality is an important issue to the railway industry in the era of regulation. The quality of the service has become an important demand in order to attract not only passengers but also new market shares. Cargo services wants to promote and offer the same kind of high-speed services that is offered to passengers such as commercial speeds, frequency, accessibility, attractive travel time (door–to-door), reliability, price and safety. High-speed light freight can undertake an increasingly use of variable processes for different types of service that high-speed offers. Depending on the motive, travel periods or other circumstances influenced by demand the price offered (and purchase conditions) can vary considerably.

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3 METHODOLOGY

3.1 Introduction

The transportation planning process includes many different objectives and reflects the wishes of a wide range of interests. A sustainable transport system seeks to ensure that the major issues of economic development, social equity and environmental stewardship are addressed within the transport sector (Zietsman et al., 2006). The discussion about the economic benefits in new transport investment, such as roads, seaports or rail lines are generally based on economic development arguments common for both transport investment and economic growth (Gramlich, 1994). Usually, transportation decision-makers require additional information about the effect of investments and policies on the environment, business, productivity, economic growth, income distribution among other concerns in order to ensure that investments produce benefits that exceed the cost of achieving them (OECD, 2002a).

Decision-making in the context of sustainability of transport involves the evaluation of a discrete set of alternatives while considering conflicting objectives. Traditional appraisal methods for transport decision-making are mainly focused on the quantifiable finance and economic aspects of the investment. However, decision-making in the transport sector is often performed with single-objective decision-making methods as described in Chapter 2. The principles expressed become a standardized mode to compare costs and benefits for any investment appraisal. In many cases the application of the economic techniques to any project has not been easy. The reasons are usually related to the impossibility to take non-monetary issues into account such as social and environmental aspects of particular alternatives or to cover the overall preferences and objectives from different interesting groups that take part in the evaluation process.

As a consequence, it becomes mandatory to use techniques that include these multiple and conflicting objectives and lead to the application of multi-criteria decision-making methods. Multi-criteria decision-methods show how to deal with problems with a large amount of information, identify trade-off between conflicting goals and compare available alternatives in a systematic manner (Janic, 2003). The Multi-Attribute Utility Theory (MAUT) is a multi-criteria decision-making approach which makes possible to include a full range of criteria or objectives and a wide range of externalities. The results can be used by the decision-makers as a basis for deciding about the most appropriate alternatives in order to support the allocation of resources in the most effective way.

The purpose of this chapter is to provide insight about how a special MAUT method, called Multi-attribute Tradespace Exploration (MATE) can be used on the practice of transportation planning and act as a key decision making method in transportation. MATE method typically uses MAUT method to aggregate attributes into a single criteria score, the Multi-Attribute Utility (MAU) (Keeney and Raiffa, 1993) and Tradespace Exploration (Ross et al., 2002). Thus, MATE is a value-driven tradespace exploration method that has been evolved over the past decade by MIT's Systems Engineering Advancement Research Initiative (SEAri) (Ross and Hastings, 2005) and has been mostly applied in aerospace case studies (Ross et al., 2010) and utilized in research examining requirements' generation (Diller, 2002), policy uncertainty (Weigel, 2002), space system architecting and design (Ross, 2003), current engineering (Stagney, 2003), spiral development (Roberts, 2003), evolutionary acquisition (Derleth, 2003), modularity (Shah, 2004), orbital transfer vehicle design (Galabova, 2004) and value robustness (Ross, 2006).

This chapter also presents the methodology of the practical part of the current research. In that section there is a description of a specific application of MATE applied to complex transport systems in order to support decision-making in transport investments. Moreover, a first insight of the presented method is applied on the future Lisbon-Madrid high-speed rail line in order to deal with the introduction of containerized cargo operation in the life cycle operation.

3.2 Decision Methods

3.2.1 Single-criteria vs Multi-criteria

Evaluation of transport plans and projects has been carried out using a varied methodological framework. The methods can be grouped in two major categories, the single criteria methods (monetary approach) and the multi-criteria methods (non-monetary approach). The cost-benefit analysis (CBA), as a monetary approach, is the most used evaluation technique for assessing investment. In the transport field, as already described, it is the support tool in the majority of European countries (HEATCO, 2005; OECD, 2005) and abroad (EVA-TREN, 2008; PIARC, 2004) and it is also widely adopted by international organizations such as the World Bank and the European Commission, among others. Despite the number of official guidelines – European guidelines (European Commission, 2008a), national guidelines (CEDEX, 2010) or more specific guidelines (as (European

Investment Bank, 2005) for rail investment – they show some differences on how CBA must be performed. The CBA evaluation process uses money as measure unit in order to reduce all costs and benefits associated to the investment as a common value. Once all relevant effects of an investment are quantified the concept of inter-temporal discount is used to translate future costs and benefits to present day by a social discount rate. As a result, the future values can be compared with the present ones (Beria et al., 2012).

On the other hand, the multi-criteria methods were found to be helpful since they made possible to include a broad range of quantitative and qualitative issues in the decision-making process. That is, the major advantage of a multi-criteria analysis is the ability to account for a wide range of different and relevant criteria, even if these criteria cannot be expressed in monetary terms. Several methods have been developed to assess the relative importance of projects on multi-criteria analysis (Levine and Underwood, 1996; Olson, 1997; Reed et al., 1994). The MAUT approach tries to apply objective measurement to decision-making and allows the decision-maker to allocate relative weights to the different criteria selected (Mickelson, 1998; Zietsman et al., 2006). The MAUT evaluation process considers that in any decision problem there is a utility function defined by a set of feasible alternatives that the decision-maker seeks to maximize, intentionally or not (Olson, 1997). Each alternative results in an outcome, which may have a different number of dimension. MAUT measures these values, one dimension at a time, followed by an aggregation of these values across the dimension through a weighting process (Zietsman et al., 2006).

3.2.2 Multi-Attribute Decision Method

The multi-attribute decision making problem focuses on decision-making problems with a finite number of criteria and alternatives. In order to understand the overall method a multi-attribute decision problem is considered with m criteria and n alternatives. Criteria and alternatives are represented by $C_1 \dots C_m$ and $A_1 \dots A_n$, respectively. The decision table addressed the features of the multi-attribute decision making process, as presented in Figure 3.1.

		x_1	.	.	x_n
		A_1	.	.	A_n
w_1	C_1	a_{11}	.	.	a_{m1}
.	.	.	.	.	.
.	.	.	.	.	.
w_m	C_m	a_{m1}	.	.	a_{mn}

Figure 3.1 Decision Table

In the decision table each row fits a criteria and each column describes the performance of an alternative. The score a_{ij} describes the performance of alternative A_j against criterion C_i. For the sake of simplicity it is assumed that a higher score value means a better performance since any goal of minimization can turn into a maximization goal. Weight w_i reflects the relative importance of the criteria C_i to the decision. The weights $w_1 \dots w_m$ are assigned to the criteria and are always positive. The use of (criteria) weights is controversial since it opens up the analysis to a certain amount of subjectivity. However, weight is an important tool to allocate the relative importance of the different criteria, as they are perceived by the decision-maker (Zietsman et al., 2006). The values $x_1 \dots x_n$ associated with the alternatives are the final ranking values of the alternatives. Generally, higher ranking methods values mean a better performance of the alternatives. That is, the alternative with the highest ranking value is the best of the alternatives.

The multi-attribute decision-making techniques can rank the alternatives, that is, the single most preferred alternative can be identified or a short list of a limited number of alternatives can be selected followed by a detailed appraisal (Fülöp, 2001). Besides the monetary based and the elementary methods, there are two main families in the multi-attribute decision-making methods. Those are based on the multi-attribute utility theory and outranking methods. The multi-attribute utility theory consists of aggregating different criteria into a function, which has to be maximized and the mathematical conditions of aggregation are studied. This theory allows a complete compensation between the criteria, that is, the gain on one criterion might be compensated by the loss on another (Fülöp, 2001; Keeney and Raiffa, 1993).

3.2.3 Tradespace Exploration

The tradespace exploration method is useful to understand complex solutions to complex problems. The term ‘tradespace’ is the combination of the words ‘trade-off’ and space. Tradespace is a combination of graphical representation, supporting database and mathematical models of all possible solutions to a given design problem. The tradespace, according to Hastings and McManus (2008) exposes the feasibility solution set, and also exposes the best solution without preconceptions and underlining design trades. This results in a robust solution in order to explore further explorations through more detailed studies.

In order to understand a tradespace exploration it is important to understand the feasible solution set. The possible solutions are generated by enumerating design vectors. The design vector contains design variables that are influenced by a designer regarding the system. A design vector contains all design variables of a system. In practice a set of limited key design variables are the ones that better represent the attributes that stakeholders are interested in (Nickel, 2010). This key design variables could be determined by a Design Value Matrix (DVM). The DVM can be used to prioritize design variables in terms of strength of impact on attributes, as well as capturing and communicating the selection of design variables as drivers of stakeholder values. An DVM example can be found in Ross and Rhodes (2008) and Figure 3.1 is a simplified representation of this method.

Along the top of the DVM are listed the attributes defined from stakeholders whereas the design variables are listed horizontally. The mapping indicates the strength of a design variable to drive an attribute. However, the decision analysis requires a measure value and methods to determine the 'best' option to decision-makers. In the case of a single-attribute problem, finding the best solution can be undertaken through more traditional optimization methods (Gerst, 2011). However, in a multi-attribute space no single solution optimizes all attribute values. That is why it is important to find the best or most cost-effective solution. Instead, a *Pareto front*ier can be used to enable value trade-off among design alternatives. The strengths of the tradespace is that it allows unrealistic systems to be rejected, good ones to be improved, and key problems to be mitigated at a very early stage (Hastings and McManus, 2008).

3.2.4 Multi-Attribute Tradespace Exploration

Multi-Attribute Tradespace Exploration (MATE) is an emerging conceptual design methodology that applies the multi-attribute utility theory to model and simulation-based design (Ross et al., 2004). As already mentioned MATE methods have been developed by MIT's Systems Engineering Advancement Research Initiative (SEAri), and is a framework that organizes the existing advanced design tools into a coherent method (SEAri, 2009). MATE method offers a tool for establishing decision criteria and for generating and evaluating solutions (Nickel, 2010). The strength of the method comes from the ability to quantitatively assess many design choices very early in the design process which allows designers and users to explore many design options, and prevents focusing on a single design point (Hastings and McManus, 2008).

The following section explains the process used in MATE. The intention is the conceptual understanding of the method and its aims in the overall context. Moreover, for a deeper understanding, an example of a 48-step process for applying classic MATE can be found in Ross (2003).

3.3 Multi-Attribute Tradespace Exploration Framework

In order to define the process concept it is necessary to satisfy the user needs, find the scope of solution space and decide the scope of the analysis to be performed. The model approach suggested allows a traceable calculation of attributes, utilities and costs, given an enumerated vector of possible design architectures. Figure 3.2 shows the support schema of the MATE process.

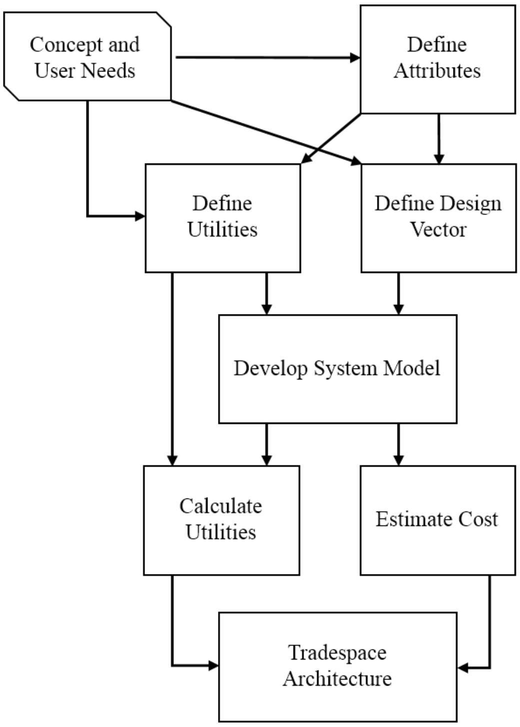

Figure 3.2 MATE process description

The first step, the need for identification, encompasses scoping decision-maker needs and eliciting attributes and preferences. This step is critical in order to transform qualitative user needs to qualitative metric ones. Attributes are decision-maker designated metrics that describe the performance characteristics of the system and have been described as ‘what the decision makers need to consider’ and/or ‘what the user truly cares about’(Hastings and McManus, 2008). Attributes should be quantifiable and able to predict reasonable fidelity high level models. Usually, attributes are the result of the user needs and not the design features to perform. Attributes must be complete, operational, decomposable, non-redundant, minimal and perceived independently to ensure complete coverage of a decision-maker’s preference (Keeney and Raiffa, 1993). Besides, attributes have a definition, units, a range and a direction of increase value and all of these characteristics must be determined in order to properly design a system. However, attribute independence is sometimes hard to accomplish in the beginning of a study, and the attribute list can sometimes change during this process.

After the selection of the attribute list, the attributes are associated to utility curves. Together, the attributes and utility functions define a wide range of functional system outcomes, evaluated in terms of their utility to the user. Moreover, preference weighting factors are elicited through formal stakeholder interviews. Single-attribute utility curves are aggregated using a form of a multiplicative utility function. The utility functions are dimensionless representations of the relative desirability that are normalized to range from 0, minimally acceptable, to 1, highest of expectations.

The design space consists of a number of design variables that define a large number of possible physical designs. The design space is a reduction of all possible design solutions to a tractable number, given the infinite choices. The design alternative enumeration is the second phase and involves using the elicited attributes to compose a set of feasible solutions. This is done through inspection of the attributes and proposal of various design variables. Design variables are quantitative parameters of the system, which taken together describe the system's architecture. Each possible combination of design variables define a design vector. This last phase entails the development of models to link design solutions to articulated value. A full-factorial selection of the design space is enumerated, typically using parametric computer models, which take each design vector as input and return as output the attribute metrics and system costs (Gerst, 2011). A utility function is then applied to the resulting attributes and cost versus multi-attribute utility plots can be generated, forming a tradespace (Ross, 2006). These variables are under the designers or system engineers' control and has a large impact on the attributes of the system. There is a certain tension between including more evaluation variables in order to explore a larger tradespace and the computational effort for actively exploring such large space.

Tradespace is composed by thousands of potential mapped architectures resulting from attributes, utilities and costs. The final objective, regarding the tradespace, is to reduce the tradespace to design's worth and uncover the key design trades. Thus, data visualization and manipulation techniques are usually essential to understand the complex design space (Shaw et al., 1999). However, attention should be focused on designs that, for a given cost, produce the highest utility. That is, the region of the tradespace referred as *Pareto front*. Designs that are not on the *Pareto front* are dominated, since better designs are available at the same or lower cost. Further details, benefits, and challenges of *Pareto front* are further discussed.

3.4 Utility Theory

The utility theory is widely used in the fields of economics, decision analysis, and operations research. The concept of utility is used to map the attributes of a design to the preferences of the decision makers. The attributes are what the decision-makers care about, and the utility captures how much the values of the attributes are desired in a way that attributes can be quantified. A single attribute utility is a normalized measure of preference for various values of an attribute. The multi-attribute utility combines single attribute utilities into a combined metric that can be used to rank decision maker preferences for any set of possible values of the attributes (Hastings and McManus, 2008).

An overview of concepts could be done by key references, as in (Neufville, 1990a) on Applied Systems Analysis: Engineering Planning and Technology Management or in Decisions with Multiple Objectives: Preferences and Value Tradeoffs from (Keeney and Raiffa, 1993). In the Keeney and Raiffa (1993) book there is a statement concerning the formal theory behind the method in great detail.

The utility theory provides a better way to get the decision-maker preferences and needs than most other techniques, and can be quantitatively coupled to other tools and models (Ross and Hastings, 2005). In a simply manner, the theory of decision analysis is designed to help the individual make a choice among a set of pre specified alternatives (Keeney and Raiffa, 1993). The problem relates the decision-maker choices to several alternatives, each of which may result in a consequence describable in terms of a single attribute. The decision-maker does not know the resulting consequences but can assign probabilities to the various possibilities that might result from any course of action. If an appropriate utility is assigned to each possible consequence and the expected utility of each alternative is calculated, then the best course of action is the highest expected utility (Keeney and Raiffa, 1993).

3.4.1 Single Attribute Utilities

Single attribute utilities map single attributes onto decision-maker needs. Afterwards the attributes and their acceptable ranges are defined and the requirements are considered. The attribute is a function or output of the proposed system that the decision-maker is interested in, so it is a functional requirement. Some forms of requirements are shown in Figure 3.3.

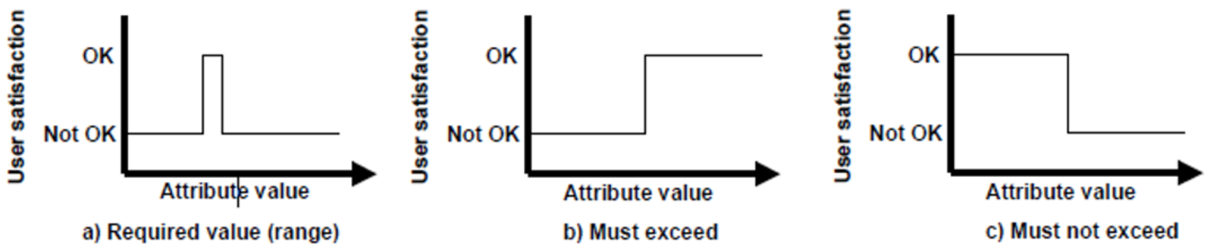

Figure 3.3 Forms of requirements (source: adapted (Hastings and McManus, 2008))

If the decision-maker has already a firm need for specific values of a proposed attribute, the attribute it is not a good attribute, and should be treated as a constant on the tradespace. However, the decision-maker needs are not as complete as suggested in the previous figure. The decision-maker needs presented in Figure 3.4 shows some more realistic expressions of the decision-maker needs. Nevertheless, not meeting a requirement does not mean invalidating the system, though it may displease the decision maker.

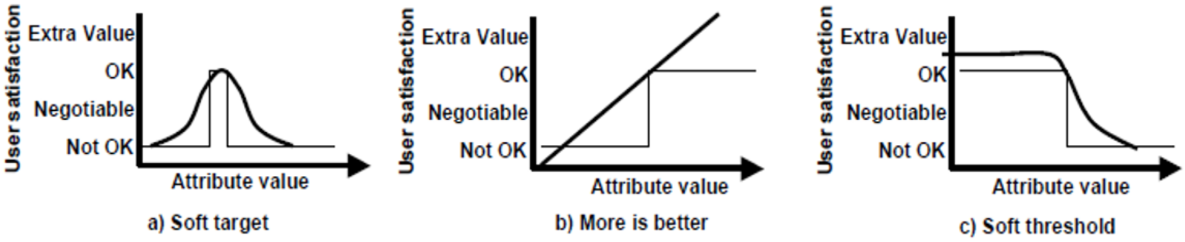

Figure 3.4 Realistic expressions of the decision-maker needs (source: adapted (Hastings and McManus, 2008))

Rather than the qualitative measures of decision-maker satisfaction presented, the utility defines a quantitative measure. Thus a dimensionless scale from zero to one is used. So, for any value of an attribute x_i, the utility is defined as in *(3.1)*:

$$U_i = U_i(x_i) \quad (3.1)$$

The utility is defined to be zero at the lowest acceptable value of x_i, x_{i^*}, and one at the highest or most desirable level of x_i, x_{i^*} as represented in *(3.2)*

$$\begin{aligned} U_i(x_{i^*}) &= 0 \\ U_i(x_{i^*}) &= 1 \end{aligned} \quad (3.2)$$

Zero represents the lowest possible level of decision making satisfaction that the decision maker might consider. It is also the bottom end of the negotiable range. According to Hastings and McManus (2008), the utility is somewhat non-intuitive, since it is curious to think zero as 'no utility', but it is computational convenient and an established convention. Negative values of utility are by definition excluded. One represents full satisfaction of the decision-makers. This limit may need to be chosen randomly since values greater than one create mathematical difficulties and should not be used and the zero position is arbitrary. Utility interpretation is somewhat dangerous. Therefore, a higher metric can be better than a lower one, but a utility of 0.5 may not be half as good as a 1.0 (McManus et al., 2004). A single utility attribute curve is demonstrated in Figure 3.5.

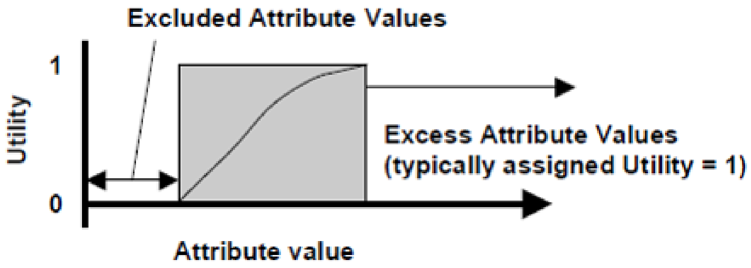

Figure 3.5 Single Attribute Utility Function (source: (Hastings and McManus, 2008))

Several forms of a utility function are represented in Figure 3.6. The properties of the utility scale are explored in detail by Neufville (1990b). The simplest form is the linear relation between the attribute and utilities. The diminishing return is also common for higher attribute values. The threshold or S curve is a common representation. Other monotonic forms are possible and can also be used. In the 'less is better' functions the utility decreases with rising attribute values. The non-monotonic function represents a function where the best value is not at one of the extremes. An attribute with a non-monotonic utility function can be redefined or decomposed into one or two attributes with monotonic utilities.

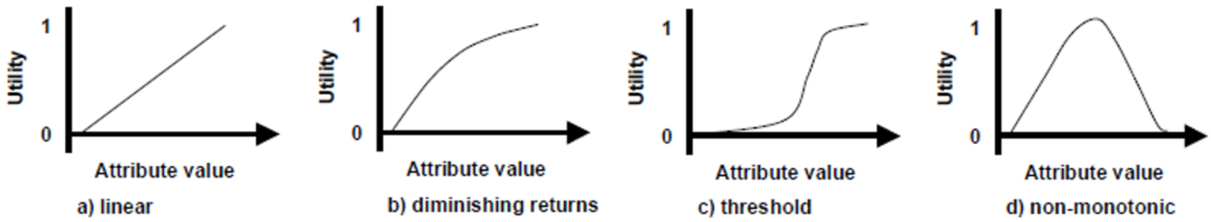

Figure 3.6 Utility Function Forms (source: (Hastings and McManus, 2008))

Lottery Equivalent Probability

Usually, the utility function form is built on the participation of decision-makers. If it is the case, one method to explore the active participation is the Lottery Equivalent Probability (LEP) method for drawing utility functions (Neufville, 1990a; Ross, 2003; Seshasai, 2002). The LEP method article proposes questions framed in issue between two possible results (lotteries), in order to provoke a reaction in the decision-maker. This technique does not deal with the uncertainty of results, since they are handled afterwards. The probabilities are a mechanism for extracting the basic utility curves for the attributes. This method is enhanced with interviews to the decision-maker. The decision-maker is asked to suspend disbelief and answer the questions as accurately as possible (Hastings and McManus, 2008).

The LEP method is viewed as an absolute method for extracting decision-maker utilities, rather than the best available modes. The greatest difficulty in the use of the method is to find a representative decision-maker that can pass through a successfully LEP process (Neufville, 1990b). The decision-maker must be knowledgeable enough to understand the questions and provide intelligent answers.

3.4.2 Multi-Attribute Utilities

Multi-attribute utility provides an idea for assessing values and subjective probabilities of individuals in the presence of uncertainty (Dyer et al., 1992). The logical consistency of multi-attribute utility is based on the mathematical theory for utility models upgraded with a diversity of techniques that address the limited cognitive abilities of decision-makers. So, given the n attributes x_i with known utilities $U_i(x_i)$. The question focuses on how utilities can be combined in a multi-attribute utility U.

Additive Utility Function (the weighted sum)

One way to combine the single attribute function into a multi-attribute function is the weighted sum:

$$U = \sum_{i=1}^{n} k_i U_i \tag{3.3}$$

where k_i is a scalar weight for utility i. This can be found by asking the decision-maker the combined utility of a design with attribute i set to its best single-attribute-utility value $x_{i(max)}$, and all the other attributes set to their worst value $x_{j(min)}$ for $j \neq i$ *(3.4)*.

$$k_i = U\left(x_{1(min)}, x_{2(min)}, \dots, x_{i(max)}, \dots, x_{n(min)}\right) \tag{3.4}$$

For U to be a properly normalized utility, these coefficients are under the restriction that*(3.5)*:

$$\sum_{i=1}^{n} k_i = 1 \tag{3.5}$$

This function is only valid under some limits. The key one is that the single attribute utilities must be completely independent of each other in the sense that the utility of one attribute is not affected in any way by the value of other attributes. According to (Keeney and Raiffa, 1993) the additive multi-attribute function can only be used if the equation *(3.5)* holds in all cases. In practice this could be true but it is very difficult to prove for anything more than small values of n. Nevertheless, the present function is a reasonable choice if the single attribute utilities are independent.

Simple Multiplicative Utility Function

Other function is

$$U = \prod_{i=1}^{n} U_i \tag{3.6}$$

This function implies a higher degree of interaction between the utilities. The decision-makers require that all of the single attribute utilities need to have a high value for the combined utility to be high. For a combined utility to be equal to one all the individual utilities must be close to one. On the other hand, if the individual utilities are close to zero the combined utility will also be close to zero. This function represents a demanding decision-maker that requires high performance of all parts.

Simple Inverse-Multiplicative Utility Function

The present function implies a high degree of interaction between utilities of a simple type:

$$1 - U = \prod_{i=1}^{n} (1 - U_i) \tag{3.7}$$

Or

$$U = 1 - \prod_{i=1}^{n} (1 - U_i) \tag{3.8}$$

The decision-maker desires that any of the single attribute utilities has a high value for the combined utility value to be high. The combined utility is closed to one if any of the individual approaches is closer to one. Otherwise, all of the individual utilities have values near to zero for the combined utility to be closer to zero. This function is an easy way to please the decision-maker who will be satisfied for the excellence in any area. The poor performance in one area may contribute to the poor performance of the solution.

The Keeney-Raiffa Multiplicative Utility Function

From Keeney-Raiffa derives the following form (Keeney and Raiffa, 1993):

$$KU + 1 = \prod_{i=1}^{n} (K k_i U_i + 1) \tag{3.9}$$

Changing these values into the formula for multi-attribute utility, where K is the largest non-zero solution to:

$$K + 1 = \prod_{i=1}^{n} (Kk_i + 1) \tag{3.10}$$

This function allows a single interaction between the utilities expressed by the value of K. This interaction, if not too strict, can be understood as simple interactions covered by previous simple functions. If the k_i values collected using *(3.4)* tend to be high:

$$\sum_{i=1}^{n} k_i > 1 \tag{3.11}$$

Which means that the decision maker is happy with partial solution. The equation *(3.10)* yields K values less than one. In the limit of even some of the k_i approaches 1, K approaches -1 and Keeney-Raiffa function reduces to:

$$1 - U = \prod_{i=1}^{n} (1 - Kk_i) \tag{3.12}$$

(3.12) is a modified form of the inverse multiplicative function. It is similar to the inverse multiplicative function if the k_i are all 1.

If equation *(3.5)* is satisfied, that is, the k_i sum is one, there is no meaningful non-zero solution for K. In this way, if $K = 0$ and after some manipulation, the equation is reduced to equation *(3.3)*, the weighted sum.

If the k_i values collected using equation *(3.4)* tend to be low:

$$\sum_{i=1}^{n} k_i < 1 \tag{3.13}$$

The decision-maker is unhappy with partial solution. In this case the equation *(3.10)* yields K values greater than zero. In the limit some k_i approaches zero and K approaches $+\infty$. This turns (Keeney and Raiffa, 1993) function into equation *(3.6)*, the simplest multiplicative function.

Keeney-Raiffa Multi-Attribute Utility Function

In order to the Keeney-Raiffa Multi-Attribute Utility (MAU) function to be valid, the single attribute utility functions are under two conditions:

1. If a decision-maker chooses a couple of attributes, which consist of attribute x with value x_1, and attribute y, with value y_1, over a second pair x_2 and y_2, that choice will not be affected by the third

attribute value, z. This is called ‘preference independency’. It ranks the preferences over any pair of attributes that is independent of the values of the other attributes. According to (Neufville, 1990c), this criteria is difficult to be formally checked.

2. The single utility function $U_i$will be transformed by a linear transformation, as result of the change in the value of the attributes. This condition is referred as ‘utility independence’. This second criteria is slightly stricter in the mathematical sense than the first one, but presents few additional difficulties in practice. It requires that the single attribute utilities remain utilities in the mathematical sense for all values of the other attributes (Hastings and McManus, 2008).

The result is a multi-attribute utility function, well-behaved, and it is important that the nature of the trades between the single attributes be understood as part of the tradespace evaluation.

Multi-Attribute Utility Method

The multi-attribute utility method is the recommended technique for tradespace analysis situation. It provides insights about which design could provide the best decision-maker utility. However, it may not be the most appropriate in all situations. That is, if the decision-maker needs are quantifiable and well known, it could be much more useful than the abstract definition of utility. On the other hand, the decision-maker needs may be obscure or may not be accordingly to the conditions (such as independence of single attribute preferences) required by multi-attribute utility methods. In this case, the tradespace might need to be explored with parametric multi-attribute utility or be explored in the absence of the single utility function.

The multi-attribute method is a formal method for analyzing the decision-maker preferences which is very useful in tradespace exploration. The result point may not represent the right performance of the decision-maker needs. The point reflects the insight and quantifies the decision-maker preferences in order to proceed with the exploitation of the tradespace. At this stage no options are fixed, correctly or incorrectly.

The traditional processes sometimes take too long and result in products that do not satisfy customer needs since they can be too costly, or difficult to manufacture, or have poor quality, or do not support contradictory preferences. The utility analysis can help to solve these problem by focusing on creative and analytic effort on decisions that affect important design functions. Therefore, the utility analysis identifies the best tradeoffs – particularly under uncertainty – and by disaggregating design decision problems into consensus results.

3.5 The Pareto Front

The *Pareto front* is the most important part of the tradespace. That is, the *Pareto front* is a set of designs that produces the highest utility for a given cost, or has the lowest cost for a given utility. Finding the *Pareto front*ier of a multi-criteria problem involves a selection of optimization techniques, which are designed to efficiently search the space of all possible solutions (Jilla, 2002). Figure 3.7 shows a tradespace example and the trades that can be conducted during the conceptual design. Each point represents a potential design and the *Pareto front* is visible in the upper left. The *Pareto front* integrates the architectures that offer the maximum utility for a given cost. That is, the points along this frontier are such that value is maximized for each possible cost level.

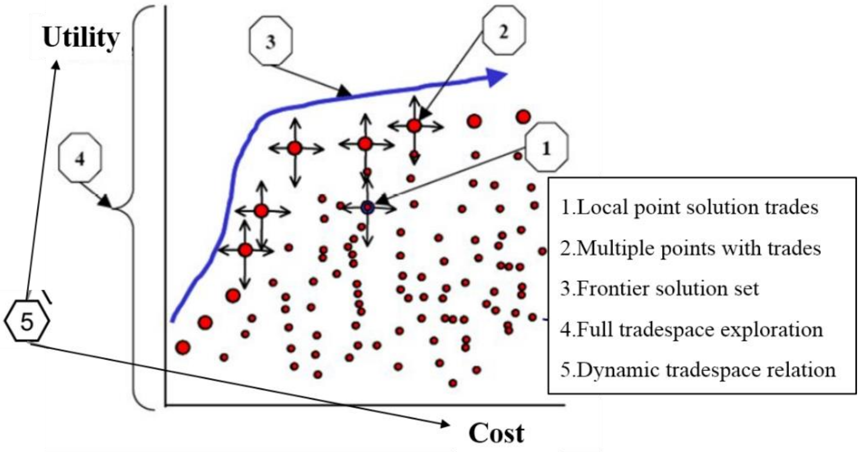

Figure 3.7 Trades within the design space (source: adapted (Ross and Hastings, 2005))

The efficient identification of the frontier is important when the full space of options is too large to be computational tractable or understanding. On the *Pareto front* it should be possible to find a design with the same performance but cheaper, or of the same cost but higher performing. On the other hand, making decisions between designs on the *Pareto front* can make a true cost-benefit trade (Hastings and McManus, 2008). Exploring the *Pareto front* shape often reveals the limits of the system since, given the uncertainty and the inaccuracy of the designs in the *Pareto front*, it could change based on user needs changes or analysis accuracy. A special attention should be given to designs that are closer to the *Pareto front*, even if they are not on it. That is, the tradespace goal is the understanding of the entire tradespace, even away from the *Pareto front*.

3.6 MATE-ilities

In a MATE study, network analysis could be applied to a series of temporally-linked tradespaces, enabling the quantification of '-ilities' as decision metrics across design alternatives. The '-ilities' are defined as the life cycle system properties such as flexibility, robustness survivability, among others, that are critical for delivering sustained stakeholder value (Richards, 2009). The '-ilities' cannot be incorporated as traditional attributes in MATE due to three theoretical inconsistencies: the lack of decomposability, the lack of perceived independence, and redundancy. Their definition is related to changes in system form or function, since they are quantitatively dependent on other objective function variables. Tradespace studies typically look at the relation between function and resulting system performance in terms of system objectives. The performance in an aggregated, multi-objective space is dependent on performance in each of the single objectives. By choosing an appropriate aggregation technique, it is important not to double-count the single objective performances. Aggregating '-ilities', which by definition are measures of the ability to maintain attributes under changing conditions into a multi-attribute objective function, runs into a double-counting problem. An active area of research is seeking to formulate an appropriate basis for aggregating '-ilities' with other system attributes. In the meantime, the '-ilities' remain disaggregated and their impact in a tradespace is study assessed independently (McManus et al., 2007).

The incorporation of time-dependent context variables in MATE covers six '-ilities' - changeability, flexibility, adaptability, scalability, modifiability, and robustness for assessment in trade studies (Ross, 2006). Thus, in order to incorporate time into traditionally static cost-utility tradespaces is used the Epoch-Era Analysis (Figure 3.8). Whereby a system life cycle or 'era' is modeled as a set of discrete epochs.

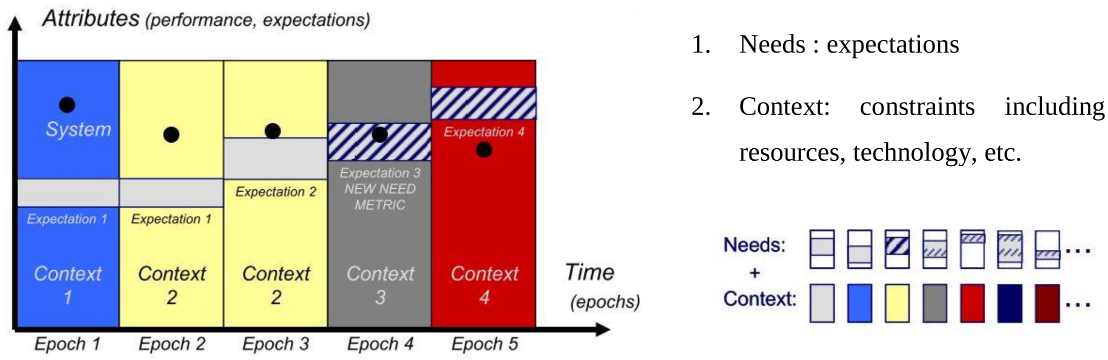

Figure 3.8 Epoch-Era Analysis (source: (Richards, 2009))

The equivalent to short-run analysis in economics, in a given epoch, defines a scenario in which constraints, design concepts, available technology, and articulated attributes remain fixed. Dynamic MATE strings together multiple static tradespaces over time to approximate dynamic system contexts and expectations. System states might be represented within an epoch using a network tradespace. The design vectors in the tradespace represent all meaningful system states. A dynamic model may be approximated within the tradespace as transitions between design vectors over time (Richards, 2009).

3.7 Multi-Attribute Tradespace Exploration applied to Complex Transportation Projects

Transport investments have a long life from planning to implementation. Thus, the improvement of efficiency and coordination management regarding the evolution of the network capacity and the infrastructure quality is mandatory (MacCrimmon and Toda, 1969). The Multi-Attribute Tradespace Exploration method applied to Complex Transportation Projects (MATE-T) holds as objective to aggregate the information provided, checking costs and benefits. In addition, the method also emphasizes both the complexity and sensitivity appraisal, testing the convenience, preferences and interests about each interest group. In this way, operational, socio-economic and environmental performance are used in the scheme of the evaluation criteria. Weights can be assigned to the criteria to emphasize their importance for the different interest groups, like users (passengers or freight), transport operators, transport managers, manufactures, investors, local and central (European) policy makers and local community members. Then, under the opinion of experts or from representatives of particular interest groups (by an interview or survey), weights are given regarding its preferences. The result is determined by the selection of the preferable alternatives under given circumstances in order to improve the feasibility of the study.

3.7.1 Transportation Projects' Impacts

Transportation projects' impacts can be defined as consequences of the project. The range of impacts considered in transportation project evaluation has changed over the time, with improvements of model computing systems. In contrast with the past, the decision-making has evolved to a more explicit recognition of the distinct nature of the different roles, in particular regarding public institutions, major interest groups and the transport system providers independently of the public or private nature.

Cascetta (2009) defined a list of the impacts that should be considered to characterize a transportation project, even if the classification of the impacts is sometimes arbitrary:

- Economic impacts are defined as changes in the state of the economic system brought about. This might include changes in residential and commercial property values and in economic production resulting from changes in accessibility or changes in economic consequences of accidents directly and indirectly related to the project. Economic externalities are measured in monetary units or can easily be translated into such units.
- Land use impact is related to land use and its quality. In this category changes in the geographical structure of a region or in the urban assessment are included.

- Social impacts can be defined as impacts on social values and changes in the relationship among people or institutions brought by the project. There are effects of different types: social effects, change in cohesion and stability, changes in equity or social-economic status.
- Environmental impact is related to the effects on the physical environment. These can be further classified as effects on the ecosystem, on noise and air pollution, and on visual perception.

The potential impacts presented need to be decomposed and adapted to the transport project in study. However, not all the potential impacts listed are relevant to the evaluation and some of them might be absent or negligible. In other cases, some impacts may be present but deemed irrelevant to the analysis.

3.7.2 MATE-T Framework

MATE-T is selected for identifying the preferable alternatives in transport projects. Transportation projects include a large set of possible uses and could be scoped in terms of the aspects of the problem to be considered or the level of the detail of the solution to be developed. The method classifies the different criteria into a ranking with compensatory methods – as weighting alternatives, in order to allow the establishment of a trade-off between a countable number of criteria. The evaluation criteria are chosen to express the operational, socio-economic and environmental performance of the select transportation system but also to select effects related to user service. The trade-off represents the small changes in evaluation criteria that need to be compensated.

The technical challenge of the appraisal is the quantification of project objectives regarding decision-variables, which is important for the evaluation of alternatives. The decision-variables are design related and they are also representative of different appraisal scenarios. However, the most difficult aspect is to measure and integrate the information regarding the objective(s) in order to produce a reasonable result regarding the best option, with quality.

As it happens in MATE, the information is presented in a decision-making matrix that allows an easy calculation of the impacts of the project in terms of cost and benefits. The decision-making matrix takes advantage of the information that is available to the traditional cost-benefit analysis and relates to both concerns/objectives as with stakeholders. The key issue is to summarize the main economic and financial implications of the project showing the stakeholder preferences and the distribution of cost and benefits. The decision-making matrix also combines effects related to non-monetized concerns and overall indicators regarding the profitability of the investment.

Regarding the transport appraisal, the most common objectives are related to the service, like fares, travel time, reliability of service, comfort, time convenience or safety; operation such as direct and indirect cost and fees which may include subsidies and taxes; investment, maintenance which accomplishes direct and indirect cost, fees and may also include subsidies, taxes and externalities related to environmental and land development.

The decision-making matrix is adaptable to any transportation project appraisal and contains the key information for the analysis. The stakeholder-objective relation varies from one project to another, as well as the criteria to define the context. In this way, each stakeholder is associated to a set of attributes that translate the expectation and objectives regarding the project in appraisal. The main difficulty is related to the stakeholder analysis, his objectives and their relationship in order not to overlook any relevant issue.

The tradespace presents all designs and evaluates the best alternatives regarding all interests and across different domains. The aim is to find a feasible solution design within an acceptable range of stakeholder's costs and benefits regarding a changing environment and value context. The final solution would reflect the expectation of the different interest groups in order to find the best admissible solution, given all requirements and constraints.

3.7.3 The Lisbon-Madrid High-Speed Rail Connection

The present methodology was selected to deal with the analysis of the different stakeholders' perspectives, while dealing efficiently with the required resources. The Lisbon-Madrid high-speed rail line is a huge transportation investment with a broad range of stakeholders which have different objectives and concerns with regard to the project's investment. The main goal is to use MATE method adapted to complex transport system and evaluate the line investment and the suitability for carrying goods in the daily operations, using the free slots left by the passenger services.

Figure 3.9 shows the support schema of the MATE-T process applied to the Lisbon-Madrid high-speed rail connection. The appraisal starts with the selection of the relevant stakeholders – group of individuals with similar interests and the definition of the evaluation bounds. The variables selected are not only related to the design of the high-speed rail service (e.g. frequency of the trains) but also to business interactions between stakeholders (e.g. track rent paid by the operator), and assume a value in a certain discrete interval. The concerns of each stakeholder defined are expressed by a set of attributes that describe the performance's characteristics of the high-speed rail project (e.g., average travel time, operational costs, and rolling stock investment). The attribute translates the stakeholder needs and are then associated with utility curves. Together, the attributes and utility functions define a wide range of functional outcomes, evaluated in terms of their utility to the user. At the same time the selected attributes are weighting through formal stakeholder interviews. Then, the single-attribute utility curves are aggregated using a form of a multiplicative utility function. The utility functions describe the way stakeholders appraise the high-speed rail service, and translate the evaluation by a dimensionless representation of its relative interest that is normalized to range from 0, minimally acceptable, to 1, the highest expectation. On the other hand, the design variables that define the number of possible designs are defined.

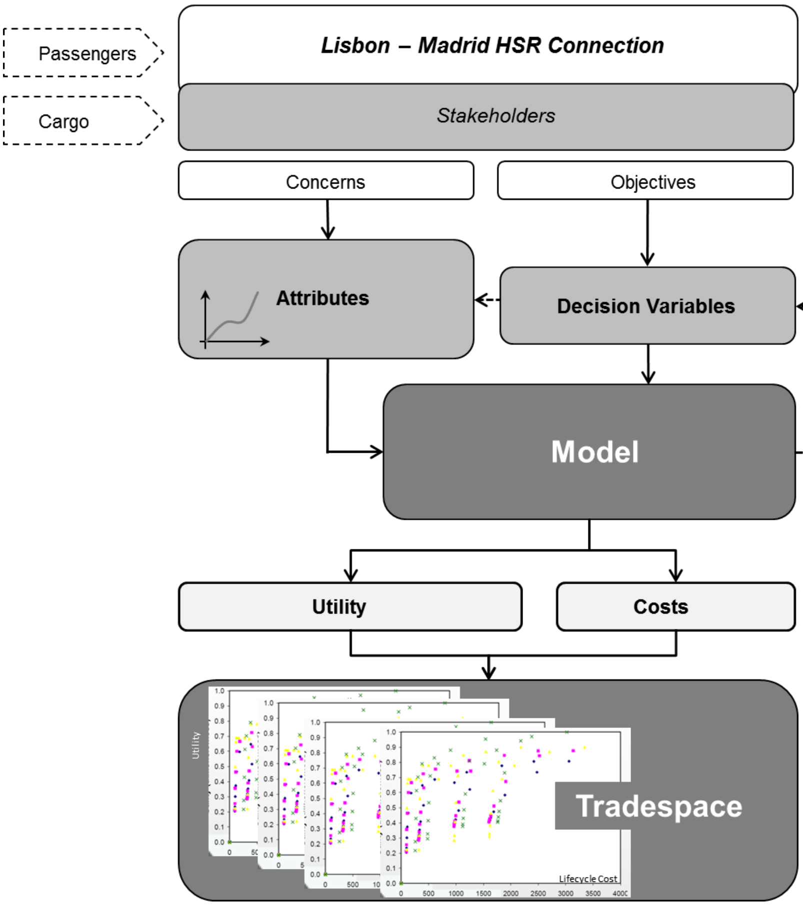

Figure 3.9 High-speed rail line model

The model is the design space where all possible design solutions using the elicited attributes to compose the set of feasible solutions are enumerated. Each solution is then analyzed in terms of costs and utility, given each stakeholder's perspective. The cost for each solution is assessed according to the life cycle cost that each stakeholder 'has in mind' for a particular solution. Cost is computed from the life cycle analysis regarding the high-speed rail service, not only considering the impact of the decision variables but also all the other costs associated to the high-speed rail line (e.g., infrastructure costs, externalities).

The tradespace includes the cost and utility relation for each high-speed rail design solutions analyzed by the stakeholder. The tradespace, assessed by the stakeholder, combines the life cycle cost with the utility for each design solution (tradespace point) and resulting in a cloud of points. The cloud represents the space where trade-offs are implemented and where the global vision of all the stakeholders merged in order to reach the final result of the assessment. Since the tradespace is evaluated stakeholder by stakeholder, the result accomplishes as many tradespaces as the number of stakeholders considered. The different tradespaces reflect the different points of view that each stakeholder has regarding the Lisbon-Madrid high-speed rail line. As a result it is mandatory to evaluate the solution in order to find a common solution that satisfies all the selected stakeholders.

The *Pareto front* is an optimization technique, which is designed to efficiently search the space of all possible solutions. The *Pareto front* is applied to the tradespaces and defines the set of designs that produce the highest utility for a given cost, or has the lowest cost for a given utility. In order to find common solution among all tradespaces, it is required to evaluate the *Pareto front* in order to find the best admissible solution, given all requirements and constraints. That is, if the tradespace has one single design, there is only one solution that is selected, with different cost and utility by the stakeholders, as presented in Figure 3.10.

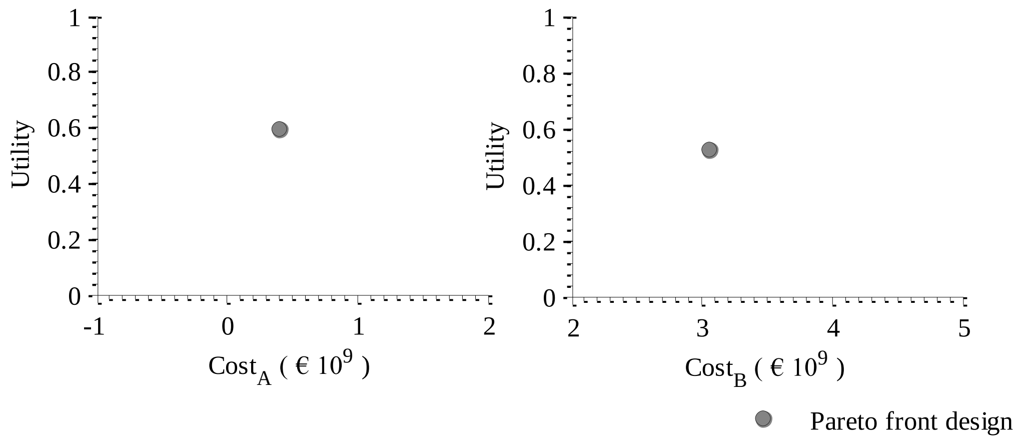

Figure 3.10 Tradespace of two different stakeholders with one single design

However, if the tradespace accomplishes more than one design, it is necessary to find the compromise design that best fits the interest from all stakeholders. Figure 3.11 presents the tradespace of two stakeholders regarding the same appraisal. The designs (light dots) are evaluated differently by the stakeholders and the *Pareto front* (dark dots) do not select the same design nor the same optimal solution.

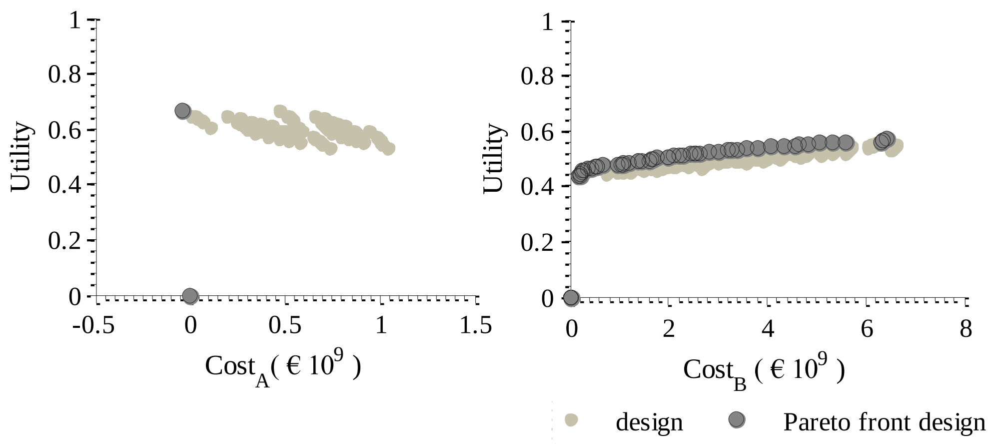

Figure 3.11 Tradespace of two different stakeholders with multiple designs

In order to find the solution that best fits the interest, it is necessary to relax the *Pareto front* 'function' in order to find the designs that are closer to the *Pareto front*, even if they are not on it. The concept relies on the translation of the *Pareto front* in order to represent the need of stakeholders to search for a common solution that best fits their common interests. That is, stakeholders are relaxing their utility and accepting a possible non-optimal solution present in the tradespace. Figure 3.12 presents a tradespace with several evaluated designs.

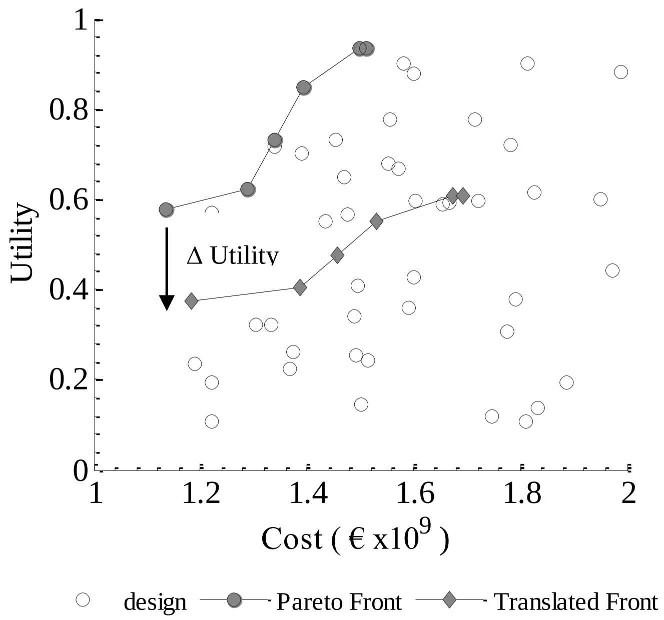

Figure 3.12 *Pareto front* and Translation front

Pareto front selected the optimum solutions and the Translated front encompasses the additional designs that support the appraisal evaluation. Thus, based on the set of optimal solutions identified in the tradespace, a *Pareto front* curve is obtained and then this curve is translated stakeholder by stakeholder until a common solution is found. The common solution will accomplish all the designs in the space between the initial *Pareto front* and the relaxed curve.

The Translated front represents a relaxation of the stakeholder with regard to its utility. The translation is described by a value *K* that represents, in percentage, the difference between the utility in the *Pareto front* and the utility in the Translated front. Therefore, a utility lost is assumed and the related cost associated is determined. The *K* value is accessed through an iterative process, until the common solution is found. This iterative process is described through the following steps and according to Figure 3.12:

1. Adjust a second order polynomial function to the *Pareto front* for each stakeholder. Assume a value of K equal to 0 (equal to the *Pareto front* function);
2. Increase the value of K in 0.01;

3. Relax the second order polynomial function by assuming a translation of the Pareto curve representing K percent of lost utility;
4. Collect each non-efficient solution within the solution area between the Pareto curve and the curve corresponding to the K percent relaxation - Translated front;
5. Compare the solution among stakeholder in order to find common designs in the selected ones;
6. If common solutions exist, design is found the search stop and the common solution is assumed to be the best solution that represents the best design option regarding all stakeholders' preferences. Otherwise, it is necessary to return to step 2.

The final result shows the optimal solution, the one that represents a selection of preferences of the selected stakeholders. The optimal solution also accomplishes the loss of utility that each stakeholder has regarding its initial preference in order to find the common solution.

3.8 Conclusions

MATE-T contributes to support decision-making in transport investments under the involving transport structure. Given the increasing number of stakeholders related to transport sector, it is important to clarify and adapt certain aspects regarding the traditional appraisal methods together with MATE and ensure that trade-offs between the different stakeholders are reflected during the appraisal process.

MATE-T strength is the capacity to evaluate, for a given transportation project, the stakeholder's interests in order to find the optimal solution that best fits the overall interests. The common solution is selected by the relaxation of the *Pareto front* of each stakeholder tradespace. The aim is to provide good indicators, not only about the project but also regarding its implications for the different stakeholders enrolled. The methodology intends to be simple but able to respond to the different possible scenarios and adaptable to the size and complexity of the project in appraisal.

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4 THE LISBON-MADRID LINE

4.1 General overview

The Lisbon-Madrid railway line will increase the Iberian Peninsula easiness of access to both France and the rest of Europe, which is the main objective of the future high-speed rail connection. Besides, the line aims to shift freight from road to rail and shift air passengers to rail (European Commission, 2008b). That is, freight-rail transport may be the main beneficiary, particularly the cross-border connections, since the gauge difference causes difficulties in interoperability between the new line and the existing one. Therefore, the gauge does not need to be switched, nor freight needs to be transferred from rail to road, as it is now being done to save time and money. As a consequence, transport time between France and Spain is also reduced.

The present chapter provides an overview of the high-speed line project that was suspended due to the economic crisis. Nevertheless, it is believed that its implementation will happen in a 5 to 10 year-period of time. This chapter also provides information regarding the nation’s structure and a detailed infrastructure investment analysis to be performed.

4.1.1 Background

Located in the southwest corner of the Iberian Peninsula, Portugal is a nation of approximately 10.6 million inhabitants. The mainland territory is bordered on the east and north by Spain and the south and west by the Atlantic Ocean. It possesses 1214 kilometers of border line with Spain and 1793 kilometers of coast line with the Atlantic Ocean. The physical geography of Portugal is translated in an upright rectangle of 500 kilometers from north to south and to 200 kilometers from east to west (Figure 4.1).

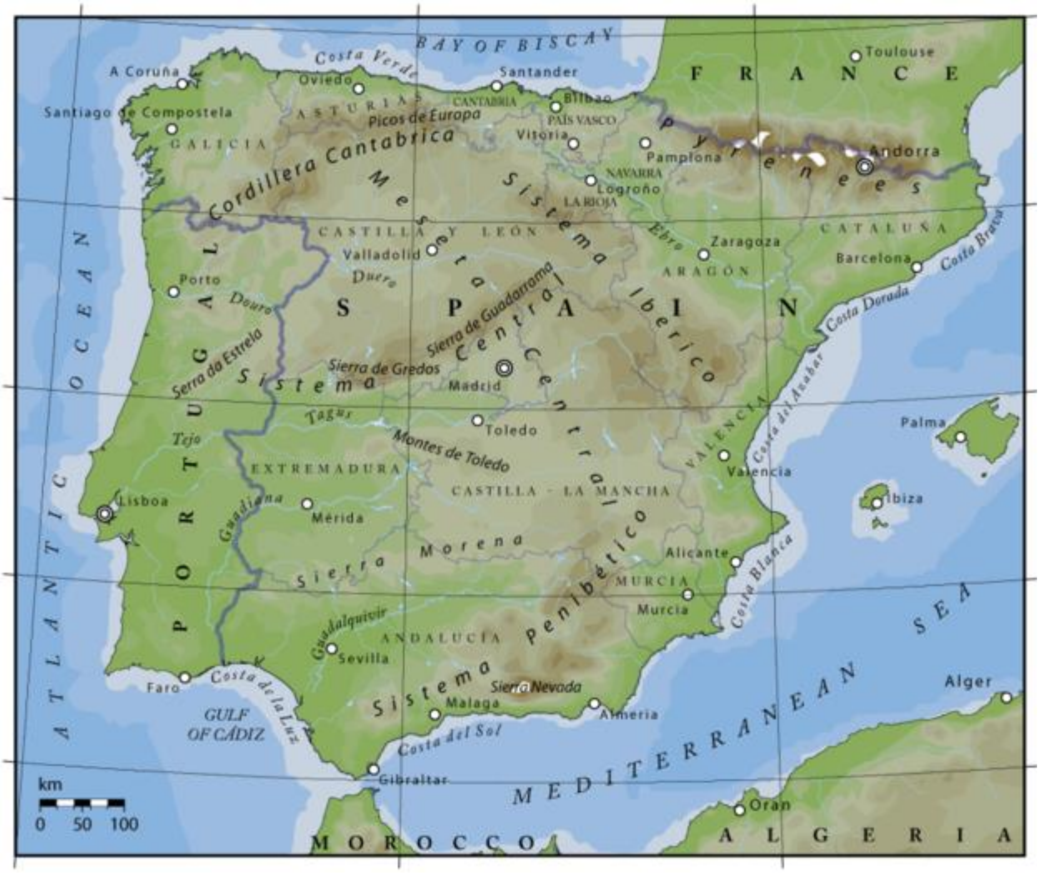


Figure 4.1 Map of the Iberian Peninsula (source: (Collins and Times, 2013))

The population is concentrated in the coastal region extending from the capital city of Lisbon to the city of Porto. The population of metropolitan areas of Lisbon and Porto are respectively, 2.8 million and 1.6 million according to (INE, 2013). Other significant urban areas in Portugal include Braga, Coimbra, Leiria or Évora, but none exceeds 200000 inhabitants.

4.1.2 Economy

Portugal became a diversified service-based economy since joining the European Union in 1986. Over the last decades, successive governments have privatized many state-controlled companies and liberalized key areas of the economy, including the financial and telecommunication sectors. The economy grew by more than the European Union average during the 1990s, but the rate of growth slowed in 2001-08. The economy contracted 2.5 percent in 2009, before growing 1.4 percent in 2010, but gross domestic product (GDP) fell again in 2011 and 2012, as the government began implementing spending cuts and tax increases, in order to be complementary with European Union conditions - the International Monetary Fund financial rescue package, agreed to in May 2011. The GDP per capita stands at roughly two-thirds of the EU-27 average.

The government reduced the budget deficit from 10.1 percent of GDP in 2009 to 4.5 percent in 2011. This achievement was only possible given the extraordinary revenues obtained from the one-time transfer of bank pension funds to the social security system. The budget deficit worsened in 2012 with a sharp reduction in domestic consumption. As a result, it took a bigger piece out of value-added tax revenues while rising unemployment benefits increased expenditures more than anticipated (Central Intelligence Agency, 2013).

4.1.3 Framework

The analysis is performed in order to evaluate the strategic region that supports the Lisbon-Madrid corridor. All the evaluation is performed according to data from different sources, but mainly supported by Portuguese rail authority – REFER, together with the Portuguese high-speed rail authority – RAVE, and the Spanish high-speed rail authority – ADIF (ADIF, 2013b; RAVE, 2012; REFER, 2013).

The area in study comprises the regions of Lisbon and the Portuguese Interior as well as the Madrid area, Toledo, Cáceres and Badajoz. To sum up, 30 different transport areas are defined as shown in Figure 4.2.

Figure 4.2 Lisbon-Madrid corridor (source: adapted (EPYPSA and EXACTO, 2011)

Currently, the transport sector for passengers and freight is clearly more favorable to road transport, especially due to the imbalances seen in recent decades. The intense investment in road infrastructure has been a decisive factor for development and a reference for mobility standards.

4.1.4 Population

The population in the corridor is 11.8 million inhabitants mainly concentrated in Madrid, Lisbon and in its metropolitan areas. The metropolitan areas comprise together more than 9 million inhabitants. Besides these two areas, the most important population centers are Badajoz, Évora, Mérida and Cáceres. Figure 4.3 presents the population spread along the corridor.

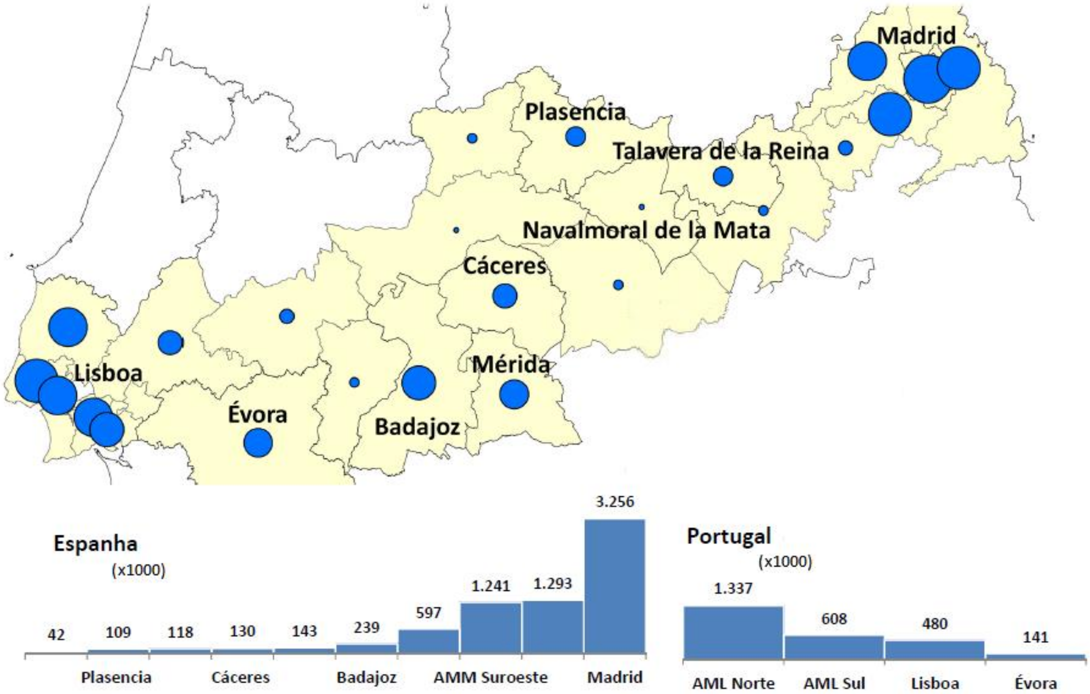


Figure 4.3 Population in the Lisbon-Madrid corridor (source: adapted (Estudios, Proyectos y Planificación et al., 2011a)

4.1.5 Socio-Economic Analysis

Similar to the distribution of population, the highest GDP values are centered in the metropolitan areas of Lisbon and Madrid.

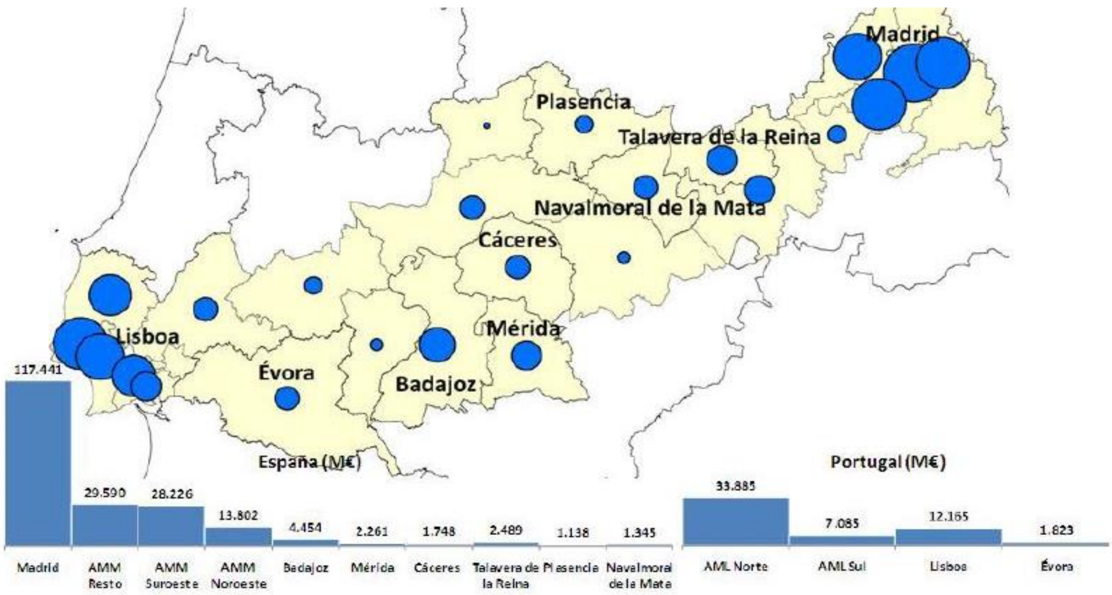


Figure 4.4 GDP distribution per area (source: (Estudios, Proyectos y Planificación et al., 2011a))

The total amount over the corridor is 288059 million euro in 2010. The metropolitan areas represent 87 percent of this amount. The activity rate of the resident population is approximately 51 percent of the total inhabitants regarding the average of the corridor. The unemployment rate represents 12.57 percent of the average workforce (EPYPSA and EXACTO, 2011). On both sides, the service sector is predominant, followed by the secondary sector, 79 percent and 73 percent of the population respectively. The corridor motorization rate is 518 vehicles/1000 inhabitants on the Spanish side and 440 vehicles/1000 inhabitants on the Portuguese side (Estudios, Proyectos y Planificación et al., 2011a).

4.1.6 Road Offer

Portugal and Spain have an extensive road network. In Portugal, the road network covers more than 2600 kilometers and the number of border crosses are over 70 (INE, 2011a; Ministério da Economia, 2014). The Portuguese roads are classified into six distinct categories: Principal Routes (*Itinerários Principais*, IP), Complementary Routes (*Itinerários Complementares*, IC), National Roadways (*Estradas Nacionais*, EN), Regional Roadways (*Estradas Regionais*, ER), municipal routes, and declassified routes. The final category represents roads that are in the process of being turned over to municipal control. The most part of the Portuguese road network (about 90000 kilometers in total) is operated and maintained by either municipal government or the national road authority, *Estradas de Portugal, S.A.* (EP), a government-owned corporation (Ministério da Economia, 2014). The main road network (about 2600 kilometers of motorways classified as IP) is managed by private concessionaires submitted to a contract with Government.

The Lisbon-Madrid road corridor links Lisbon to the border (Caia) and crosses the cities of Évora, Estremoz and Elvas by the A6 tolled-highway (Figure 4.5). In Caia, the Portuguese highway connects to the Spanish highway, the A5. Besides this corridor, other road connections are available. However all of them take more than 5 hours to be crossed in a private vehicle.

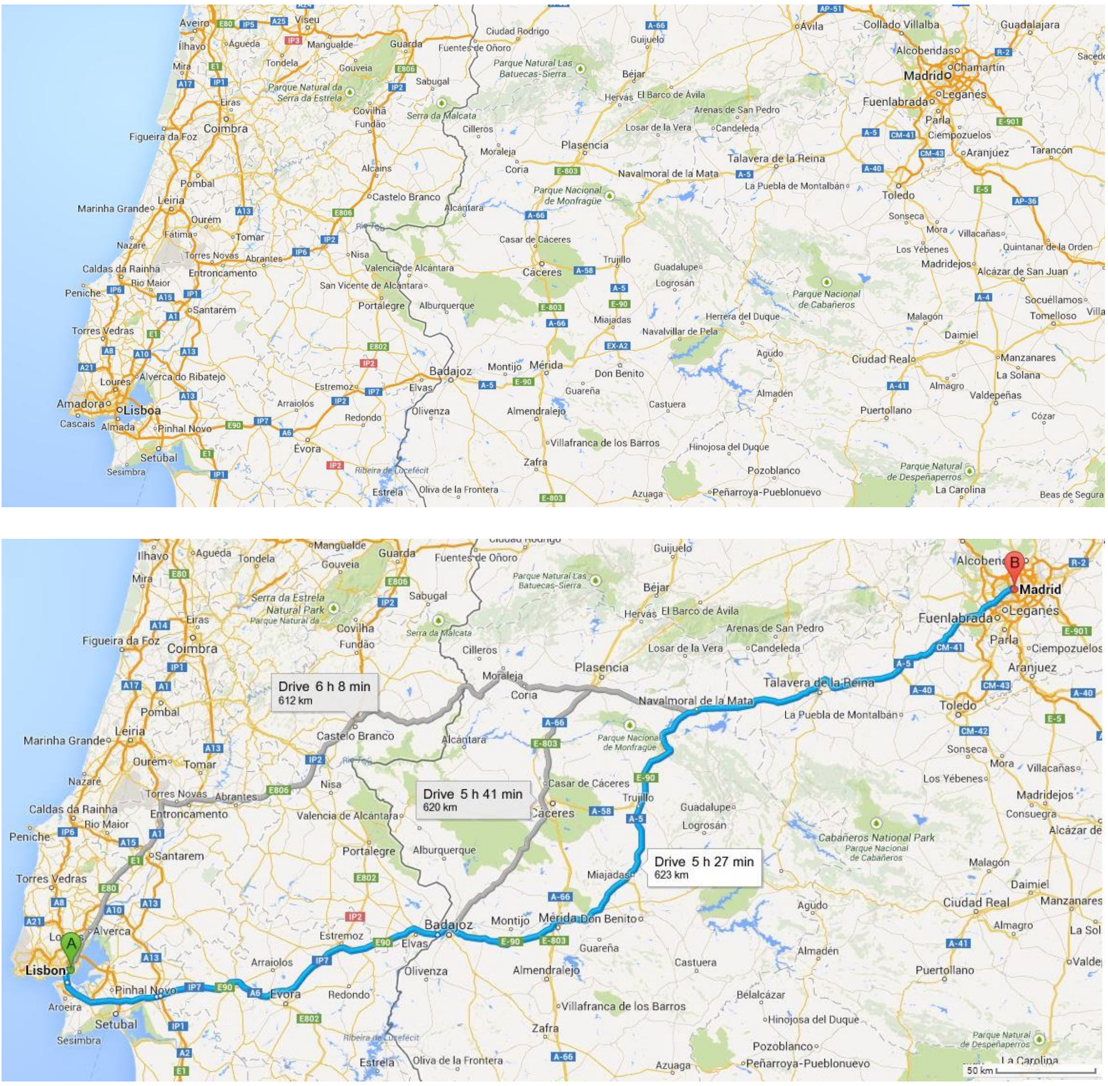


Figure 4.5 Road network (1) and the Lisbon-Madrid connection with time reference (2) (source: (Google Maps, 2013))

During 2009, the border was crossed in both directions by an average of 85300 vehicles/daily (including mixed traffic vehicles), as presented in Figure 4.6. These figures show that the intermodal freight trade by road has a dominant market share inside the Portuguese trade market. The road is the great beneficiary regarding the increase of goods delivered during the last decade, mainly between Portugal and Spain (Spim and Vtm, 2009). The road sector has a high efficiency and flexibility to ensure door-to-door transport, even considering the negative impacts in terms of congestion and the environmental constrains to the society.

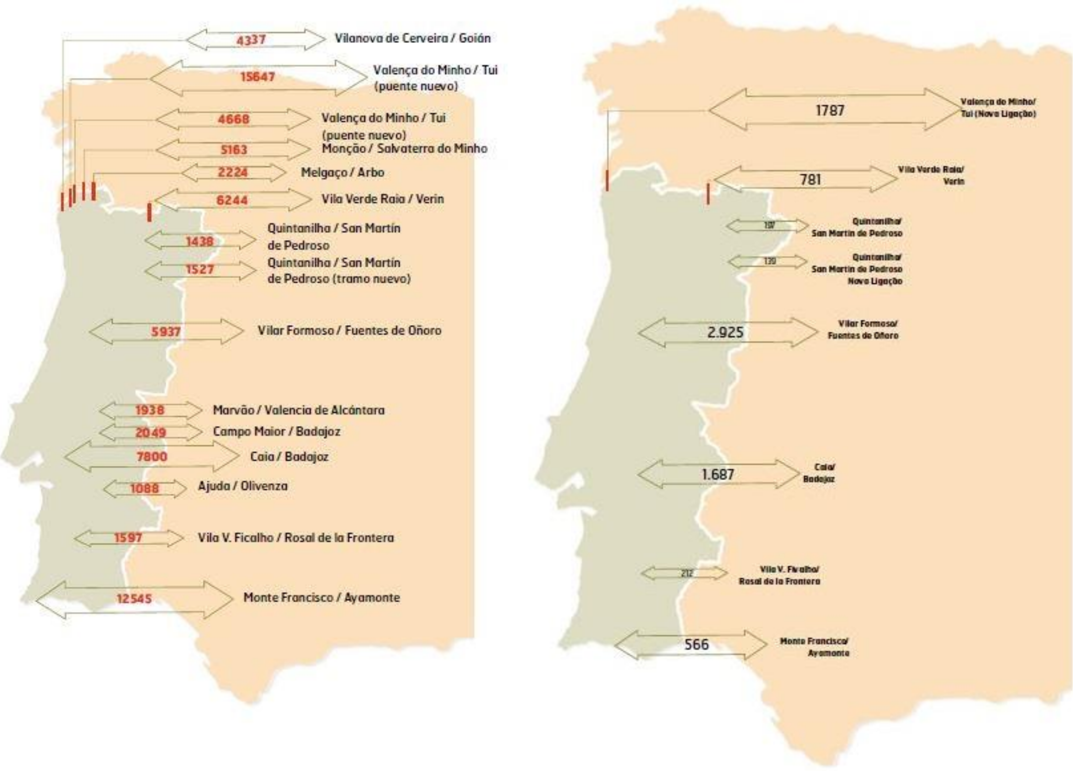


Figure 4.6 Average daily traffic vehicle on the Iberian border (1) Passenger vehicles (2) Heavy freight vehicles (source: (DGT, 2011; OTEP, 2011)

Besides the road network and the use of private vehicle, other road services are available for passengers in this corridor. One of them is the connection by bus as it can be seen in Figure 4.7. Figure 4.7 shows four main knots: on the Spanish side Madrid and Valladolid and on the Portuguese side Lisbon and Porto and three main axes: Madrid-Zamora-Porto, Valladolid/Madrid-Salamanca-Viseu-Porto/Lisbon and Madrid-Badajoz-Lisbon. There are more than 300 weekly bus services on average, offered by several operators and the average travel time is 7 hours (route related). The average travel time between Badajoz-Lisbon is 3 hours but other connections, such as Valladolid-Lisbon, take more than 11 hours by bus. The price varies from 30 euro for one single trip and 60 euro for a round trip.

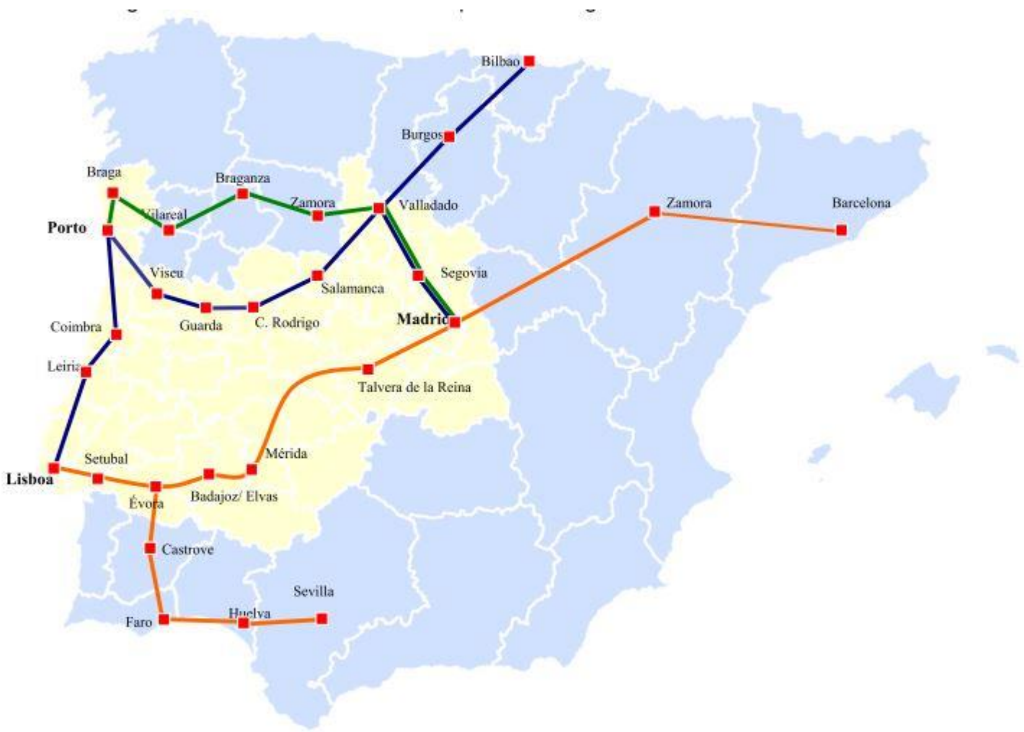


Figure 4.7 Iberia bus connection (source: (Steer Davies Gleave, 2006))

4.1.7 Rail Service

The national rail infrastructure administration features a conventional rail network that covers 2429 kilometers, manages 474 stations with passenger service or freight and ensures the provision of customer service rail. Only 67 percent of the network is electrified and 72 percent of the network has electronic signaling (Ministério da Economia, 2014). The Portuguese conventional rail network, presented in Figure 4.8, shares a common gauge with the Spanish conventional rail network. Both countries have adjusted to a common Iberian gauge of 1.668mm. Locomotives and rolling stock from Spain and Portugal are not interchangeable with the rest of European rail lines, due to the gauge issue – the rest of Europe operates Standard gauge rail network (1.435mm). Besides, the rail network shows a number of localized constraints that limits the full use of operational capacity. One of them is an old technical instruction that limits the maximum length of rail service in 500 meters. If rail compositions are longer they need a special license to run.

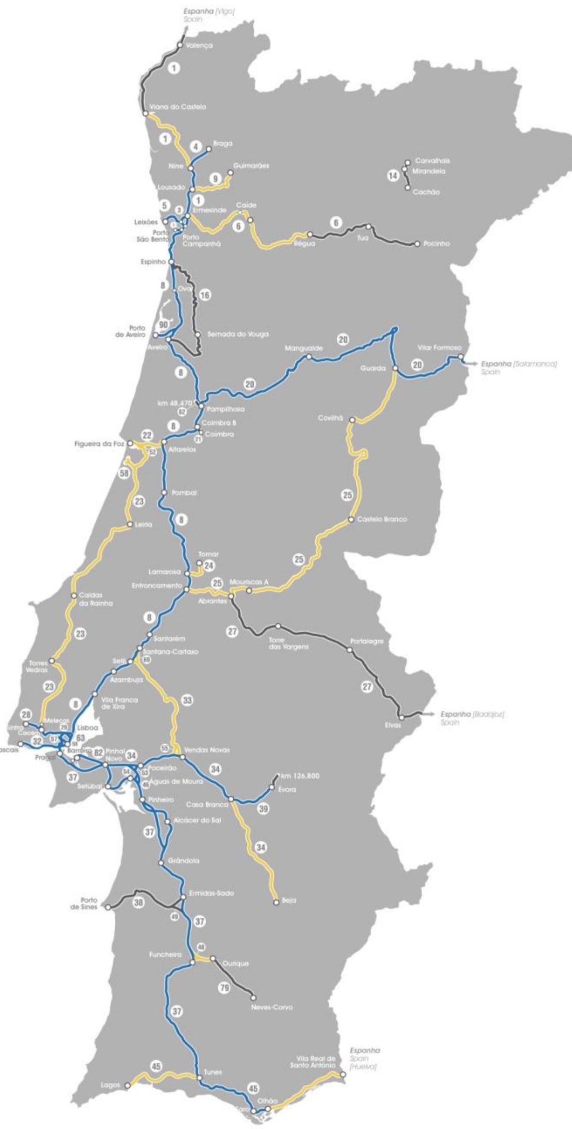


Figure 4.8 Conventional Rail Network in Portugal (source: (RAVE, 2012))

The infrastructure is owned by REFER – *Rede Ferroviária Nacional, EPE* that is the national railway infrastructure administration. REFER is one of the most important state-owned companies and is responsible for the management of the entire intercity rail infrastructure in Portugal. In addition, REFER is also responsible for the system's modernization and building new track capacity when it is requested by the Portuguese government. While REFER manages the rail infrastructure, CP – *Comboios de Portugal, EPE* owns and operates the rolling stock to provision of services to passengers and freight. These different services are split into three segments: CP Carga - handles freight, CP Regional - short trips, CP Long Distance - long trips. Besides CP, Fertagus is the other rail operator which provides passenger services. Fertagus is a private rail company which only establishes the connection between Lisbon and the south of Tagus River, via *25 de Abril Bridge*.

The passenger rail service between Portugal and Spain was – until 2012 – performed by two different rail links. Given several speed restrictions and due to the performance of the system, the rail connection between Portugal and Spain is currently held by one train per night. The Lusitania Train Hotel takes 10 hours to connect Lisbon to Madrid and 15 hours between Lisbon and Hendaye (Figure 4.9). The international rail service competes directly with bus service between both capitals.

Figure 4.9 International Rail Connections (source:(Steer Davies Gleave, 2006))

During 2011, the passenger rail systems carried more than 149 million passengers (2.6 percent less than the previous year), and the international rail services faced a higher reduction in the number of passengers carried by this mode(INE, 2011b).

The Portuguese rail network is suitable for freight transport, connecting the main borders and national sea ports. However, the low attractiveness of the rail to deliver freight between Portugal and Spain has several reasons.

The main reasons are the low regularity of supply, the lack of complementary infrastructure (as intermodal freight facilities) and the strong competition from road transport both in price and flexibility of access and broadcasting, especially at distances of medium type, like the ones between Portugal and Spain.

In 2011, the freight-rail services carried more than 2300 million tonne-kilometer of goods. However, the international rail services only represent 9.5 percent of the total amount carried out. The goods transported are now classified, regarding the European Union policies, by type of cargo according to the NST 2007 classification (UNECE, 2012). The main type of cargo delivered belong to group 03 - Metal ores and other mining and quarrying products; peat; uranium and thorium – with an amount of 2 million tons. Group 09 - Other non-metallic mineral products, with 1.8 million tons delivered is also a required type. The goods from group 07 - Coke and refined petroleum products, assume a predominant weight in the amount of freight delivered by rail, reaching more than 380 million tonne-kilometer (European Commission, 2007; INE, 2011b).

Until now, the freight-rail connection between Sines (the main sea port in Portugal) and Spain is performed during more than 7 hours and requires travelling 456 kilometers and connect with 8 different rail links. Figure 4.10 shows the existing conventional rail link between Sines and Elvas (Border) and the future rail connection.

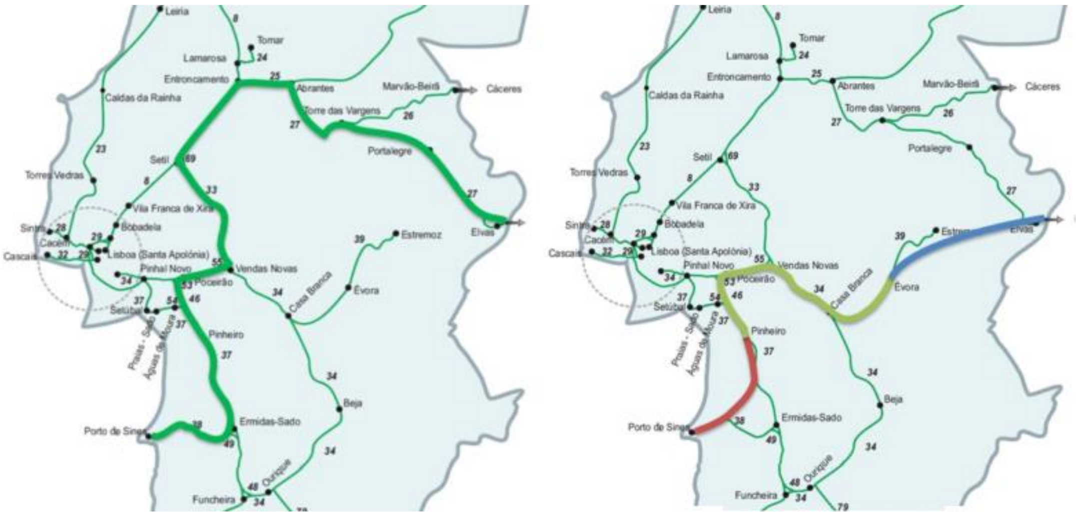


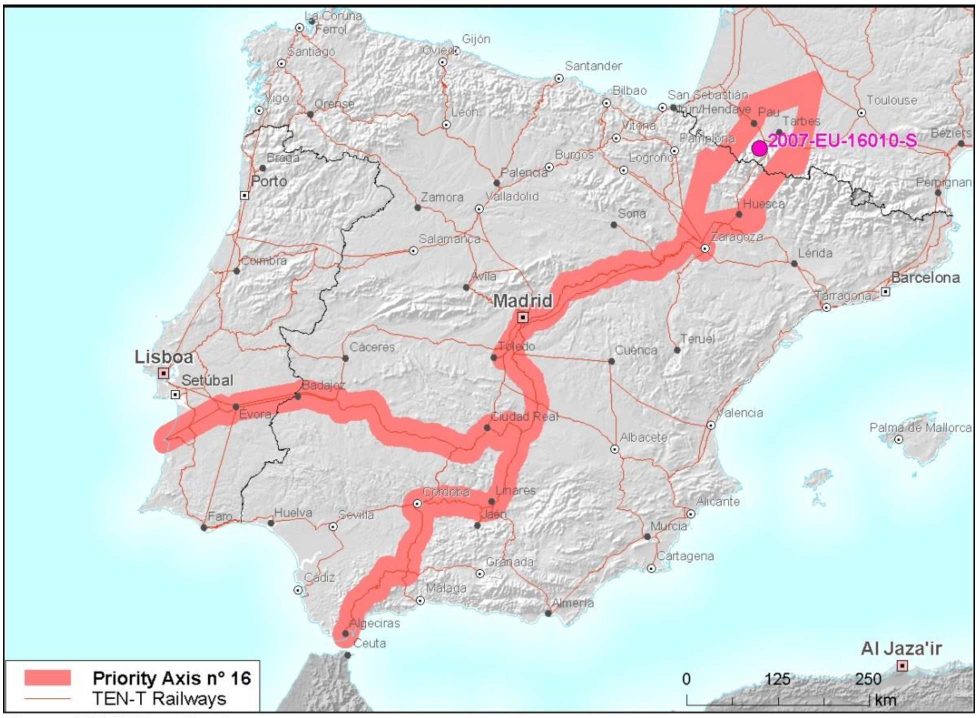
Figure 4.10 Conventional rail link (1) and the future rail connection (2) (source:(Spim and Vtm, 2009))

The rail-freight service in Portugal was liberalized and can already be performed by several private companies, as demanded by European legislation. The major rail-freight company in operation is CP Carga – Logistica e Transportes Ferroviários, which is also the second largest rail-based logistics operator at Iberian Peninsula. The IBERIAN Link service rises from a partnership between CP Carga and Spanish train operator, RENFE, given the importance of the Portuguese Atlantic ports in moving traffic in and out of the Iberian Peninsula (CP Carga, 2013).

The Iberian Peninsula faces some constraints concerning rail-cargo services. The Portuguese rail gauge has a gap of 6 millimeters compared to the Spanish gauge. This difference does not avoid interoperability, the train movement, without constraints between both lines. The gauge difference is an obstacle regarding the maximum use of the infrastructure, its operation and exploitation. The difference involves additional costs since cargo transshipment or gauge change is always required.

The first step regarding the operation of freight into the high-speed rail line connection between Lisbon and Madrid is implemented by RAVE in the study *Estratégia Logistica para a carga em AV* (In Out Global ISTE, 2004). In this study the first insights about the international trade that can be performed are presented, as well as the current means of transport and the main products to trade. The report makes and evaluation regarding the service framework in order to define the speed type to be offered (high-speed or upgraded conventional lines) and suggests the potential interested to be part of the project – in a macro level analysis. Other issues became relevant considering cargo high-speed service, since travel time is not usually a determining issue on freight transport. Until now, in conventional lines, travel time does not directly influence the modal choice and security in delivery. However, these elements are advantages by the change of gauge operations in the Iberian and European Networks.

The Priority Project 16 is related to Sines – Elvas /Badajoz rail corridor and aims at the development of a high-capacity freight-rail service linking the ports of Algeciras in southern Spain and Sines in south-western Portugal with the center of the European Union (European Union, 2007). So far, these infrastructures, as shown in Figure 4.11, have been mostly used for transshipment or to transfer to road due to the lack of an adequate rail connection. According to the Priority Project 16, in Portugal, the rail line will link the three logistic platforms of Sines, Poceirão and Elvas/Badajoz. In Spain, it reaches a major port (Algeciras) and the main logistics platform, PLA.ZA, in Zaragoza. The project also involves the construction of a new high capacity rail link for freight across the Pyrenees, connecting the French and Spanish networks, in order to provide freight flows with a rail access to the entire TEN-T network. The rail access route to the ports will be built with interoperable sleepers in order to allow operations in Iberian gauge in the first stage, but able to be converted in European gauge. The project also includes the construction of a long distance tunnel through the Pyrenees.



Source: TEN-T Executive Agency

Figure 4.11 Priority Axis 16 (source: (European Union, 2007))

The future Iberian rail network will connect Lisbon to Madrid with European gauge and is designed for mixed traffic. Between Évora (in Portugal) and Caia (in Spain), a third line in Iberian gauge will be designed only for cargo in order to link the Portuguese sea ports (Lisboa, Setubal and Sines) to the Madrid logistic centers (Spim and Vtm, 2009). On the Spanish side, there is an uncertainty about the construction of a freight facility connected to the high-speed rail line in the Madrid region. As a direct result, this infrastructure might change the rail traffic between Lisbon, Setúbal, Sines and Algeciras, central Spain. The main idea of this project has to do with the ambition of the present research which is to prove that the investment in freight-rail services can provide for a critical link in the national intermodal freight transport system, serving not only trucking and maritime shipping industries, but also supporting the Portuguese intermodal trade and global competitiveness.

4.1.8 Air Offer

Within the study area, there are three international airports, namely Madrid/Barajas, Lisboa/Portela and Porto/Sá Carneiro, which concentrate the supply of international air transport. The most relevant airports are the Madrid and Lisbon airports. The Madrid/Barajas airport is located 13 kilometers away from Madrid and the connection to the city center can be reached by metro. The Lisbon/Portela airport is located 7 kilometers away from the city of Lisbon and there is also bus and metro connection.

The international passenger service between Lisbon and Madrid has more the 5 direct flights per day. The travel time is 55 minutes and several operators perform the service. The trade of freight traffic by air is less significant in terms of volume transported, performed between Portugal and Spain.

4.1.9 Maritime Support

Currently there are nine commercial sea ports in Portugal - five main sea ports and four secondary facilities. Regarding the Lisbon-Madrid connection, three of them need a deeper description: Lisbon, Setúbal and Sines. The Port of Lisbon, presented in Figure 4.12, is located on both banks of the estuary of Tagus River and has excellent natural conditions for maritime accessibility and shelter. Regarding cargo transshipment, the port comprises berths and grounded terminals for bulk cargo and for containerized cargo. The port of Lisbon has also two passenger terminals available for cruisers ships , four docks to support recreational boating, two dock to rail-naval service, a repair yard and several infrastructures to support simple recreational boating and fishing (MOPTC, 2006a).

Figure 4.12 Port of Lisbon (source: (APL, 2014))

The Port of Setubal is a reference in the logistic chain given the efficient solution regarding the Iberian Atlantic front. The Port is located on the north bank of Sado River over a strip of 12 kilometers. Setubal seaport's ambition is to be recognized as a national leader in Ro-Ro solutions at an Iberian level, regarding time and cost for any connection to Madrid. Therefore, Setubal's sea port needs to strengthen its position in the general cargo segment and support the industrial fixation. Moreover, the Port of Setubal also needs a more efficient connection - by road or rail to the national logistic centers. (IPTM - Instituto Portuário e dos Transportes Marítimos, 2010).

The Port of Sines is the open deep-water sea port with excellent maritime access and without restrictions. Sines' sea port leads the Portuguese port sector in the volume of cargo handled, and offers unique natural characteristics to receive any type of vessels. Due to the modern specialized terminals, the sea port is able to handle with many different types of cargo. Sines is the main sea port in the Iberian Atlantic front, whose geo-physical characteristics are determinant on its consolidation as a strategic national active. Sines' sea port is the country's leading energetic supplier, receiving crude and its derivatives, coal and natural gas. It is also the main hub for general and containerized cargo. The Port of Sines presents a high potential growth, in order to become a reference port not only at an Iberian level but also at European and worldwide levels. Sines is seen as a modern port (1978), free of urban constraints, ensuring a long-term expansion capacity. The sea port of Sines also offered a good land accessibility. The land access to the sea port is included in a road and rail development plan that will allow the expected future growth of both the port and the region. The schematic plan of Sines sea port is presented in Figure 4.13.

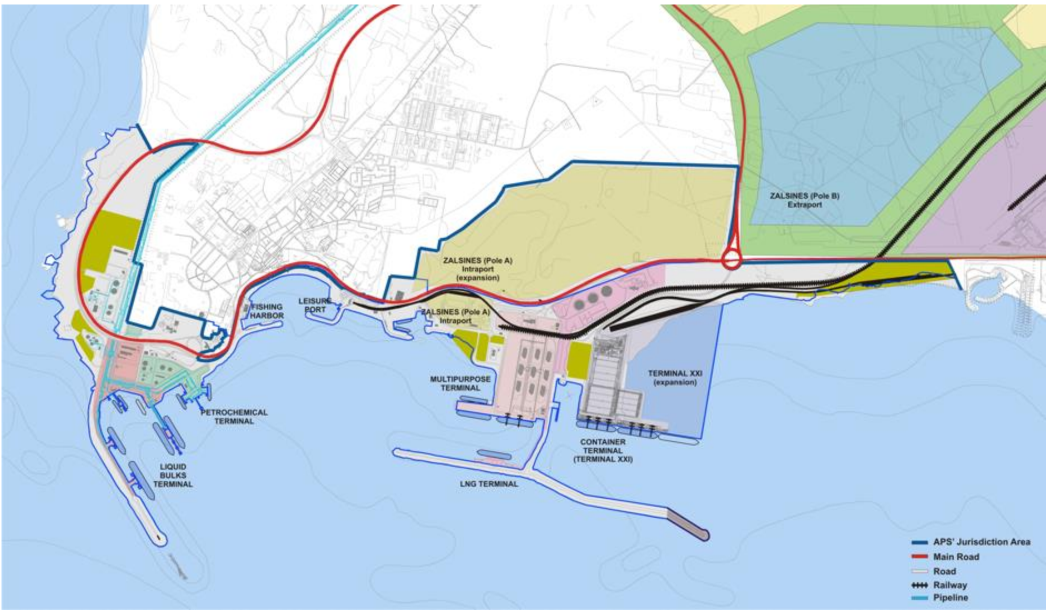


Figure 4.13 The Port of Sines (source: (APS, 2013))

The Port of Sines is supported by an Industrial and Logistics Zone, with more than 2000 hectare. These areas are already a worldwide logistic platform, able to receive the main players of all logistic sectors. Within the scope of *Portugal Logístico* plan (the Portuguese logistic strategy), the sea port is fully integrated within the national urban platform of Poceirão, as well as on the Elvas/Caia trans-boundary platform (APS, 2013; MOPTC, 2006b).

The Spanish port sector is of great importance due to the next location of the most important shipping lanes in the world. Together with its long coastline cover a strategic area suitable, in the context of international shipping to be consider. In this way Spain might be consider as a logistic platform in southern Europe. The sea ports, in Figure 4.14, act as anchors of logistic transport chains.

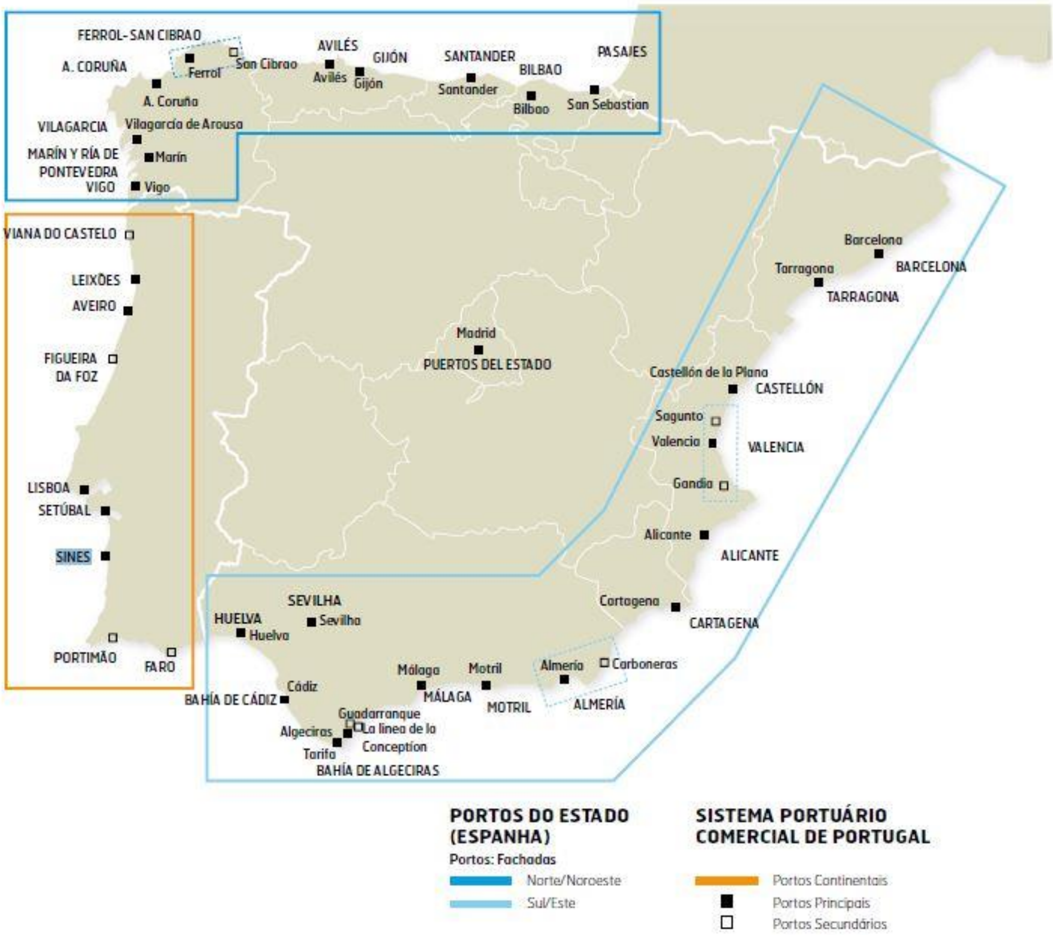


Figure 4.14 Iberian Sea Ports (in blue the Spanish sea ports and in orange the Portuguese sea ports) (source: (OTEP, 2011))

4.1.10 Freight Transportation Terminals

The good quality of the network and the ability to generate added value is related not only to the value and ability of links and connections, but also with the transfer capacity and the quality of port terminals. The logistic platforms have a crucial role to play in order to ensure freight-operations efficiency. The importance of transport and logistic cost in transport chain leads to a need of cost improvements in the transport sector as condition for an integrated European infrastructure network. The PROMIT is the European coordination action for intermodal freight transport programme that helps and supports the coordination and cooperation of national and European initiatives in order to integrate individual transport acts into a door-to-door supply chain (Permala et al., 2009). The dynamic of the transport sector ‘actors’ is not dependent on the quality of the infrastructure, in the traditional sense. The freight sector undertakes fundamental changes and restructures actions due to the policy changes and market regulation demands from European Commission (European Commission, 1998). The future logistic platforms should form the next stage in the freight restructuring process.

European Union provides opportunities to develop new intermodal transport options including rail transport as part of the intermodal transport chain for reducing congestion and encourage more inter-modality inside Europe. Intermodal freight transport provides transport for consolidated loads such as containers, swap-bodies and semi-trailers by combining at least two modes (European Commission, 2002; OECD, 2002b). The intermodal freight transport has frequently been seen as a potentially strong competitor to road transportation and also to be more environmentally friendly (Janic, 2007). The aim is to create an integrated market, not only to dismantle internal barriers and provide conditions for fair trade, but also to give characteristics of economic and monetary union structure. Intermodal transport in Europe has registered a high rate of growth supported by promotions and subsidies received by different European countries (Ballis and Golias, 2002).

The Portuguese logistic system grew without any defined order, as a result of the multi-hubs of logistic facilities located near the major demand areas such as Lisbon and Porto. Nowadays, Portugal aims to articulate railways, roads and ports in order to boost the country's economic activities. In this context, the ambition is to expand the ports hinterland and attract international investment, mostly the Spanish investment. An efficient supply chain and a competitive freight distribution integrated with a cost reduction strategy promotes the attraction and retention of business activities and the development of a sustainable industrial infrastructure. The Portuguese policy, *Plano Nacional de Politicas de Ordenamento de Território,* defines the international corridors with higher connectivity and accessibility (Ministério da Economia e do Emprego, 2011). The *Portugal Logístico* – other policy, was planned and studied in order to rearrange and develop the Portuguese logistic system. The goal is to turn Portugal into an Atlantic platform for intermodal inbound flows to the Iberian and European market. The Atlantic platform is important to promote the logistic potential as well as a secure economic growth. It is also important to increase environmental sustainability and territorial cohesion. In these way, it is possible to develop and integrate a system which includes planning and the execution of a strategic platform network articulated with other transport infrastructures. The overall volume of goods transported can take advantage of Portugal's geo-strategic position and the maritime-port system's capacity (MOPTC, 2006c). The logistic platforms should be articulated among maritime, rail, road and air ones. They offer a range of added value services to the entire logistic chain. The national network of logistic platforms is composed by twelve logistic facilities supplemented by two air freight centers, one in Lisbon and the other one in Porto (Figure 4.15).

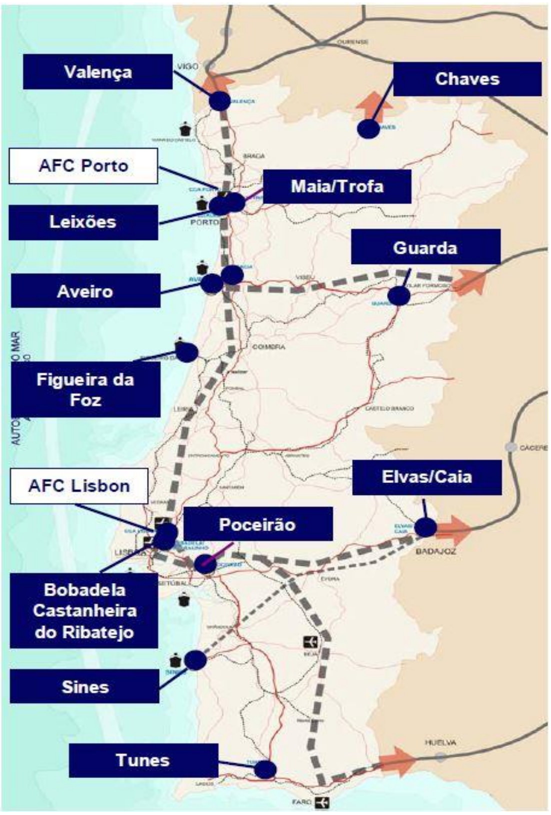


Figure 4.15 National network of logistic platforms (source: (Correia, 2007))

The intermodal terminals planned for the corridor in study are Sines and Poceirão. A deeper insight is given to Sines seaport and to the future rail-road terminal located in Poceirão: Sines Logistic Platform is an operational multimodal facility – maritime, road and rail, integrated in the main axis of the multimodal Trans-European Network. The logistic platform has the mission to support the Sea port of Sines and support industrial and service companies. The multimodal facility of Sines is composed by two areas, as shown in Figure 4.16, one intra-port (ZALSINES (Pole A)) and other adjacent to the port (ZALSINES (Pole B)). The adjacent area has a total of 215 hectare and is located under the jurisdiction of the Port Authority of Sines, being accessed by road and rail.

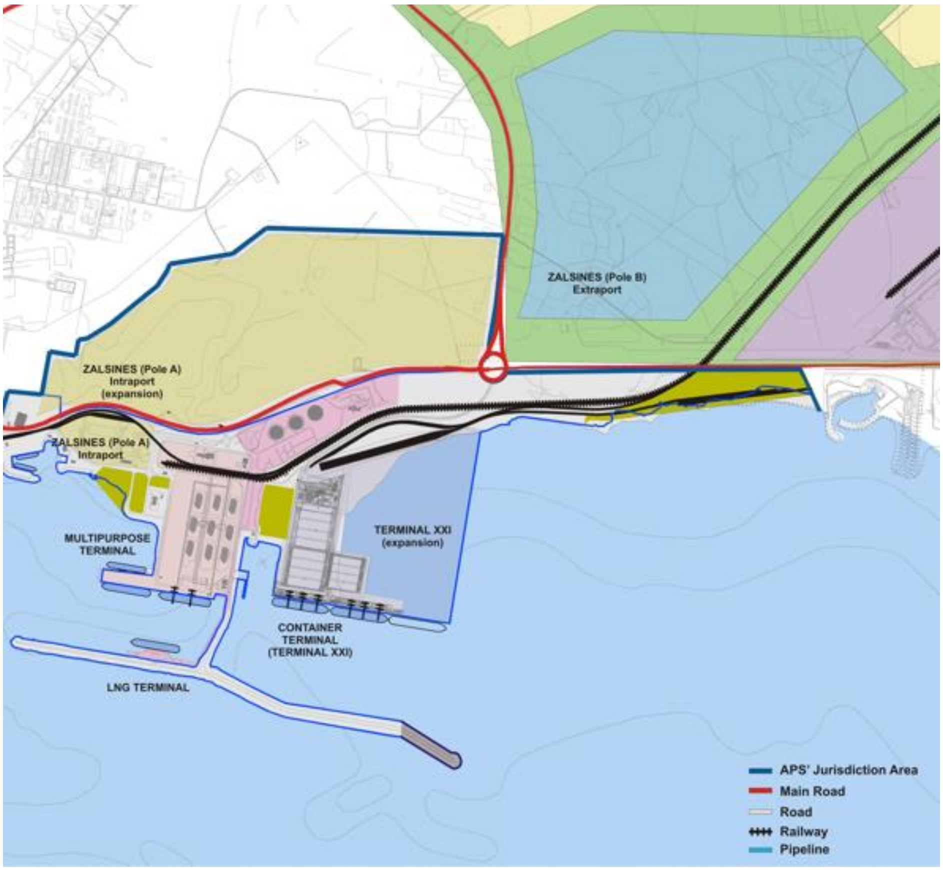


Figure 4.16 Logistic Platform of Sines (source: (APS, 2013))

The Poceirão Logistic Platform is planned to an area of 600 hectare, and has urban characteristics since it converges with the existing rail lines from Alentejo and Sines (Figure 4.17) and a road connection (A2, A12, A13). The intermodal freight terminal is a matter of study by RAVE and REFER, since the platform is part of the Lisbon-Madrid high-speed rail link. The logistic platform will cover an area of 37 hectare and the construction occurs in three planned phases. The construction area complements three reception and expedition lines, four rail lines and three multipurpose transshipment rail-road lines. Its maximum capacity is 315000 TEUs/year and the rail lines will have a length of 750 meters. The logistic platform of Poceirão also has the power to handle with general freight such as steel, cars, machinery. The platform has a containerize area and dedicated rail links (LOGZ, 2009; MOPTC, 2006c, 2007).

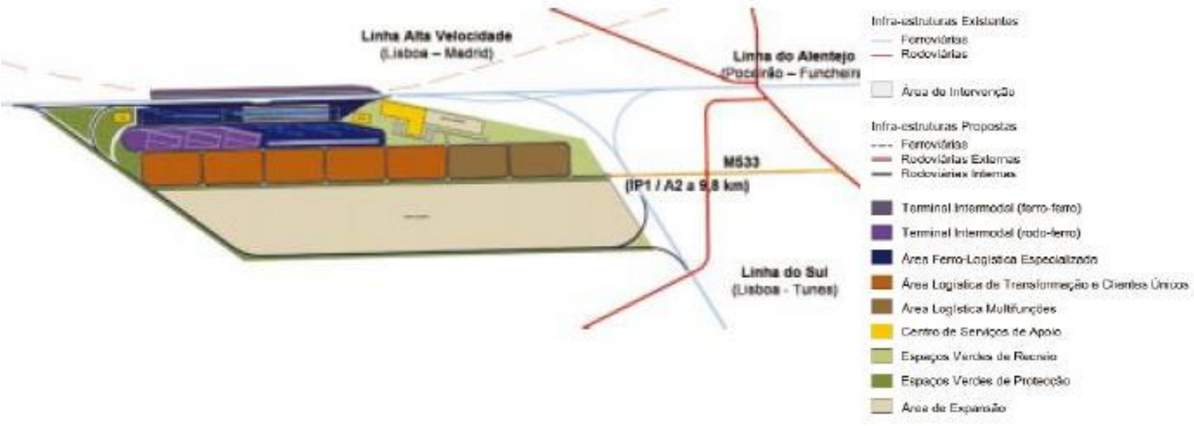


Figure 4.17 Poceirão Logistic Platform (source: (MOPTC, 2006c))

Following the same line of ideas, in the Spanish side it is necessary to evaluate the offer of the important multimodal centers on the path of the Iberian rail link between Lisbon and Madrid. Spain is currently developing its rail terminals in order to become the terminals' logistics focal points capable of fostering inter-modality. The terminals might reduce the environmental impact of transport and optimize usage of different transport modes. In Spain, the rail terminals are mainly owned by ADIF - Administrator of Railway Infrastructures. ADIF is a state-owned company that answers to the *Ministerio de Fomento*, and plays a leading role in promoting the rail sector. ADIF works to convert the rail as an ideal means of transport and easing access to the infrastructure under fair conditions. Its aim is to promote the Spanish rail system as a safe means of development and management, an efficient and sustainable infrastructure to the highest quality standards in environmental terms (ADIF, 2013b). ADIF has promoted operation concessions of some terminals to independent entities regarding transport service operators. Figure 4.18 is representative of the intermodal rail terminals' network in Spain.

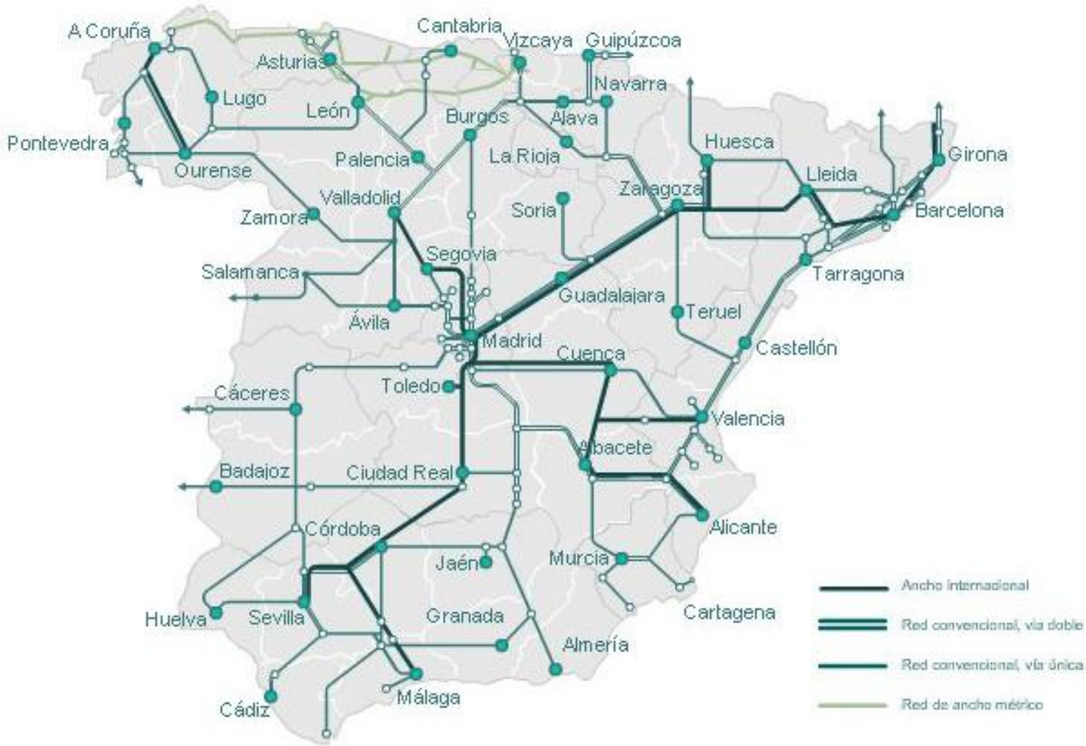


Figure 4.18 Intermodal terminals in Spain (source: (ADIF, 2013b))

Madrid enjoys a privileged geographical location in the center of Iberian Peninsula, which makes it the ideal location for becoming a major logistic activity center, both for peninsular as for southern Europe, North Africa and South America. Madrid’s equidistant position is also a key element for complying with the driving regulations and resting times in transporting goods by road. It is important to stress that Madrid absorbs almost 60 percent of intermodal goods traffic produced in Spain and around a third of total Portuguese traffic of goods. These percentages enable the major international transport companies, the largest industrial and commercial package operators, to establish their operational and logistics centers in the community of Madrid.

The Madrid Logistic Platform is the combination of several centers and infrastructures belonging to the Community of Madrid for all the activities such as transport, storage, handling and distribution as presented in Figure 4.19.

Figure 4.19 Madrid Logistic Platform (source: (Puerto Seco, 2013))

As presented, the main platforms are located in the Barajas/Coslada area and comprise the Air Cargo Centre of Madrid-Barajas Airport, the Coslada Transport Centre and the Madrid Dry Port. Moreover, there is another series of infrastructures, over and above these centers, which complete the Madrid logistic network. They are the Madrid Transport Centre, Mercamadrid and the Abroñigal-Viválvaro railway area (IMADE, 2004).

In the planning phase is the development of an intermodal logistic platform, with terminals for container traffic close to Madrid and only served by Iberian gauge. The plan proposes a bypass for freight, which would allow for intermodal rail uses and complementary services. However, for the same area, the construction of a freight terminal connected to the Lisbon-Madrid high-speed rail line is not (yet) defined.

4.2 The Iberian Link

The high-speed rail network requires a new travel concept, new segmentation models for demand and new market position in articulation with other modes of transport. The main idea is to complement modes rather than compete between them. In 2003, the Iberian Summit held in Figueira da Foz, Portugal and Spain defined the first high-speed network routes to be performed between both countries. The Priority Project n. º 3 - The high-speed rail axis of southwest Europe is a key project that ensures the continuity of the rail network between Portugal, Spain and the rest of Europe (Figure 4.20). The future high-speed rail line (built to standard European gauge in Spain and Portugal) links Lisbon to Madrid. From Madrid, two branches – Atlantic and Mediterranean – connect to the French high-speed rail network. The improved transport links provide a substantial boost to economic development across the Iberian Peninsula, in particular allowing rail-traffic from France without any gauge changes (European Commission, 2012c).

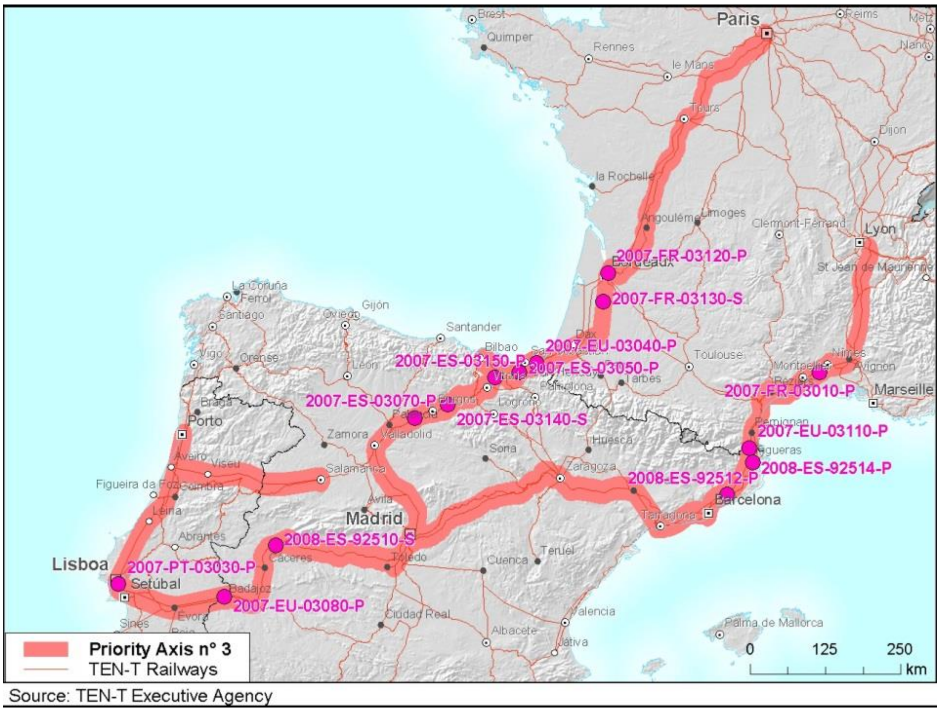


Figure 4.20 Priority Axis n.º 3 (source: (European Commission, 2013b))

The following Iberian Summit, held in Évora, in 2005 (Ministério dos Negócios Estrangeiros, 2005) defined new dates to implement the Iberian connection and pointed the effort to build the line allowing mixed traffic with a travel time of 2 hours and 45 minutes without stops. The meeting also defined a working group to study the interoperability, operation and management models related to the service to be performed. RAVE - *Rede Ferroviária de Alta Velocidade, S.A.* is the entity responsible for the project and has the mission to manage all the strategic operations (RAVE, 2012).

In Spain, the Strategic Plan for Infrastructures and Transports (Ministerio de Fomento, 2006) stressed the future rail link between Lisbon and Madrid and the link to the Extremadura region. The strategic plan of the Iberian rail connection was revised in 2008 between Portugal and Spain, during the Iberian Summit held in Braga (Ministério dos Negócios Estrangeiros, 2008).

The high-speed connection between Lisbon and Madrid is designed to operate with speeds of 350 km/h in double track and in European standard gauge (UIC). The line design allows the connection to other European countries through Madrid, where all Spanish high-speed rail network converge. Besides Lisbon and Madrid the linkage has seven intermediate stops: Évora, Caia/Badajoz (border connection), Mérida, Cáceres, Plasência, Navalmoralde la Mata and Talavera de la Reina, in its path. (Figure 4.21).

Figure 4.21 High-Speed Rail connection (source: (RAVE, 2012))

The decision to connect Lisbon to Madrid follows the European demand. It is expected that the connection may renew the rail structure and demand by rail between both countries. The high-speed line will have a 630 kilometers extension, 210 kilometers on the Portuguese side and the remaining 420 kilometers on the Spanish side. The life cycle investment will be made over a period of 40 years and includes the project, construction, financing, maintenance and provision of all rail infrastructures and also has European financial support.

In the near future, it is expected that a Lisbon-Madrid connection can work as the backbone of all the transport infrastructure designed for this Iberian link. Considering this, a good connection between the conventional rail line, freight facilities, sea port and the (new) airport will be mandatory. In Portugal the high-speed rail project should be viewed as an opportunity in terms of strategy and should not be limited to the traditional projects of transport and engineering (RAVE, 2007).

The implementation of the high-speed rail network in Portugal is considered to be a priority investment by the Portuguese government. This is due to the need to guarantee journey duration and mobility standards and competitiveness equivalent to those achieved on the main European economic axes. The creation of these high-speed rail links is a critical factor for Portugal's integration into the European rail network, creating the conditions to boost competitiveness - in the Iberian and European context - of the Portuguese regions which have higher population density and generate most of the nation's wealth (RAVE, 2008), as presented in Figure 4.22.

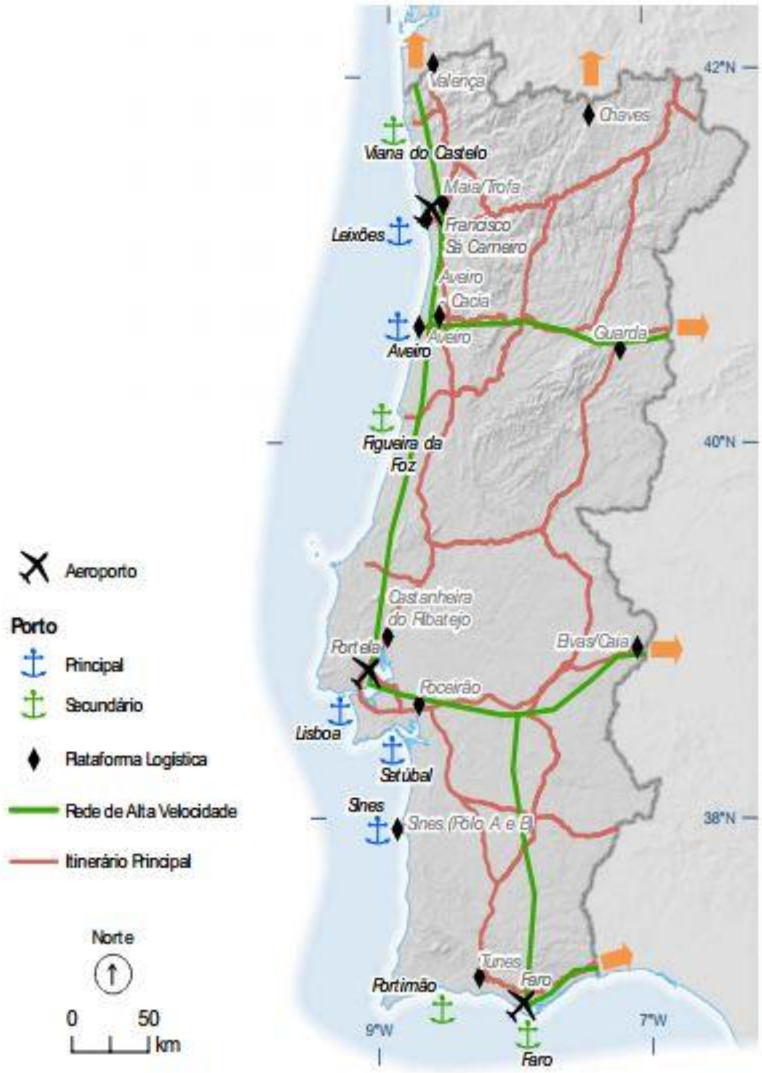


Figure 4.22 Transport Infrastructure System (source: (MOPTC, 2009))

4.2.1 Business Model

As it has happened in several European rail infrastructures, the rail project investment is high and the operating cash flow is usually not enough to cover all investment costs. The business model is based on public-private partnership, state support, European Union grants and European Investment Bank debt financing. This model is expected to achieve significant risk transfer to private sector, greater efficiency in managing and implementing the project, minimizing overall funding cost, maximizing the amount of debt financing and also ensuring good quality service.

RAVE – *Rede Ferroviária de Alta Velocidade, S.A.* is a public limited company with exclusive public capitals (RAVE, 2012). The Portuguese State holds 60 percent of the company and 40 percent is held by REFER – *Rede Ferroviária Nacional, EPE*, the national railway infrastructure administrator (REFER, 2013). RAVE is a 50 percent shareholder in AVEP – *Alta Velocidade Espanha-Portugal* (High-Speed Spain-Portugal), a European economic interest group created to study rail links between both countries in partnership with ADIF – the Spanish Railway Infrastructure Management company (ADIF, 2013b; REFER, 2013). AVEP is responsible for the coordination of market research studies, defining routes, and other technical aspects of the trans-crossing sections of this rail system. Moreover, AVEP also coordinates applications and procedures in order to obtain European funds for the project.

The Portuguese State has important strategic aims regarding the high-speed rail network, some of them based on the Trans-European transport policy. The main reason is to encourage a modal shift to rail, in order to create a sustainable patter of transport, with a minimum environmental impact. Therefore, it is necessary to develop a more profitable rail sector and provide opportunities to Portuguese companies to participate in all aspects of the project and develop their expertise in the rail sector. Besides this, the project improves the links between Portugal and Spain and with the rest of Europe. REFER, as the Portuguese infrastructure rail manager, has carried out most of the rail infrastructure investment. However, the enrolment of the private sector is mandatory in both construction and operation management.

Portugal, as member of the European Union, is required to observe the *Protocol on the excessive deficit procedure*, or Stability Pact. The pact requires that new public infrastructure cannot exceed 3 percent GDP and the level of aggregated public sector debt cannot exceed 60 percent of the annual GDP (KPMG, 2005). According to several calculations, the State support regarding the investment would be around 40 percent, assuming a 5 percent discount rate, which corresponds to the indicative long term financing cost and the rest of the grants available being supported by the European Union.

The whole project is not financially viable on its own, so the value chain needs to be disaggregated to allow that some parts of it become viable. In simplified terms, revenue from passengers flows down to the operator, to the rolling stock, to the superstructure and finally to the substructure. The grants from the European Union and the Portuguese State flow up in the opposite direction. Given the financial forecasts, the operator and rolling stock and the superstructure could be private-owned but the substructure needs to be public-owned and financed. The need to get the right financial balance affects the choice of the size of superstructure and operational units. The stations are seen as a separate income. This allows the stations to be acquired and have their own financial autonomy. Portugal is a high priority market for the European construction industry. The country continues to invest in infrastructures and continues to benefit from several European funds (KPMG, 2005).

European Investment Bank (EIB) is compromised with the Portuguese Government to finance the development of the high-speed rail. Under its credit policy, EIB is able to lend up to a maximum of 50 percent of total costs for a project (EIB’s view of total project costs for a rail would include all elements of the project including stations and rolling stock). The EIB is able to lend at very competitive rates with maturities in excess of 30 years.

Commercial banks have an established track record lending to infrastructure projects. Banks have developed a good understanding of the risks. Their supervisory role as a capital provider underpinned their ultimate rights to ‘step-in’ and takes over an underperforming or defaulting project as a strong disciplinary force for project managers. This is considered an important part of the rationale for Private Partner Partnership’s (PPP). The commercial bank market for project loans is dominated by European bank players, although there is an increasing number of North American, Australian and Japanese banks who are active in the sector (KPMG, 2005).

The bond markets have a significantly larger appetite than the bank market. Primary purchasers of infrastructure bonds tend to be institutional investors such as pension funds; however, there is now an active secondary market where infrastructure bonds are more widely traded. Almost all recent large project bond issues have been credit enhanced or wrapped, the guarantee most often provided by a monoline insurer. Pricing is usually better than bank debt, even after taking into account the guarantee fee charged by the monoline insurer. Maturities of 30 to 50 years are achievable with principal amortization profiles that are significantly back-ended. The cost of the monoline guarantee will depend on the structure of the project and the degree to which project cash-flows are exposed to revenue risks (KPMG, 2005).

4.2.2 General Design

The Lisbon-Madrid high-speed rail line connection has a length of 645 kilometers, in which 200 kilometers of this line is in Portugal and the remaining 445 kilometers are in Spain. This research follows the main guidelines approved in the Iberian Summit agreements between Portugal and Spain (Ministério dos Negócios Estrangeiros, 2008). The general configuration of the high-speed rail line for exploitation refers to infrastructure, power facilities, security facilities and communications. This is an international rail line with different extentions in each country which enables mixed traffic (passengers and cargo). The mixed-use might cause an increase need for maintenance due to higher annual rate than the infrastructure regularly allows.

The line is composed by nine stations and different types of service (long distance, regional and cargo) that are explored with different types of trains. Moreover, some attention should be given to the last 50 kilometers of this line, since it is shared with the Madrid-Seville high-speed rail line and presents several traffic restrictions (Figure 4.23).

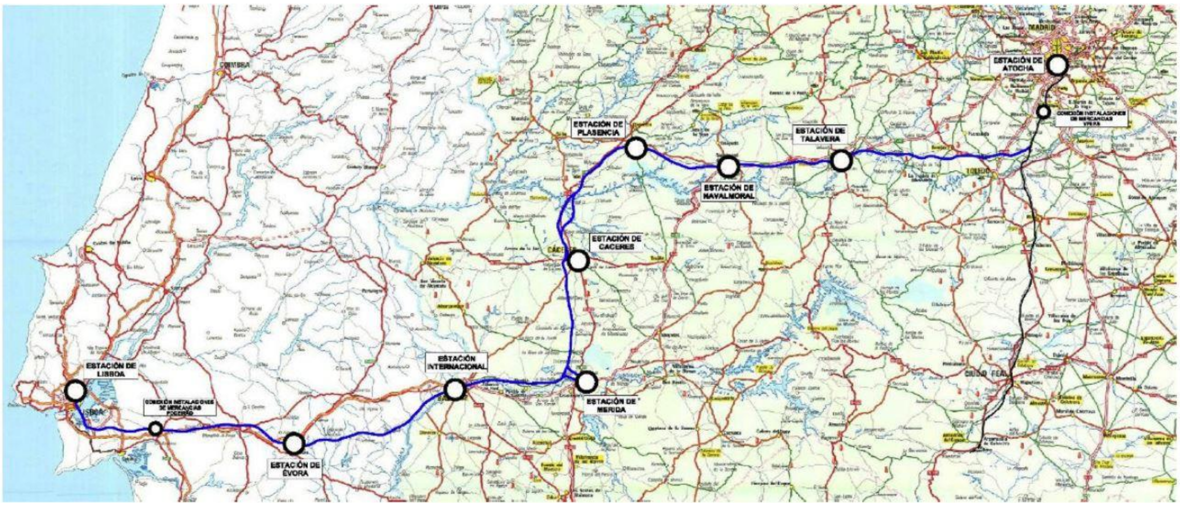


Figure 4.23 Lisbon-Madrid high-speed rail line connection and all stations (source: (MOPTC, 2007)

The infrastructure managers of each country have different technologies for different subsystems, which are allowed since the technical specifications for interoperability are prized (Tis.pt and SENER, 2008a). The infrastructure and required equipment for high-speed rail lines differ from the conventional lines. The required improvements embrace design and construction aspects from signaling system and communications, to the type of superstructure (rails and sleepers), and also the power system and the catenary. The quality and design of each subsystem is related to the type of traffic, the design speed and the expected number of movements per day. Thus, the Lisbon-Madrid line has a design speed of 350 km/h and needs a signaling and communications system appropriate to this design speed.

The infrastructure maintenance has higher standards than the conventional rail requirements. The running of high-speed trains requires a track geometry quality much higher since there is extra wear caused by the dynamic stresses that the line is object. Thus the maintenance should be daily during all life cycle in order to prevent damages that may cause traffic disruption, mainly during the rush hours.Therefore the design, construction, operation and maintenance of the Lisbon-Madrid high-speed rail line shall accomplished all requirements defined from the Technical Specifications for Interoperability (ERA, 2013).

4.2.3 Mixed Traffic Line Design

The construction of a new high-speed rail line does not usually involve the renewal of the existing line, according to several studies held by (López-Pita, 2001). Consequently the Lisbon-Madrid connection will offer a better geometrical quality when compared to the conventional lines. However, some construction constraints need evaluation, regarding cargo-rail services. One of the constraints is related to the introduction of cargo trains on rail line used only by passenger trains. The other one is related to the impacts on geometric characteristics of the line and on line capacity due to the introduction of cargo rail service.

The line is designed for a maximum speed of 350 km/h and has several speed restrictions. The first relates to the first 50 kilometers the line Madrid-Lisbon shares with the high-speed line between Madrid and Seville. This section is not designed for 350 km/h and does not allow mixed traffic. The maximum speed in this section is 270 km/h and allows only for passenger trains. Likewise, on the bifurcation point on the Madrid-Seville to Caceres, the maximum speed that can be achieved is 220 km/h. The access stations also require speed limitations - Talavera de la Reina has a speed limit of 150 km/h. Navalmoral de la Mata station needs to reduce speed to 200 km/h. Finally the Tagus bridge, according to the preliminary studies that consider speed limitation of 100 km/h. According to recent studies, the construction of the line is carried out in two stages. The first phase, scheduled for 2015, links Poceirão - 36 kilometers from Lisbon – with the border. Poceirão will be incorporated in a change of gauge in order to connect to the existing conventional line. In 2020, access to Lisbon will be finalized on European standard gauge (UIC) from Poceirão (Figure 4.24).

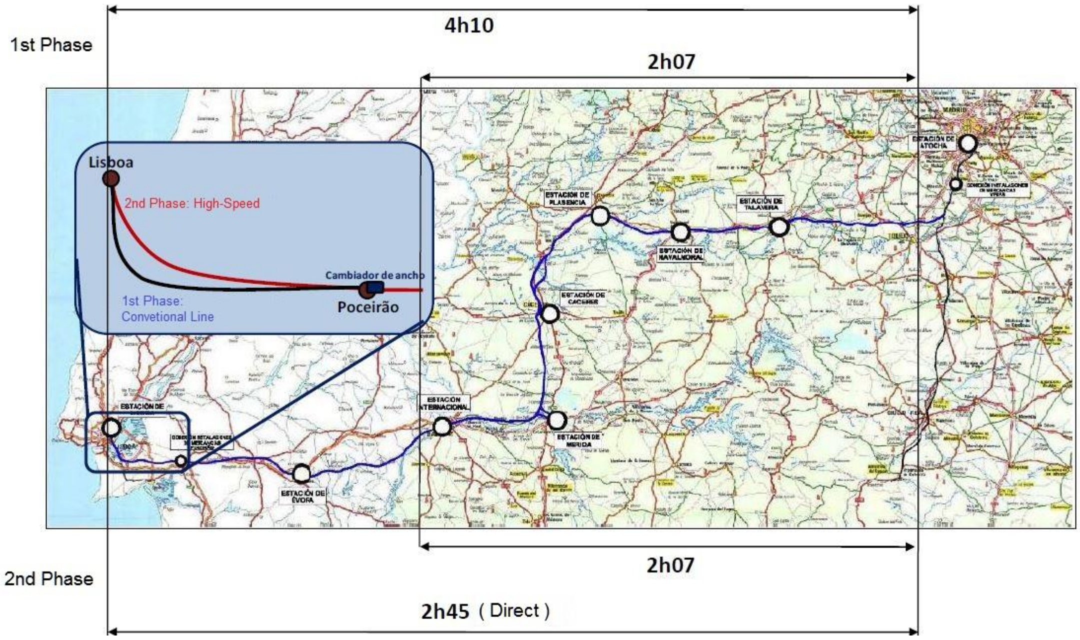


Figure 4.24 Construction phases: I and II (source: adapted (Estudios, Proyectos y Planificación et al., 2011b))

For the present research, only a phase is considered. The single phase includes all stations connected to European standard gauge (UIC) and the two cargo rail facilities needed to support the transport of cargo - one in Portugal and the other in Spain and also all necessary infrastructure and superstructure. The following sections provide the services and the assumptions considered.

4.2.4 Capacity

The rail line capacity definition is difficult to define. Traditionally the capacity of a rail infrastructure is measured in trains per day through theoretical standard capacities based on the characteristics of the line. The comparison of existing traffic with the theoretical capacity provides an indicative value of use. The result is determinant for the evaluation of more or new investment in order to avoid congestion. One way to determine the capacity parameter is to relate the number of trains able to cross a given section in one day, to the type of traffic, the traffic's heterogeneity, usage over the day, maintenance needs and time schedule. For a high-speed rail line as the one in study, the 'standard' capacities for a double track and a block between station is 100-150 trains/day according to the european experience (European Investment Bank, 2005).

4.2.5 Project's Life Cycle

The life cycle of a project runs from the starter year to the last year of operation period. During the appraisal period both investment and operation time are included. The investment period is specific for each project and depends not only on construction-related constraints, but also on the availability of financial resources and on administrative and political issues. Regarding the Lisbon-Madrid high-speed rail project, the main elements of the investment project are the line infrastructure, the track superstructure (with electrification and signalling system) and rolling stock over a 40-year period.The lifetime of the different rail line components is characteristic of each component. This is why special attention must be given regarding the renewal and the residual value of the different elements. For instance, the minimal operating period for the infrastructure is established according to the potential loss of functionality or safety of the element. The residual value of the asset produced by the investment at the end of the operating period depends on the remaining functionality of the project's components. However, the residual value is difficult to estimate since it is related to the technological capacity (obsolescence), the potential alternatives to the project and the cost of its eventual disposal.

4.3 Demand

The traffic demand evaluation considers the impact on three different traffic categories: existing traffic, diverted (or captured) traffic and generated (or induced) traffic. The existing traffic includes the effects on users of the existing transport services. With the future project the quality of service might be improved and also might affect the fares that users have to pay. If the existing infrastructure continues to have operation costs, the non-diverted users of other modes may suffer some effects that should also be considered. The effects on new rail users diverted from other modes (car, bus or air transport) to rail has consequences on the new investment. Usually, diverted (or captured) traffic is related to the change in benefits in travel time, safety, reliability and comfort; changes in operation cost for service providers and also delayed investment costs in other modes. Some rail traffic captured to road can also be considered as consequence of the project. Finally the generated (or induced) traffic is represented by the impacts on the brand new users who were not travelling before but started using the rail due to the investment applied.

4.3.1 Passengers

The demand follows the results obtained from the application of growth models to socio-economic projections and also the predictions regarding the high-speed rail line through the application of modal split analysis for a given scenario and time horizon. The global modality by region and motive was determined by applying the projections of the mobility explanatory variables on the growth models adjusted to the current situation. The projections were made by applying the growth deducted from adjusted models to each transport zone. The projections also considered the border effect reduction, and the estimated growth of home to work travels between Lisbon and Évora (Estudios, Proyectos y Planificación et al., 2011b).

The projections were performed for the period 2010-2030. The total volume of international travel in the Lisbon – Madrid corridor grew from 7.5 million trips to 12.4 million trips, with a compound annual growth rate of 2.5 percent. The growth is stronger for the first years of projection. The annual growth rate between 2010 and 2015 is 3 percent and will be decreasing until 2030, with an annual growth rate of 2.3 percent (Estudios, Proyectos y Planificación et al., 2011b). Similarly, the projections on internal travel inside Portugal are performed through the implementation of socio-economic variables in growth gravity models adjusted to the original study. The projections show that the growth of domestic travel goes from 4.3 million annual trips in 2010 to 5.2 million trips in 2030, which infers an annual growth rate of 1.1 percent. In the case of Spain, the internal travel is determined by the enforcement of a proportional growth to the projected socio-economic variables that allow to get the travel trend. Throughout the study area, the total travel (all modes and all reasons) grows from 15.6 million trips in 2010 to 21.3 million trips, which indicate an annual growth of 1.6 percent over the projection period. The growth rates vary according to the period in analysis. From 2010 to 2015, it is growing 2 percent per year, between 2015 to 2020 it will grow 1.3 percent, 2 percent from 2020 to 2025 and until 2030 it is expected to grow 1 percent. With regard to the travel growth by region, the trips that record the highest growth are the radial trips, that is the ones that connect Madrid to Extremadura (Spain) (Estudios, Proyectos y Planificación et al., 2011b). The demand evaluation is resumed in Figure 4.25.

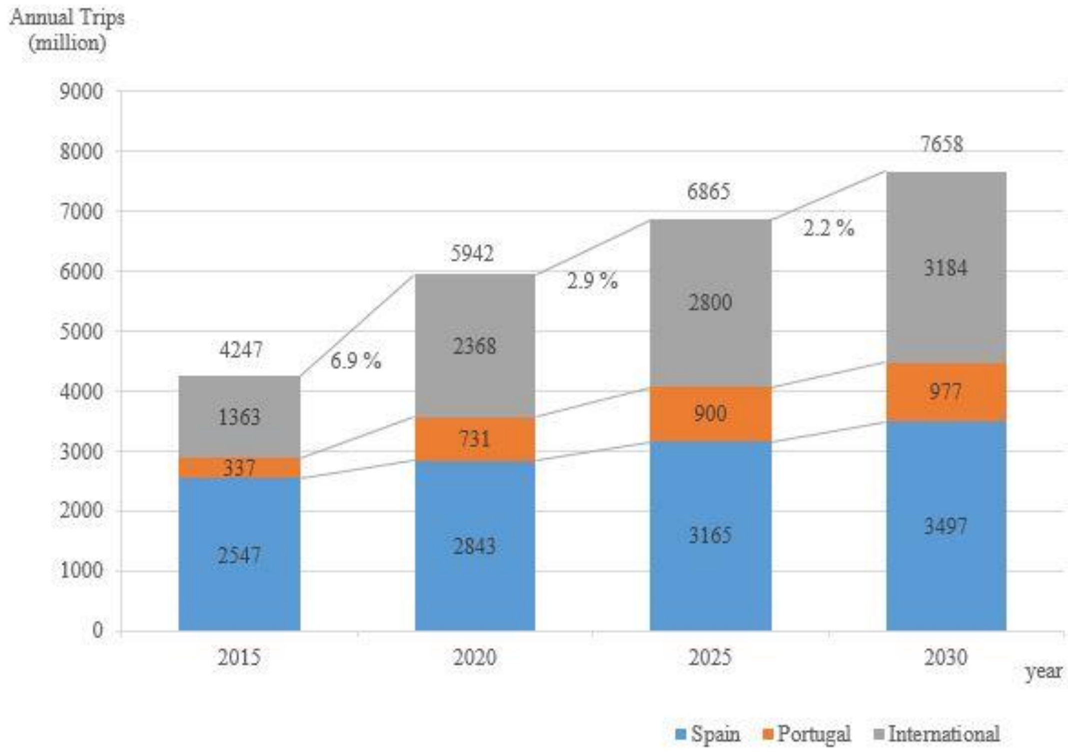


Figure 4.25 Changing demand in the Lisbon-Madrid high-speed rail line

As result the demand data is evaluated by motive and by means of transport. The flows between stations and the induced and captured traffic, according to the studies performed by RAVE, are also considered (Estudios, Proyectos y Planificación et al., 2011b). The passenger service starts in 2015 and ends in 2045. The evaluation data is based on available data from the Lisbon-Madrid high-speed rail line consulting studies.

4.3.2 Cargo

Currently there are 30 million tons of goods being tranfered between Portugal and Spain. In 2045 this value is expected to reach 55 millions tons. This is equivalent to an average annual growth of 1.7 percent. From this total amount, 13.5 million tons are produced in the Lisbon-Madrid corridor (Estudios, Proyectos y Planificación et al., 2011b).

The present research considers that the Lisbon-Madrid high-speed rail line is prepared to receive cargo-rail since the beginning of operations, in 2015. In addition, the line will also be able to handle operation and exploitation issues. In order to estimate the interest of cargo transport in the Lisbon-Madrid high-speed line, the demand matrix between the Spanish and Portuguese regions has to be defined defined. For cargo demand it is accepted that an annual growth rate forecast for the corridor will lead in 2025 a potential market of 10.1 million tons.

Besides, for each region there will be estimates regarding the capture rates related to the composition of the flow of goods by type of product and type of relationship. The evaluation of the capture distance to reduce economic activity and evaluation of regions with spread economic activity is also considered. The starting point is the estimation of the capture rates by type of product. It is assumed that there won't be interest of great specific weight as metallurgical products or raw and building material, since they are not the main scope to be delivered by the high-performance of cargo-trains.

The cargo service data considered were obtained from the Iberian road cargo surveys done in 2008 (INE, 2009a) (INE, 2009b) and also from data stated on the last RAVE reports (EPYPSA and EXACTO, 2011). The direct competition faced by high-speed rail-cargo service is road-cargo, since both share the ambition for containerized cargo. Presently, the Lisbon-Madrid freight trains mainly deal with heavy raw freight needing more than 10 hours to get to the destination. Road-truck transport takes care of the other types, namely light cargo and containerized ones. RAVE reports (EPYPSA and EXACTO, 2011) consider that the cargo demand between Spain and Portugal will achieve, in 2045, the amount of 55 million tons. According to RAVE, the Lisbon-Madrid link designed with an European standard gauge (UIC) that might capture an amount of 930 thousand tons in 2025 and 1250 thousand tons in 2045. In this study, the cargo operation service has the same lifespan, form 2015 to 2045, as the passenger's operation service. Moreover, it is considered that diverted traffic from road represents 0.82 of the total amount of cargo delivered in this rail line.

4.4 Exploitation

To operate the high-speed rail line, several services need to be scaled according to the exploitation scenarios defined and the demand results. Moreover, it is important to define services, frequencies, fares and the rolling stock to be used by the operators and applied to the different services. The distance between stations is common to all references presented and is indicated in Table 4.1.

Table 4.1 Distance between stations in kilometers

	Lisbon	Poceirão	Évora	International	Mérida	Cáceres	Plasência	Navalmoral	Talavera	Madrid-Sevilla	Madrid
Lisbon	0	36	121	203	261	319	383	441	505	594	644
Poceirão		0	85	167	226	283	347	405	469	558	608
Évora			0	82	140	198	262	320	384	473	523
International				0	59	116	180	238	302	391	441
Mérida					0	57	121	180	244	332	382
Cáceres						0	64	122	186	275	325
Plasência							0	58	122	211	261
Navalmoral								0	64	153	203
Talavera									0	89	139
Madrid-Sevilla										0	50
Madrid											0

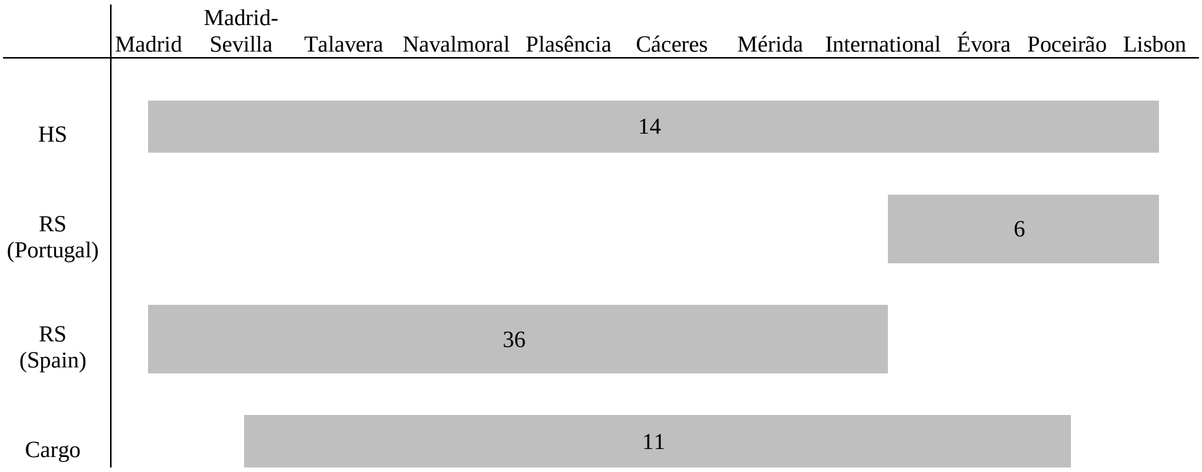
4.4.1 Operation Service

The high-speed rail line operation is constrained by the infrastructure. Given the available data and the uncertainty regarding the type of services to be offered and in order to simplify the analysis two passenger services are considered to represent the chosen scenarios: a long-distance high-speed (HS) and the regional high-speed service (RS). The long-distance high-speed serves Lisbon-Madrid without stops, as a direct service. The travel speed is around 250 km/h and is considered a travel time of 2 hours and 45 minutes (RAVE, 2012). The regional high-speed service serves all intermediate stops with lower speed than the long-distance connection and has a travel speed around 200 km/h. The regional service only operates inside each country and has the international station as connection point.

Regarding cargo, the service performed has a direct connection between two intermodal rail-road terminals, one closer to the city of Lisbon and the other one closer to Madrid. The first one is an upgrade of an intermodal terminal located at the village of Poceirão in Portugal and defined according to the demands of *Portugal Logístico* report (MOPTC, 2006c). The second one is near Toledo area (Spain) and this analysis considers it with a five time more expensive and larger than Poceirão in Portugal (MOPTC, 2007).

Table 4.2 presents the layout of the reference services considered for the Lisbon-Madrid high-speed rail line – for an average day of the year 2015.

Table 4.2 Reference services considered for the Lisbon-Madrid high-speed rail line



The number of services for the passengers are based on the frequencies proposed by RAVE (Estudios, Proyectos y Planificación et al., 2011b). Regarding cargo service, the frequency is established according to the number of trips required to transport the referred demand. The cargo-trains that operate between the two intermodal terminals consist of 12 rail-cars. Each car weighs about 24 tons which together with the weight of the engine, around 82 tons, gives the weight of an empty train of 370 tons. It is assumed that each rail-car is equivalent to two TEU (twenty-foot equivalent unit) that has a capacity of 28.6 metric tons per rail-car. The average load factor per train is 0.75, and the load per train is equal to 344 tons and considers that the operation occurs during 300 days per year. The load units are determined according to Janic study (Janic, 2007).

4.4.2 Daily Shipment

According to RAVE data, the line operates on a daily basis, as well as the allocated line facilities. The service design considers the average annual set from the seasonality and type of service. The occupancy values and the working days selected for the present case study are demonstrated in Table 4.3:

Table 4.3 Occupancy and working days

	Occupancy	Working days
HS	85%	365
RS	65%	365
Cargo	75%	300

To estimate the required unit-trains a range of 18 hours maximum service is established. Besides, it is required to consider a rotation train period of at least 45 minutes to long-distance units and 30 minutes to regional high-speed and cargo services.

4.4.3 Rolling stock

Due to the geographical location of the Lisbon-Madrid high-speed rail line it is expected that the rolling stock used on the line has similar characteristics to the ones already employed in the exploitation of other lines in the Iberian Peninsula. The rolling stock selected should fulfil the Technical Specification for Interoperability (TSI) which enables rolling stock from the rest of Europe to operate in this line. The rolling stock must respect the maximum dimensions as well as maximum length of 400 m, the European standard gauge of 1435 m, the 25kV tension power and the ERTMS (European Rail Traffic Management System) signaling system (Tis.pt and SENER, 2008b).

For the long-distance service, the rolling stock considered has similar characteristics to Serie-102/112 Talgo-Bombardier. This train is similar to the acquired to the Madrid-Tarragona and Zaragoza-Huesca high-speed lines. The initial composition may articulate until 12 carriages and has a capacity of 318 passengers. It is approved for speeds of 330 km/h, although it is designed for 350 km/h. Moreover, the average load factor for long-distance service is considered to be 0.85. Long-distance service operates during 18 hours per day, 365 per year. The operation is dimensioned to be performed with a minimum distance time of 5 minutes between trains and 45 minutes to change the train direction.

The rolling stock selected for the regional high-speed service has similar characteristics to Serie-104 CAF-Alstom. These compositions are smaller in size and with lower capacities - 237 passengers, and are only used for medium distance trips. Similar to the long-distance service, the regional high-speed operates 18 hours per day, 365 per year. The operation is dimensioned to be performed with a distance time of 5 minutes between trains and 30 minutes to change the train direction. The load factor considered for regional high-speed service is 0.65.

In order to integrate cargo in the Lisbon-Madrid line a selection of a proper rolling stock, able to transport cargo demand is required. The rolling stock selected has similar characteristics to passengers' rolling stock, regarding the load per axle and aerodynamic structure. The price value for cargo rolling stock is defined to be 40 percent less than the market price for the passenger long-distance service rolling stock.

4.5 Operation

The operations are split between passengers and cargo. By doing this, at least two different operators are considered: one for passengers and another for cargo service. The services carried out by both of them are unique. Passengers and cargo are never mixed in the same train service. The operator takes the risk on the operating costs and also takes some or all revenue risks. The operator employs drivers, train staff and station staff, and uses the rolling stock to provide rail service. The operator is also responsible for rolling stock maintenance, especially the day-to-day routine maintenance.

4.5.1 Cargo Operations

The development of the high-speed rail line network provides an opportunity to improve cargo-freight service. The main reasons are the use of a high-speed rail network that shortens travel times offered for cargo services and the use of the European gauge network offers the possibility for longer trips. The rail-road terminals provide the space, the equipment and the operation environment for transferring intermodal transport unit between different transport modes. Rail-road terminals consist of a wide range of facilities, ranging from simple terminals providing transfer between two or three modes of transport, providing a number of added-valued services such as storage, empty depot, maintenance repair, etc. Analysis of the full costs of a given intermodal transport network requires an understanding of the network size, of the intensity of operations, of the technology in use, and of the internal and external cost of individual components of the system in study (Janic, 2007).

On current plans the Lisbon-Madrid line is able to support cargo-rail but it raises important affordability questions related to operations. Several adaptations need to be performed in order to become the reliable high-speed rail freight service. The most important is related to the rolling stock type. The rolling stock chosen needs careful study. Besides, track access charge should be adjusted to encouraged cargo operators to provide the cargo service.

The high-speed cargo service should focus on express cargo, urgent loads and in shorter delivery times. In order to perform a reliable service, it should offer a higher frequency of service between two direct points and a selection of cargo loads. The selected cargo is the one compatible with the pre-determined requirements prepared for the selected line. The products to be delivered have high added-value, such as post, pharmaceutical items, fresh products (flowers, fish, vegetables or fruit) or electronic components, in order to provide a one-day (or less) stock operation for the final consumers or industries.

To support rail-cargo activity the Lisbon-Madrid line should integrate a rail-road facility in order to turn the service commercially viable. On the Portuguese side the logistic platform of Poceirão is seen as the back-up support for the considered containerized cargo (Figure 4.26).

Figure 4.26 Poceirão (source: (RAVE, 2011))

Poceirão is located 36 kilometers from Lisbon and has excellent road and rail access conditions. As already mentioned, the freight logistic facility of Poceirão is linked to other European facilities which enable the traffic consolidation from Lisbon, from Setubal and Sines Sea ports to flow to the Iberian hinterland. The expected investment is 500 million euros for an area of 270 hectare (MOPTC, 2007).

On the Spanish side, no investment is until now projected. The best location for this facility would be before the Lisbon-Madrid line merges with the Madrid-Seville line. That is 50 kilometers away from Madrid, near Toledo area. The dimension of the Spanish facility is assumed to be five times larger and more expensive than the Poceirão rail-road facility in Portugal (Figure 4.27).

Figure 4.27 Toledo area (source: (Ministerio de Fomento, 2012))

Regarding the internal facility cost, there are internal and external costs associated to the movement of cargo. Internal costs compromises the operator's costs of moving units between shippers and receivers. The collection, distribution, line hauling and transshipment of units moved within intermodal system determines the internal cost of the network. The cost of each component embraces the cost of the ownership, insurance repair and maintenance, labor, energy, taxes and tolls/fees paid for using the network. The handling cost of a load unit at each terminal includes the transshipment cost and the handling cost according to (Ballis and Golias, 2002; Janic, 2007).

The external costs are the costs that the network imposes on society, since they are not internalized. Usually external costs are estimated indirectly using methods such as willingness-to-pay for avoiding mitigating or controlling particular impacts. The external cost includes the damages by burdens such as the local and global air pollution, congestion noise and traffic accident. The external cost of the intermodal terminals includes the cost of local and global air pollution imposed by the production of electricity for moving cranes used for transshipment of load units (European Union, 2001).

Moreover, a typical rail road terminal is a complex system where many parameters are interrelated, like terminals location in relation to spatial allocation of production and consumption centers, the existence of antagonistic terminal to access to the major rail road network. Thus a rail-road terminal should include in it the following elements: rail siding for train-wagon storage, marshalling and inspection purpose; transshipment track (loading track) for the train loading/unloading operation; storage or buffer lanes for containers; loading and driving lanes for trucks and internal road network.

Regarding cargo operation, the service is never mixed with passenger service, and the cargo train should travel with a speed similar to the regional high-speed service (RS). Moreover, the cargo service uses the free slots left by the passenger services and has a daily operations schedule. This type of service performs a direct train operation which consists of a train that runs between two terminals without handling on the way. Direct trains represent the most economic and rapid rail operation mode. Regarding the direct trains, two variations may be applicable: block trains (the number of wagons are dependent on spatial demand) and shuttle trains (fixed train formation). The current appraisal analysis is performed only with shuttle trains. However, the model could accomplish block trains formation.

4.6 Investment Analysis

To evaluate the infrastructure and its performance, it is essential to quantify operation and maintenance costs required on the Lisbon-Madrid high-speed rail line. The following items describe the cost related to operators as well as manager's costs. The items also quantify the pre-operational costs related to line investment, rail-road facilities and all required investment to make the line viable.

The cost of the high-speed rail line is based on the life cycle investment over a period of forty years, in which are included the project, construction, financing, operations, and maintenance. The project involves the construction of new lines and stations, the purchasing of new rolling stock and additional operating costs and also externalities costs (such as noise or air pollution). The required cost data are obtained from several studies from the European high-speed rail lines, as presented in (Campos et al., 2007; Janic, 2007). To supplement the reference data information provided by RAVE (2012) and data obtained from some interviews conducted to the different stakeholders directly involved in the process (e.g. cargo companies, rail companies, and the Portuguese government) is also taken into account.

4.6.1 Infrastructure Investment Cost

The investment cost are the relevant cost regarding the rail line project and should include planning costs, land property costs and construction costs. The planning costs include the design costs, planning authority resourced and other costs directly related to the project incurred after the initial decision to go ahead. Land cost and property cost include the acquiring cost of land and all associated properties, compensation payments and legal costs. Finally, construction costs include the required preparation of infrastructure, superstructure and work supervision.

The investment amounts are expressed in 2011 terms without inflation effects and without including value added tax (VAT). The data presented have been updated taking into account the annual inflation rate provided by the Portuguese Statistic Institute (INE), for Portugal and Spain. The investment in 2011 constant prices is 5.3 billion euros, as presented in Figure 4.28.

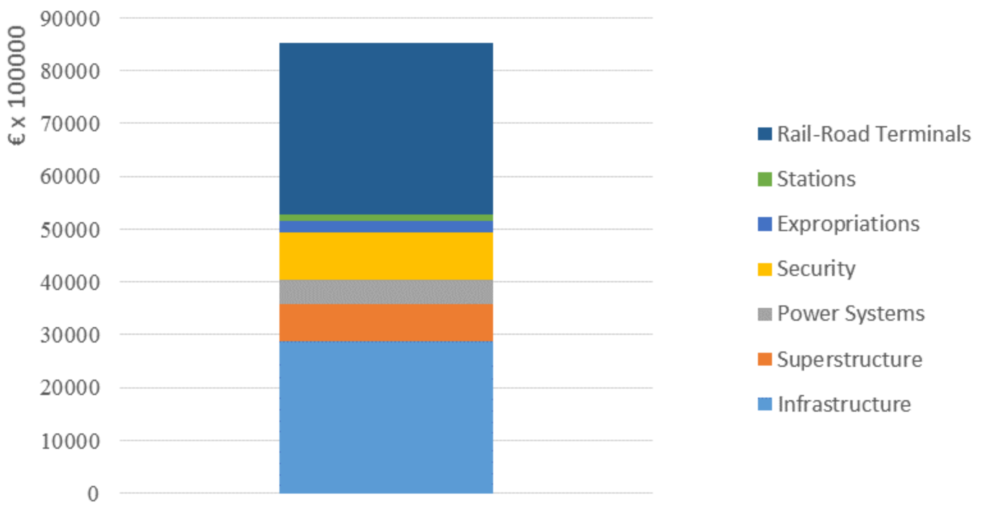


Figure 4.28 Investment Cost (2011)

The Portuguese investment is 1.7 billion euro and the Spanish investment is 3.5 billion euro. From the total amount, the higher percentage corresponds to the investments made in the infrastructure, followed by security and superstructure investments. The high-speed rail investment in the Lisbon-Madrid line began in 2007. It is envisaged that the line will start operation in 2015 together with the passenger and cargo services.

4.6.2 Maintenance and Operation Costs

The operation and maintenance costs of the infrastructure are based on the *Manual de Avaliação de Investimentos em Ferrovias* updated for 2011's values (Estudios, Proyectos y Planificación et al., 2011b). The four main groups of costs considered are: maintenance costs of the line and required teams; cost of maintenance and operation of stations; traffic management cost; safety system cost.

To the maintenance and operation costs must be added the general cost values which are estimated to be 5 percent of the present items. Moreover, the use of the rail line for cargo operations considers an increase in the maintenance cost values. Regarding the nine stations planned for this line, the operating costs differ and relate to the type of station. Madrid/Atocha and Lisbon/Oriente are considered large stations, Badajoz and Évora/Caia medium stations, and the rest are small.

The operating costs are determined assuming different sale cost ratios, number of seats offered, the operating time and distance travelled by the rolling stock as well as maintenance. Regarding passengers, the following are considered: sales cost, vehicle operation cost, line operation costs, personnel operation costs, facilities operation (stations), and the management related costs. Following the same cost structure, the operating cost related to cargo-rail services also consider the rail-road terminal operation cost, the personnel cost and the sales issues related to cargo costs (Janic, 2007).

4.7 Infrastructure Savings

Similar to a cost-benefit analysis, the MATE-T model also considers the benefits generated for the transport infrastructure in analysis. The benefits considered are the ones generated by the project as well as the ones that benefit the whole society.

4.7.1 Time Savings

The time savings are calculated as the difference between the travel time in the situation without project and with project, for passengers or cargo capture using the Lisbon-Madrid high-speed rail line. For induced traffic a time saving equal to half of the weighted average time savings of passengers or cargo picked from other modes is admitted. The reference values considered are the ones defined (Estudios, Proyectos y Planificación et al., 2011b). Regarding cargo service, the value assumed is the one that represents the time savings between the situation with and without project.

4.7.2 Safety/Accident

Safety is usually treated separately from other user benefits. The change in accident rates for the different modes and alternatives are used to estimate economic benefits, multiplying them by the relevant unit value per accident or per causality. The variation of the cost of accident is the result of the probability of the passengers captured by the new line in suffering an accident when compared to other modes and without project. The monetary value related to accidents is defined according to the Spanish Road Traffic Department and by Rave (Estudios, Proyectos y Planificación et al., 2011b). Regarding cargo services, the value considered is the one that represents the amount of cargo captured from road, following the same evaluation used for passenger services.

4.7.3 Network and Environmental Effects

Railway projects have considerable impacts on the environment. In the case of a new rail line, environmental impact changes should be included in the project design and be part of the investment cost according to European demands (European Investment Bank, 2005). The environmental benefits are determined in terms of the air pollutants and greenhouse gases emissions, noise and other environmental aspects. Regarding the Lisbon-Madrid high-speed rail line, the environmental aspects should be compared with other modes of transport, with and without project. The monetary cost is updated regarding the 2011 inflation values from the *Manual de Avaliação* (Estudios, Proyectos y Planificación et al., 2011b; RAVE, 2012).

4.8 Evaluation Parameters

4.8.1 Residual Value

Residual value is the net present value of asset and liabilities in the last year of evaluation. Its use in the evaluation of transport investment projects aims to incorporate the positive net benefits generated beyond the evaluation time. There are several methodologies for its calculation. Theoretical residual value is obtained from an assumption about the most efficient use of the asset after the operating life cycle. Usually, the residual value is positive if the rolling stock can still run without major problems and the infrastructure and superstructure are still operational. However, the residual value may be negative, if the best option is associated to major renovation costs.

The European demands recommend the use of a value that corresponds to the residual asset market value. RAILPAG (European Investment Bank, 2005) and HEATCO (HEATCO, 2006) guidelines suggest that the residual value should be equal to the value of underappreciated investment. Other method suggests that the residual value should be the present value of the future investment revenues. For this research, the method follows the RAILPAG guidelines and assumes that the residual value of the investment depends on the useful time remaining of each component of the project at the end of the evaluation period (European Investment Bank, 2005). Based on RAVE reports, the investment has an average duration of 50 years, investment in electrification is 40 years and investments in signaling and telecommunication have a lifespan of 20 years.

4.8.2 Economic Analysis

The economic analysis appraises the project contribution to the economic welfare of the whole society, which is the political target of the project promoter. It does not contemplate the specific financial interests of the various stakeholders as is the case in the financial analysis. The economic analysis is based on resource costs. For many items the market provides good indicators of the cost. However, some others are not directly tradable. The non-marketable impacts affects transport users and non-users through externalities. Moreover, the final objective is to evaluate the impact of the investment on the society as a whole. The MATE-T method evaluates the contribution among stakeholders and sums up the impacts on individuals as final result.

4.8.3 Discount Rate

The appropriate discount rate is likely to be different between different funders. Traditionally the public sector has a lower discount rate because it benefits future generations more highly than the private sector. Hence, for a very large infrastructure project which might not expect to reach capacity from 10 to 20 years after a construction period of up to ten years it might be much more difficult to finance other than in the public sector. Governments tend to disapprove private finance for public projects because even if they are more efficient and therefore could complete projects at lower direct cost, the higher cost of borrowing is likely to make a project more expensive. Moreover, the project remains on the public sector balance sheet if there are guarantees, which leads to greater government liabilities (Vickerman, 2007b).

The discount rate used in the transport sector should be the same irrespective of the type of project. However, it has been a rather common practice in some countries (and in the analysis of certain institutions) to use lower rates for rail projects under the contention given some benefits of these projects. There is no agreement on which discount rate should be used for the transport sector. Theoretically, it reflects the 'preference for the present' of the aggregate of economic actors. Its value is actually a critical criterion applied to select or accept projects. In theory, it should be linked to the economic situation. In practice, acceptable rates of discount are often set at country level for infrastructure, and can reflect not only economic realities but budget constraints in the public sector. High discount rates favors the acceptance of projects with lower investment and/or a concentration of benefits in the short term, whilst lower rates push forward those projects with longer-term returns. A wide range of discount rates is being currently used in the rail sector, as listed in (Estudios, Proyectos y Planificación et al., 2011b; European Investment Bank, 2005).

4.8.4 Price Elasticity of Demand

The study of passengers demand focuses on factors which determine the choice performed by the user. The elasticity estimates the competition in transport and predicts the income for the service in study, the infrastructure demand or the units necessary to satisfy the demand. As a consequence elasticity may be used for pricing or regulatory policies (Coto-Millán et al., 1997).

Price elasticity of demand is a measure used in economics to show the reaction, or elasticity, of the quantity demanded of a good or service to a change in its price. More precisely, it gives the percentage change in quantity demanded due to a price change. The formula for the price elasticity is calculated as *(4.1)*:

$$Elasticity = \frac{\%\ change\ in\ quality}{\%\ change\ in\ price} \tag{4.1}$$

If the price elasticity of demand is equal to 0, demand is perfectly inelastic (i.e., demand does not change with price changes). Values between zero and one indicate that demand is inelastic (this occurs when the percent change in demand is less than the percent change in price). When price elasticity of demand equals one, demand is unit-elastic (the percent change in demand is equal to the percent change in price). Finally, if the value is greater than one, demand is perfectly elastic (demand is affected to a greater degree by changes in price).

The data related to passengers demand are all based on the study performed by Steer Davies Gleave (Steer Davies Gleave, 2007). According to Steer Davies Gleave’s study, the high-speed service demand is remarkably inelastic. The generated revenue is caused by the price increase. However, in projects such as the high-speed rail connection between Lisbon and Madrid, other objectives are taken into consideration such as the accident reduction, traffic congestion that also needs to be evaluated against the simple revenue optimization. Six different fare levels are determined to be evaluated, and demonstrated in Table 4.4, for the Lisbon-Madrid line for the year 2015.

Table 4.4 Price Elasticity of demand (source: (Steer Davies Gleave, 2007))

Δ Fare	Δ Demand	Elasticity
-50%	20%	-0.41
-20%	9%	-0.46
-50%	20%	-0.41
-20%	9%	-0.46
-10%	5%	-0.46
10%	-4%	-0.41
20%	-7%	-0.36
50%	-13%	-0.25

Regarding cargo price elasticity, several studies stress that freight demand is considered. Thus, there are only a few alternatives where the transportation mode (rail or road) has some structural or essential advantage in the carriage of a particular type of freight over certain length (MEYRICK and Associates, 2006). In this case, the freight demand is classified as being non-contestable, that is, not affected by other mode competition. However, traffic elasticity is particularly relevant from an environmental point of view (Bue Bjørner, 1999).

Prices are the direct, perceived cost to users. Sometimes price is limited to a monetary cost but it can include non-monetary cost such as time, discomfort or risk. The non-monetary relations may affect consumption decision. Consequently a small price difference can have a large effect on travel decisions mainly on consumers which have many competitive options (Litman, 2011). There should also be a distinction between measurement of transport demand in tonne-kilometer and measurement of traffic in vehicles-kilometer (driven kilometers)

Economist measures of price sensitivity uses elasticity definition as the percentage change in consumption of a good caused by one percentage change in its price or other characteristic. However, few estimates of freight transportation direct and cross-elasticity are available in the literature. Freight transportation price elasticity are rarely estimated separately for different market segments, that is, different categories of goods, and do not take explicitly into account the spatial characteristics of the geographic network (Beuthe et al., 2001).

The selected elasticity is based on a geographic information system model of the multimodal network for freight transportation in Belgium embedded within the trans-European network. The geographic information system transport model is used to obtain measures of transport demand elasticity (Beuthe et al., 2001). Furthermore, it models a complete set of conditional elasticity for road, rail and waterway freight transport and for 10 different groups of commodities. Also, separate elasticity has been estimated for short and long distance markets. The elasticity is computed by means of a multimodal network model of freight flows and the minimization of generalized transport costs. The approach has some limitations as presented by (Beuthe et al., 2001), such as the model being static or unable to measure long-run elasticity integrating the effects of induced demand. As a result, the elasticity is taken for the one that represents the total cost variation for a NST-R group type 9 and considering the long distance rail mode as presented in Table 4.5. In order to turn the appraisal more suitable, four new values are added to the reference ones. The new values are based on the elasticity design for passengers determined by RAVE studies. The following values are also presented in Table 4.5.

Table 4.5 Elasticity

Δ Fare	Δ Demand	Elasticity
-15%	23%	-
-10%	13%	-
-5%	8%	-1.54
5%	-8%	-1.54
10%	-11%	-
15%	-20%	-

4.8.5 Taxes and Subsidies

Taxes and subsidies are financial transfers without any impact in the economic evaluation. The effect is also considered in MATE-T evaluation.

4.9 Multi-Attribute Tradespace Exploration applied to Complex Transportation Projects

4.9.1 Stakeholders

The appraisal contributes to support the decision for rail investment under the evolving structure of the sector. Due to the increasing number of stakeholders involved in this sector, it is important to clarify the views and to ensure that the trade-offs between the different stakeholders are properly reflected in the present appraisal process. It is important to evaluate how added-value produced by cargo service is important to the stakeholder's community that might be involved. In this way several interviews were conducted to a set of decision-makers, in order to evaluate their expectations regarding the line behavior and on the potential impact of the cargo services in European standard gauge and the possible constraints. The following entities are important decision-makers regarding Lisbon-Madrid line scope and were interviewed during the appraisal process.

Instituto Portuário e dos Transportes Marítimos, IP (IPTM, IP):

IPTM, IP is a public institute whose main objective is the supervision, planning and coordination of the maritime-sea ports. The IPTM regulates and supervises the related activities. The seaports located in the

Atlantic area are the main goods supplier. The interview allowed to collect information about operations and to identify critical factors regarding the business model development. The sea-port authority emphasized the importance of the Madrid's area supply as the way to expand the business, stressing the key role of the new rail connection for the success of this objective. IPTM also stressed the importance of a better articulation between the seaport and the rail network, expanding accessibility levels and extending the influence of the ports to a wider hinterland.

Comunidade Portuária de Lisboa:

The Lisbon Sea port community is the hub of the sea port business which includes pilotage, trailers, dealers, shipping agents, brokers, freight operators, suppliers or road and rail operators. Currently the main flows in the operation of the Port of Lisbon are the containers and bulk dry on the other hand the roll-on/roll-off traffic (Ro-Ro) is losing importance. The rail connections between the sea port and Spain or other European countries are mainly carried out by *Linha do Norte* and *Linha da Beira Alta*. According to the Lisbon sea Port Administration, the use of the Lisbon-Madrid high-speed rail connection may add some competitive advantages when compared to Spanish sea ports in the supply of the metropolitan area of Madrid. The main advantage is its location and distance to markets, since it can save two days by sea travel. However, to become real, the sea port needs to improve the infrastructure and do several investments. The higher sea port performance is related to the increase of the containers operation area and the improvement of the rail service.

Porto de Setúbal:

The Sea Port of Setubal wants to improve the infrastructure operations and project the sea port as a reference in the logistic chain and as an efficient solution to link the Atlantic seaboard. According to the Port of Setubal, the investment in the Lisbon-Madrid corridor has the advantage to be a direct link between Extremadura and Madrid. This could lead to price decreases and shipping time reduction to Spain. The sea port considers that freight traffic is growing, which is sustained due to growth in container traffic but also Ro-Ro traffic, steel products and bulk solids.

Porto de Sines:

The Sines Sea Port is the largest national port regarding the amount of goods processed, mainly due to the solid and liquid bulk. However, container traffic is a strong commitment from the Port and the international terminal (Terminal XXI). The Sines Container Terminal is administrated by PSA-Sines (Port Administration of Singapore). This terminal is located 150 kilometers south of Lisbon and is free of any urban congestion. The terminal is also well connected by road and rail to the main hinterland. Moreover, Sines is positioned to be the preferred Atlantic gateway for Portugal and Iberian Peninsula (Figure 4.29).

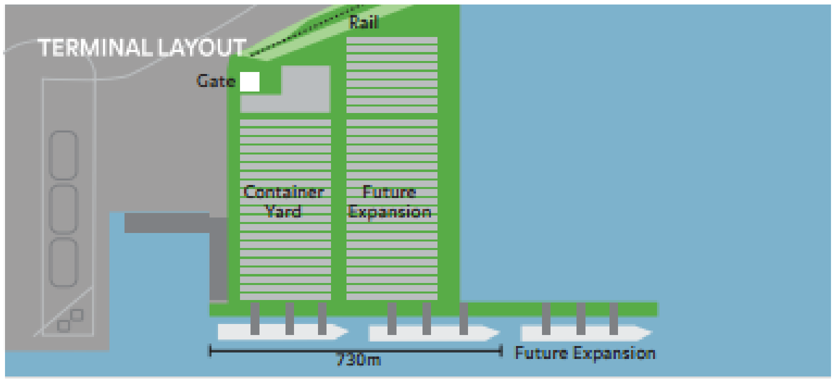


Figure 4.29 Sines Container Terminal (source: (PSA, 2013))

The development of new accessibilities by rail are critical factors for the port expansion. The Port Authority considers that pre-established idea that the transport of goods by rail is only feasible for distances greater than 700-1000 kilometers is not real. Sines Sea Port has currently the longest rail platform in the country, regarding freight services, which represents approximately 22 daily trains. The inner railway harbor is well assembled and its development is already planned. However the current rail connections to link Sines to Lisbon has pendent limitations to the length and weight of the freight train. Usually the freight train is composed by 44 TEU (14 wagons), with a gross weight of 980-1060 tons and a length of 410m. If there is a double line, the tensile stress in this haul would increase the towed load up to 1500 tons (maximum value limited by technology). The Port's authority is concerned with the connection between Sines and Grândola – 50 kilometers away from Sines that change the present restrictions. Regarding the potential of freight transport by high-speed rail line, the Port's Authority says it is only of interest if you do not need any gauge change along the route held.

Comboios de Portugal, CP:

According to CP, in any country the introduction of high-speed rail system is not peaceful either for cost reasons or related contesting. A project like the one predicted for Portugal cannot be analyzed only by the profitability regarding the infrastructure costs and should be seen as a road investment. The high-speed rail needs to meet the users' expectations in order to arrive as soon as possible to their destiny. For CP, it makes no sense to stay out of high-speed rail operation. The main reason is the loss of all long-distance traffic. The net effect and also the integrated rail system linking the high-speed and conventional sub-systems is the strong argument that CP has to position itself as high-speed rail operator. There are multiple factors that distinguish and put CP as the most competent authority to carry out the high-speed rail project. The experience of more than 10 years with the *Alfa-Pendular* rail train; the link between services that allow mobility gains by linking high-speed services and conventional services; the flexibility that CP has to adapt the exploitation model and the ability to maximize the high-speed rail operations value and finally the fact that CP can ensure the best frequency services and schedule adjustments. The rail transport should be seen as the mean of transport that has a close relationship to transport and infrastructure with the aim of producing the best quality transport service for the client. Additionally, new sections, maintenance, and repairs might be privileged in order to avoid a bad quality regarding rail infrastructure (CP, 2008)

Takargo:

Takargo is a private rail freight operator explores three corridors linking Lisbon to Zaragoza, Tarragona and Madrid/Barcelona, in partnership with SPC Multipurpose (logistic operator), Rodocargo (rail operator), Trasitex (logistic operator) and ComsaRail (private Spanish railway operator), under the brand of Ibercargo Rail. The main objective of the Ibercargo Rail is to offer an integrated logistic solution with focus on the Iberian rail corridors, ensuring the connections between major ports, logistic facilities and the main consumption centers. The competition with road transport requires a business model that maximizes the use of the rolling stock in order to avoid downtime on shipping. The road enjoys a number of advantages compared to rail regulations that place a higher level of service competition. Thus, the locomotives are prepared to run on Portuguese and Spanish network, as well as the drives have the necessary qualifications to operate on both networks. This partnership offers a door-to-door service which reduces the time between the rail and the final destination. The rail services to Madrid are performed by Vilar Formoso, given the limitations imposed on weight and length of rail wagons (Figure 4.30).

Figure 4.30 Iberocargo Rail services (Spim and Vtm, 2009)

The Lisbon-Madrid high-speed rail connection is seen as an upgrade in the rail infrastructure that can support new trades or new markets. Moreover, several operational issues should be resized such as the provision of overtaking zones with a more suitable length regarding the train dimensions. However, in rail-freight transport the possibility of using the European Standard gauge line (UIC) is completely discarded.

According to Takargo, the rail freight transport remains in a competitive framework of limited resources and competitive costs. Usually, shippers do not value the deliver operation that endears the shipping invoice. As example, if there are two services to choose, one that delivers the goods in 12 hours for 10 euro and a second that delivers it in 24 hours for 6 euro, the same shipper will prefer the service that takes 30 hours and costs less than 4 euro. The price variable is very sensitive together with the reliability of service and arriving time. The Lisbon-Madrid high-speed rail connection for cargo services is seen as a brand new market to explore by Takargo. Takargo believes that in the beginning the captured traffic consists of road transfers and then sea port traffic would also use the rail infrastructure. The container transport to Madrid needs to deal with the empty return, given the consumerist market and the dislike of shippers to use containers to other traffic than the sea. Some reservations are expressed to supply the Madrid marker by the national sea ports.

Road Cargo Operators:

In order to identify the main users of the rail corridor, the road operators are consulted since they are the main actors of this business area. The operations are fully based on road due to the reliability and flexibility of service. The volumes and number of trucks operated daily confers the cargo the grouping potential to be delivered by rail. The commercial speed of transport is considered an important factor for logistic operators. The average commercial speeds on the road are 80 km/h. The travel time between Lisbon and Madrid is 9 hours. Taking that the maximum driving time is 9 hours daily (twice a week are admissible 10 hours), the time that driver can drive without interruption is 4 hours and 30 minutes (with a forced stop of 45 minutes). The rail operations are only viable if the travel times are lower compared to the road and there is no impact on operating costs. In order to achieve the success, the critical factors from the perspective of the management logistics chain are the transport cost, the reliability of service and the tracking and tracing of freight. Consequently, the road cargo operators express the strong contribution that the high-speed rail connection between Lisbon and Madrid could have on closer economic relations, cultural and social ties between the two metropolitan areas, with huge repercussion in terms of growth and trading. At this time, it is important to the innovate process in order to anticipate the customer needs and gain competitive advantages. In this context, the use of rail services is seen as a competitive option. The group of decision-makers regarding a transportation infrastructure are huge. However, several limits need to be defined in order to find the most important and representative stakeholders and evaluate the project’s performance. The identification of the number of public and private partners involved in rail investments and the distribution of costs and income among them is politically sensitive and an essential component of the decision-making process. It is thus crucial that all relevant stakeholders are detected at an early stage of project appraisal. The approach follows the guidelines defined by the Rail Appraisal Guidelines (European Investment Bank, 2005) to select the main group of stakeholders:

Rail Users

Rail Users are the critical group in the financial and socio-economic analysis, since they represent the potential demand and are the payers of both high-speed rail and other transport services. Their goal is to have a competitive, high frequency, safe service with the lowest fares. The users group integrate users from passenger service (long-distance and regional high-speed) and also cargo-rail suppliers. Rail Users are spread.

Alternative Modes User

Alternative Modes User are together with the Rail User, the critical component in the financial and socio-economic analysis. The idea is to evaluate the impact the new transport infrastructure generates in the dynamic system.

Transport Service Operators

The Transport Service Operators group are represented by public or private rail or coach operators and freight companies. The future high-speed rail line operator(s) is included and has as ambition to obtain the best deal from the investment performed (European Investment Bank, 2005). That is, rail operator needs high fare revenues by paying the minimum for the service operation. The other (conventional rail line) operators aim to keep their current business without losing market share to the new high-speed rail service nor aiming to benefit from it.

Infrastructure Manager

Infrastructure Manager are the private company or the public authority that administrate the high-speed rail line infrastructure and its use. Regarding the European regulations, the rail manager only manages or is also the owner of the infrastructure. The rail manager cannot be the rail operator (European Investment Bank, 2005). The goal of the manager is to grant the use of the line to operators, charging a rent for this, and to keep the maintenance costs as low as possible. A single rail project only affects one infrastructure manager. However, there is a possibility of dividing the network into several managers.

Government

The Government group are characterized by the various political decision makers (European Union, national, regional or local) that are involved in the project. They represent the society (users and non-users) and its perspective with regard to the high-speed rail project. Their goal is to reduce the negative impacts (e.g., accidents, environmental impacts) and increase subsidies to the project. The stakeholder information can be organized in a matrix as represented in Table 4.6.

Table 4.6 Stakeholder Matrix

Stakeholders								
Users				Transport Service Operator			Infrastructure Manager	Government
Induced Demand		Captured Demand		Rail Operator Passenger	Rail Operator Cargo	Other Operator(s)	Rail Manager	
HS | RS	Cargo	HS | RS	Cargo					

4.9.2 Attributes

The project quantification effects regarding the attributes and objectives is useful in order to compare alternatives. However, the most difficult part of the project appraisal is to define how to integrate the available information regarding the objective and produce the best option regarding its qualities. As it happens on cost-benefit analysis, the stakeholder's objectives are the profitability's maximization. However, regarding the stakeholder Government it is more difficult to establish goals and objectives. For the present study the Government role aims to optimize the use of resources for the welfare of society as a whole.

The attributes are set according to the RAVE studies, data provided by other European high-speed rail lines, already mentioned, and also from interviews made to a random group of stakeholders. The attributes are split into four categories (Table 4.7), namely: User Service, Operation, Assets and External Effects. Some attributes are defined as a function of the decision variables and other attributes are constant, since they do not depend on the decision taken. The attributes are presented with the reference units used.

Table 4.7 Attribute selection

Attributes		Units
User Service	Convenience	trains/day
	Service Value	€/pkm €/tkm
	Travel Time	€/h | €/t
	Safety/Accidents	€/pkm €/tkm
Operation	Spare Capacity	€/train.km
	Service	€/train.km
	Traffic	€/seat.km
	Vehicle	€/train | €/train.km
	Track	€/train.km
	Staff	€/train.h
	Facilities (Stations)	€/pkm €/pass

Attributes		Units
		€/train
	Rail-Road Facilities	€/t
	Subsidies	%
Assets	Infrastructure Investment	€/km
	Rolling stock	€/train
	Rail-Road Facilities	€
	Residual Value	€
	Infrastructure & Superstructure (Maintenance)	€/km
	Rail-Road Facilities (Maintenance)	€/t
External Effects	Network	€/pkm €/tkm
	Environmental	€/pkm €/tkm

4.9.3 Stakeholders and Attributes Matrix

The MATE-T requires the valuation of the yearly impacts in terms of cost and benefits. The information is controlled by a spreadsheet that allows an easy calculation of the relation between stakeholders and attributes. If the spreadsheet is properly organized and the reliable data is available, it is simple to obtain specific information on the concerns and objectives of the project regarding the stakeholders involved.

The distributional analysis requires the establishment of a list of relevant attributes and stakeholders for the project, as shown in Table 4.8. As mentioned before, stakeholders are all those identifiable groups that are affected in a noticeable way by the implementation of the project. The attributes are those impacts on any stakeholder that can be established and considered to have a welfare implication.

Table 4.8 Stakeholder-Attribute Matrix

Attributes	Stakeholders			
	Users	Transport Service Operators	Infrastructure Manager	Government
User service				
Operation				
Assets				
External effects				

The stakeholder-attribute matrix takes advantage of the information that should be available for the traditional cost-benefit analysis, and present it in a way that relates attributes (in the rows) and stakeholders (in columns) summarizing the main implications of the project and showing the stakeholders concerns. The matrix integrates information about high-speed rail project investment and divides attributes and stakeholders adopted regarding the evaluation to be performed. Only some cells have noticeable impact on the appraisal. These cells represent the relationship between stakeholder and attribute and the socio-economic or financial incidence. The active cells are different from project to project and also from the criteria that define the content. This evaluation is similar to the RAILPAG guideline recommendations and is adapted regarding the present project appraisal. The cell value usually requires a modelling exercise and an evaluation of all alternatives adapted regarding the present project appraisal (European Investment Bank, 2005). The cell value usually requires a modelling exercise and an evaluation of all alternatives. The major difficulty is to translate some attributes that can be essentially qualitative into monetary terms. The information in the matrix provides an integrated picture of the consequences of the project.

4.9.4 Attribute List

The list of attributes is debated with the involved stakeholders in order to evaluate in each category what is important and how to determine it. As a result, it is possible to define for each attribute, an admissible range of values and units that define the attribute for each one of them. For all attributes the reference value is always based on reference data from similar studies already performed or accurate data. They are the following:

Convenience:

Convenience represents the interest that each stakeholder has regarding the performance of the system for passengers and cargo services. Convenience is related to the frequency of trains per day per service and with each stakeholder’s interest.

Service Value (Passengers):

The value that passengers have to pay to travel by train. It is necessary to boundary this value among the captured and induced demand. For each type of passenger service the service is calculated as *(4.2)*:

$$\pm \sum Service\ Value^{Passenger} \times (€/pkm) \times traffic(pkm) \tag{4.2}$$

The value of the service is different according to the service provided and existing demand. Regarding induced demand, the service value is the one defined by RAVE as the reference value. This reference value also defines passenger fares as presented in Table 4.9.

Table 4.9 Fares

Fares	
HS	RS
0.1390 €/pkm	0.0830 €/pkm

This way, the Service Value regarding induced demand is determined as *(4.3)*:

$$\pm \sum Fare \times (€/pkm) \times Induced\ Demand \tag{4.3}$$

The appraisal model evaluates the captured demand service value as the difference between the new rail fare and the fare from the migrated mode. The fares from the migrated mode are determined by mode and based on data from RAVE, RENFE, RAILPAG guidelines, from Iberian statistics or Spanish data (CEDEX, 2010; Estudios, Proyectos y Planificación et al., 2011b; European Investment Bank, 2005). This study evaluates the travel price of bus, train, air and truck. In order to evaluate the price of traveling by car it is necessary to model the management cost of the road users as presented in the study performed by (Santos, 2007). All other mode reference fares are presented in Table 4.10.

Table 4.10 Fares from Other Modes

Fares – Other Modes			
Car	Bus	Train	Air
0.154 €/pkm	0.15 €/pkm	0.12 €/pkm	0.30 €/pkm

The Service Value regarding Captured demand is calculated as *(4.4)*:

$$\pm \sum Fare^{Rail\ Service} - Fare_i^{Migrated\ Mode} \times (€/pkm) \times Capture\ Demand_i\ .(pkm) \tag{4.4}$$

Service Value (Cargo) represents the amount that freight shippers have to pay. As it occurs with passenger's service value, the service value needs to be adapted in order to evaluate induced and captured traffic. The cargo service value is determined as *(4.5)*:

$$\pm \sum Service\ Value^{Cargo} \times (€/tkm) \times traffic(tkm) \tag{4.5}$$

As in Passenger Service Value, the appraisal model evaluates the captured demand service value as the difference between the new rail fare and the fare from the migrated mode. As mentioned before, it is difficult to estimate the future traffic, and it is even more difficult to predict income from cargo, since fares are often dependent on customer conditions. The line in study considers traffic as the most diverted from road to rail. The reference values for induced and captured traffic are described in Table 4.11:

Table 4.11 Cargo Fares (User Service)

Fares - Cargo	
Cargo Rail	Truck
0.058 €/tkm	0.10 €/tkm

The Service Value regarding Captured demand is calculated as *(4.6)*:

$$\pm \sum Fare^{Cargo\ Rail\ Service} - Fare_i^{Migrated\ Mode} \times (€/tkm) \times Capture\ Demand_i\ .(tkm) \qquad (4.6)$$

Travel Time

The travel time reduction for passengers and cargo using rail services. The type of traffic is here taken into account. For induced traffic the travel time is determined as the time difference in between with and without project. The travel time value is equal to half of the average time saved by mode. The travel time adopted reflects the type of journey's purpose (work, leisure or cargo). Regarding the captured demand, the travel time is determined by the travel time reduction given the lower occupancy. Table 4.12 presents the travel time values considered based on 2011 prices (European Investment Bank, 2005):

Table 4.12 Travel Time (User Service)

Travel Time		
Leisure (Passengers)	Work (Passengers)	Cargo
28.05 €/h	13.18 €/h	2.22 €/h

Safety /Accidents

The accident cost results from the applicability of distinct probability to the captured rail users in suffering accidents when compared to other modes. The accident cost is based on data provided by RAVE and Spanish Traffic Office and presented in Table 4.13 (CEDEX, 2010; Estudios, Proyectos y Planificación et al., 2011b).

Table 4.13 Safety/Accident (User Service)

Safety/Accident				
Car (Passengers)	Bus (Passengers)	Train (Passengers)	Air (Passengers)	Cargo
0.0221 €/pkm	0.0023 €/pkm	0.00055 €/pkm	-0.0006 €/pkm	0.0101 €/tkm

Spare Capacity

Spare Capacity is the value paid by the operator to the infrastructure manager. The value is applicable in Portugal and Spain. The fee accomplishes the taxes applied to the infrastructure. Spare capacity also considers taxes for safety and the use of the infrastructure by cargo service. The fee considers each type of service provided. The costs considered are similar to the ones provided by RAVE studies (Estudios, Proyectos y Planificación et al., 2011b) and presented in Table 4.14.

Table 4.14 Spare Capacity (Operation)

Spare Capacity			
HS	RS (Portugal)	RS (Spain)	Cargo
3.03 €/train.km	1.43 €/train.km	2.61 €/train.km	2.02 €/train.km

Service:

The Service is the value paid by the operator to the infrastructure manager. The service prices are based on RAVE demands (Estudios, Proyectos y Planificación et al., 2011b) and adapted to the current study. For the sake of simplicity, the values presented in Table 4.15 are constant during the present appraisal.

Table 4.15 Service (Operation)

Service			
HS	RS (Portugal)	RS (Spain)	Cargo
2.16 €/train.km	0.83 €/train.km	2.16 €/train.km	1.49 €/train.km

Traffic

Traffic is the value paid by the operator to the infrastructure manager. The traffic values are the ones responsible for paying the line management regarding passenger’s services. These amounts are based on RAVE and ADIF demand values and are presented in Table 4.16.

Table 4.16 Traffic (Operation)

Traffic	
HS	RS
0.0106 €/seat.km	0.0086 €/seat.km

Vehicle Operation Cost

Vehicle Operation Cost represents the exploitation cost related to rail vehicles. The operation cost is different for each rolling stock type and defined according to (Estudios, Proyectos y Planificación et al., 2011b). The considered values are presented in Table 4.17:

Table 4.17 Vehicle Operation Cost (Operation)

Vehicle Operation Cost		
HS	RS	Cargo
1431702.00 €/train	882883.00 €/train	6.03 €/train.km

Track Operations

Track Operation is the unit cost related to rail operation. The data is obtained from RAVE studies (Estudios, Proyectos y Planificación et al., 2011b). The long-distance high-speed service has a higher energetic consumption than regional high-speed. For the sake of simplicity, it is assumed that the cargo services power consumption is similar to long-distance rail services. The reference values are presented in Table 4.18.

Table 4.18 Track Operations Costs

Track Operation		
HS	RS	Cargo
1.67 €/train.km	0.42 €/train.km	1.67 €/train.km

Staff

Staff is the cost associated to the workers and the trainee in the rolling stock. The trainee starts half year before to have training in the area that he/she will work. The train staff includes drivers, cabin crew and auxiliary. The reference values to be used in long-distance high-speed and regional high-speed are based on RAVE demand (Estudios, Proyectos y Planificación et al., 2011b). The cargo train staff value is a ponderation regarding the passenger's values and assuming that cargo trains' services do not need as many staff members as passenger trains. The unit prices are presented in Table 4.19.

Table 4.19 Staff (Operation)

Staff		
HS	RS	Cargo
382.80 €/train.h	168.70 €/train.h	74.35 €/train.h

Facilities

Facilities value is related to sales and station's security. It is only considered for passenger services. The reference values are presented in Table 4.20. The first two values are related to sales and the following ones with safety and amenities. All values are based on data provided by Iberian rail studies.

Table 4.20 Facilities (Operation)

Facilities			
HS	RS	HS/RS	HS/RS
0.008 €/pkm	0.006 €/pkm	0.335 €/pass	2.340 €/train

Rail-Road Facilities

Rail-Road Facilities value is related to cargo sales and cargo handling (Table 4.21). The handling cost is based on Janic studies that stresses the need for modeling the full cost of an intermodal freight transport network (Janic, 2007).

Table 4.21 Rail-Road Facilities (Operation)

Rail-Road Facilities	
Cargo	24.173 €/t

Subsidies

Subsidies represent a pure financial transfer and allows the beneficiaries – operators and infrastructure managers to increase their internal income with the support of the Government.

Infrastructure Investment:

The infrastructure investment is the investment carried out to start the project. It includes the Portuguese and Spanish front costs as presented in section 4.6.1.

Rolling Stock

Regarding passengers, two types of rolling stocks were considered. Both long-distance service and regional services acquire the necessary rolling stock since the start of operations. Rolling stock for cargo service also acquires the equipment in the beginning of the operations. Regarding the price, a value 60 percent below the price is considered for the long-distance service rolling stock. The reference values for this study are the ones presented in Table 4.22.

Table 4.22 Rolling Stock (Assets)

Rolling Stock		
HS	RS	Cargo
24572000 €/train	14872000 €/train	14743200 €/train

Rail-Road Facilities Investment:

The rail-road facilities investment is the investment performed on both terminal facilities and assumed to be as described on section 4.5.1.

Residual Value

The residual values is the amount of an asset after the end of its useful life. This value considers the investment, rail-road investment and rolling stock.

Infrastructure & Superstructure (Maintenance)

Cost for infrastructure managers that charges rolling stock maintenance works, stations, traffic management, safety and infrastructure maintenance. The data is based on references provided by (Estudios, Proyectos y Planificación et al., 2011b) Maintenance cost already considers mixed traffic analysis. The reference values are presented in Table 4.23.

Table 4.23 Infrastructure & Superstructure (Maintenance)

Maintenance	
HS/RS/Cargo	146683.983 €/km

Rail-Road Facilities (Maintenance)

The maintenance cost of the rail-road facilities is based on Janic studies that stress the need for modeling the full cost of an intermodal freight transport network (Janic, 2007). The reference value regarding the present appraisal is presented in Table 4.24.

Table 4.24 Rail-Road Facilities (Maintenance)

Maintenance	
Cargo	11.10 €/t

External Effects

The external effects are related to the benefit of rail operations performance and environmental effects associated. The reference values assumed are presented in Table 4.25. They considered the induced and captured demand regarding passengers and cargo services.

Table 4.25 External Effects

Network					
Car	Bus	Train	Air	Cargo	Truck
0.0756 €/pkm	0.0202 €/pkm	0.0068 €/pkm	0.1012 €/pkm	0.0223 €/pkm	0.0446 €/tkm
Environment					
Car	Bus	Train	Air	Cargo	Truck
0.0290 €/pkm	0.0173 €/pkm	0.0131 €/pkm	0.0446 €/pkm	0.0287 €/pkm	0.0573 €/tkm

4.9.5 Stakeholder Expectation

Regarding stakeholder’s expectations and in order to raise a more representative approach, not all of them share the same concerns or consider the same attributes in their analysis. This evaluation takes into account the expectation of the stakeholders involved. The stakeholder’s expectations are evaluated with the interviews and also considering the set of concerns assumed by European Union recommendations (European Investment Bank, 2005). The stakeholders usually address different priorities given the different attributes that need attention within the project assessment. The priority (weights) assumed by the stakeholders for each attribute group is presented in Table 4.26. This priority has been tuned during the development of this approach and has also changed regarding the different scenarios presented.

Table 4.26 Stakeholders Expectation (Weighting factor)

<table>
<tr><th rowspan="4">Weight</th><th colspan="9">Stakeholders</th></tr>
<tr><th colspan="4">Users</th><th colspan="3">Transport Service Operators</th><th>Infrastr. Manager</th><th rowspan="3">Government</th></tr>
<tr><th colspan="2">Induced Demand</th><th colspan="2">Captured Demand</th><th colspan="2">Rail</th><th rowspan="2">Other Modes</th><th rowspan="2">Rail Manager</th></tr>
<tr><th>HS | RS</th><th>Cargo</th><th>HS | RS</th><th>Cargo</th><th>Operator HS | RS</th><th>Operator Cargo</th></tr>
<tr><td>User Service</td><td>1.00</td><td>1.00</td><td>1.00</td><td>1.00</td><td></td><td></td><td>1.00</td><td>0.15</td><td>0.43</td></tr>
<tr><td>Operation</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.58</td><td>0.60</td><td>-</td><td>0.40</td><td>-</td></tr>
<tr><td>Asset</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.14</td><td>0.20</td><td>-</td><td>0.45</td><td>-</td></tr>
<tr><td>External Effect</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>0.57</td></tr>
</table>

4.9.6 Decision Variables

The decision variables are key quantitative parameters that define the service that is provided by the Lisbon-Madrid high-speed rail line. The variables chosen are those that best represent the environment in study. Table 4.27 resumes all the decision variables chosen.

Table 4.27 Decision Variables

<table>
<tr><th rowspan="2">Decision Variables</th><th rowspan="2">Definition</th><th colspan="4">Variable type
(discrete choice)</th></tr>
<tr><th>Long-Distance High-Speed (HS)</th><th colspan="2">Regional High-Speed Service (RS)</th><th>Cargo Service</th></tr>
<tr><td>Frequency</td><td>Number of trains per day</td><td>14</td><td>6 Portugal</td><td>36 Spain</td><td>0* | 11</td></tr>
<tr><td rowspan="2">Fares</td><td>Reference value paid by the user to the operator (€/pkm; €/tkm)</td><td>0.139</td><td colspan="2">0.083</td><td>0.058</td></tr>
<tr><td>Variation range applied (%)</td><td colspan="3">±50% | ±20% | ±10%</td><td>±5% | ±10% | ±15%</td></tr>
<tr><td>Discount</td><td>Discount offered by the manager to the rail operator (%)</td><td colspan="4">0% | -10% | -20%</td></tr>
<tr><td>Rate of Return</td><td>Return on the investment (%)</td><td colspan="4">0.5% (Investment)
1.0% (User, Operation, Maintenance, External Effects)</td></tr>
</table>

* zero cargo frequency

The frequency is related to the number of trains per day for each service considered. The present values are the reference values, which means that these are the number of trains that best fit to the proposed demand. Regarding cargo frequencies two reference values are presented. The zero cargo frequency value evaluates the model behavior without cargo investment that is without rail-road facilities. The second frequency value 11 trains per day translates the number of trains required to deliver all cargo demand assumed, during the first operation year.

The fares represent the trip value (by passenger-kilometer or tonne- kilometer) to be charged to users. The fare values might change according to an elasticity curve defined both for passengers and cargo. The elasticity curve articulates fares to the value of demand. The values considered are shown in Table 4.27.

The discount is offered to passenger and cargo operators in order to make the operation more competitive. The rate of return is used for calculating the return on the investment (line and intermodal facilities) performed by the infrastructure manager.

For each decision variable considered a discrete set of values is defined, within a pre-defined range. The range and the set of values are based on the previously made assumptions and also based on RAVE reports (EPYPSA and EXACTO 2011):

- The frequency ranges for the passenger services is based on the frequencies proposed by RAVE for the different passenger services. It is assumed as reference value for long-distance high-service the value of 14 services and for regional services 6 services inside Portugal and 36 services inside Spain. The reference value is determined given the demand data and the type of rolling stock chosen for each passenger service as well as the demand of the first year of operation.
- The fare ranges for the long-distance high-speed service (HS) and for the regional speed service (RS) are defined by RAVE demand studies (EPYPSA and EXACTO, 2011). The minimum and maximum fare values are determined by the elasticity function defined on *Modelo Integrado de Procura de Passageiros* (Steer Davies Gleave, 2007) and according to the European Investment Bank Appraisal (European Investment Bank, 2005).
- Regarding cargo rail service the frequency range is established according to the reference demand proposed on RAVE studies. The cargo trains have a capacity of 344 tons and the number of working days considered is 300 days/year. The train capacity is defined according to Janic studies (Janic, 2007). The set of values within the range of each service is defined in order to have a uniform distribution of values. The minimum and maximum fare values for cargo are based on the elasticity studies made by (Beuthe et al., 2001). The elasticity assumed is the one that represents the total cost variation for a NST-R type 9 and considering the long distance rail mode. The cargo elasticity curve is adapted in order to consider a larger range of values. The adaptation made is based on the passenger's elasticity curve.
- The discount is the result of the evaluation performed and defined for this study. The discount varies between 0, 10 or 20 percent according to the selected offer by the manager to reduce the rail operator cost.
- The rate of return is assumed to be 0.5 percent for the investments performed (Infrastructures, Rolling stock, and Rail-Road Facilities) as stressed by the European Appraisal Bank for High-Speed Rail Investment (European Investment Bank, 2005) and referred in several high-speed rail appraisals as well

as in RAVE studies. Regarding all other costs, such as User Service, Operation, Maintenance or External Effects, the rate of return is assumed to be 1.0 percent.

With the set of results provided by the decision variable, the reliability of each service and its convenience is obtained regarding the number of trains per day by service.

4.9.7 Attribute Curves

Each pair of stakeholder-attribute is associated to an attribute curve that represents the utility variation for each stakeholder with regard to the attributes considered. To simplify, linear functions are assumed between utility and costs (value of each attribute). These curves have positive or negative slopes according to the point of view established by stakeholders regarding the attribute evaluation. Stakeholders can have an opposite perceived value for the same attribute. For instance, cargo service users aims to minimize the value paid by kilometers and Rail operator(s) aim to maximize the revenues from cargo service. Figure 4.31 presents a layout of the referred curves.

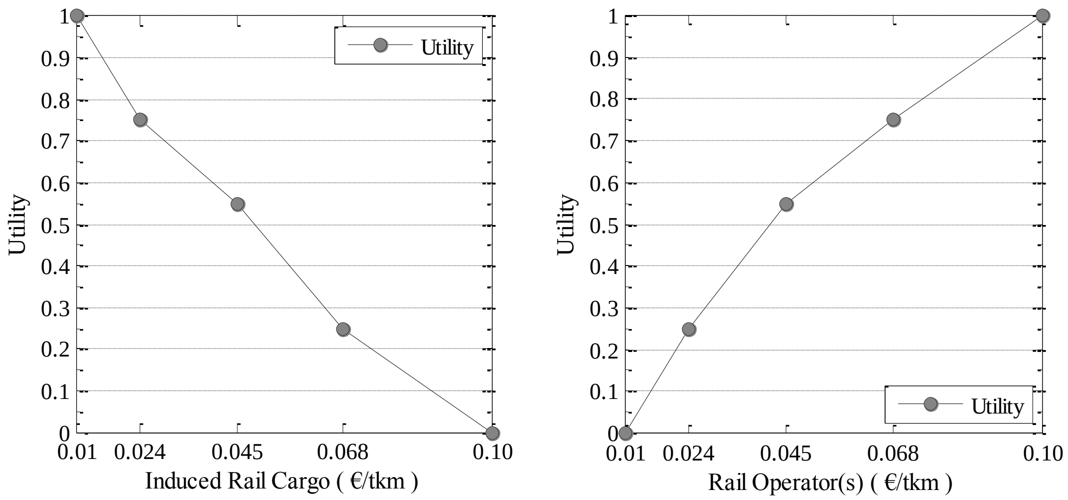


Figure 4.31 Utility Curves

4.10 Conclusions

According to the TEN-T, investing in the high-speed rail has been regarded as one of the front line actions to revitalize the rail option in order to promote the balance between the different transport modes. This balance will ensure network interoperability through the European Countries and reduce bottleneck. The Lisbon-Madrid high-speed rail line follows this European ambition. However, an investment in the rail sector usually implies a huge investment and addresses the concerns of a wide range of institutions, companies and individuals. Until now, cargo has not been seen as target revenue for the high-speed rail investment. This is related to the operational constraints that freight trains face when they have to deal with track maintenance and safety issues of the high-speed rail line.

According to what has been described, it is possible to conceive a high-speed rail line suitable for carrying goods. This means using the Lisbon-Madrid connection to deliver passengers and cargo (mixed traffic). The research is held by several studies that state that passenger demand is not enough to support all the investment cost. Regarding this, it is suggested that cargo services on the free-slots of the line is introduced, in order to increase the project revenues and the investment's efficiency. The investment in cargo-rail services can provide a critical link in the national intermodal freight transport system, serving not only trucking and maritime shipping industries, but also supporting the Portuguese intermodal trade and global competitiveness. Moreover, freight-rail service is seen to be the safest, most economical and most reliable long distance means of transport and the one that releases less carbon dioxide and consumes less energy being more environmentally friendly.

The likelihood to use rail to differentiate distinctive delivery services has become a strategic weapon rather than an operational tool in this new competitive rail environment. The service improvement becomes a relevant issue to the rail industry and an important issue not only to attract passenger demands but also to open the market to new service shares. However, the opportunity for cargo on this high-speed rail line also depends on the quality of the end to end service available and provided. Therefore, this chapter also points to solutions to overcome the lack of interoperability in the cargo structure by adding two rail-roads to the Lisbon-Madrid rail infrastructure investment.

Given the information on the nation's structure and the detailed infrastructure investment analysis, it is possible to develop the MATE-T appraisal in order to evaluate different performance scenarios about the feasibility to introduce cargo in the future Lisbon-Madrid high-speed rail line.

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5 RESULTS

5.1 The Lisbon-Madrid High-Speed Rail Connection

Results suggest the ability of the investment to integrate cargo trains in the daily routine of the infrastructure in order to improve the 'crucial' role that freight transport has in the daily-life of the society. The methodology applied intends to clarify the effects of the evaluation on various transport-related stakeholders and the estimation of the expected financial transfers between them in order to support the decision-making process regarding the investment to be performed in the future Lisbon-Madrid high-speed rail line. The process takes advantage of information that is usually available for the traditional cost-benefit analysis and also integrates the detailed data provided by the related project management agencies.

The information relates the effects to stakeholders, summarizing the main economic and financial implications of the project. The methodology, displayed in Chapter 3, takes the identification of the stakeholders into account, supported by the multi-interviews and reports' analysis where the essential information, described in Chapter 4, were collected to run the methodology. The evaluation among stakeholder and the distribution of cost and benefits are integrated with the non-monetized effects and overall indicators regarding the investment profitability.

This chapter explains how the methodology is applied in order to understand the feasibility of the whole project and the validity of the present methodology to discuss complex transportation projects. Furthermore, the scenario approach followed and the sensitivity analysis considered are presented and discussed together with the obtained results.

5.2 Result Assessment

The approach involves the analysis of the different stakeholders' perspectives, while dealing efficiently with the required resources. The tradespace is assessed stakeholder by stakeholder, according to the description in Chapter 3 and the sequence shown in Figure 3.9. Concerns and objectives of the different stakeholder were deeply debated in Chapter 4. The concerns of each stakeholder are expressed by a set of attributes and the objectives relate to the way these stakeholders assess the decision variables concerning the Lisbon-Madrid high-speed rail project.

The attributes selected, which are fully described in section 4.9 and presented in Table 5.1, are the ones that mostly represent the investment to be performed and are related to the concerns stressed by the different stakeholders regarding the introduction of cargo services in the Lisbon-Madrid high-speed rail line. In Table 5.1 the attribute value with the proper units is also presented in order to ensure the complete coverage of the stakeholder’s preference.

Table 5.1 Attribute selection

Attributes		Units
User Service	Convenience	trains/day
	Service Value	€/pkm €/tkm
	Travel Time	€/h | €/t
	Safety/Accidents	€/pkm €/tkm
Operation	Spare Capacity	€/train.km
	Service	€/train.km
	Traffic	€/seat.km
	Vehicle	€/train | €/train.km
	Track	€/train.km
	Staff	€/train.h
	Facilities (Stations)	€/pkm €/pass €/unit
	Rail-Road Facilities	€/t
	Subsidies	%
Assets	Infrastructure Investment	€/km
	Rolling Stock	€/train
	Rail-Road Facilities	€
	Residual Value	€

Attributes		Units
	Infrastructure & Superstructure (Maintenance)	€/km
	Rail-Road Facilities (Maintenance)	€/t
External Effects	Network	€/pkm €/tkm
	Environmental	€/pkm €/tkm

After the selection of the attribute list, the attributes are associated to the selected utility curves. Together, the attributes and utility functions define the range of functional system outcomes, evaluated in terms of their utility to the user. Additionally, the preference weighting factors are elicited according to the stakeholder's opinion and interviews described in Chapter 4. The weighting values selected are the ones displayed and decomposed in Table 5.2. The values were selected according to the stakeholder's preferences and priorities regarding the possibility of introducing cargo on the Lisbon-Madrid high-speed rail line.

Table 5.2 Weighting values

Weight		Stakeholders								
		Users				Transport Service Operators			Infrastr. Manager	Government
		Induced Demand		Captured Demand		Rail		Other Modes	Rail Manager	
		HS|RS	Cargo	HS|RS	Cargo	Operator HS|RS	Operator Cargo			
Convenience* (User Service)	HS	0.060	-	0.060	-	0.050	0.010	0.050	0.050	0.050
	RS	0.040	-	0.040	-	0.040	0.010	0.040	0.050	0.050
	Cargo	-	0.060	-	0.060	0.010	0.050	0.050	0.050	0.050
Service Value (User Service)	HS (Ind)	0.250	-	-	-	0.050	-	-	-	-
	HS (Cap)	-	-	-	-	0.050	-	-	-	-
	HS (Car)	-	-	0.076	-	-	-	0.075	-	-
	HS (Bus)	-	-	0.075	-	-	-	0.075	-	-
	HS(Train)	-	-	0.075	-	-	-	0.075	-	-
	HS (Air)	-	-	0.075	-	-	-	0.075	-	-
	RS (Ind)	0.200	-	-	-	0.040	-	-	-	-
	RS (Cap)	-	-	-	-	0.040	-	-	-	-
	RS (Car)	-	-	0.067	-	-	-	0.080	-	-
	RS (Bus)	-	-	0.066	-	-	-	0.080	-	-
	RS (Train)	-	-	0.066	-	-	-	0.080	-	-
	Cargo (Ind)	-	0.4	-	-	-	0.065	-	-	-
	Cargo(Cap)	-	-	-	-	-	0.065	-	-	-
	Cargo (Truck)	-	-	-	0.620	-	-	0.320	-	-
Travel Time (User Service)	Work (Ind)	0.160	-	-	-	-	-	-	-	-
	Work (Cap)	-	-	0.150	-	-	-	-	-	-
	Leisure (Ind)	0.140	-	-	-	-	-	-	-	-
	Leisure (Cap)	-	-	0.100	-	-	-	-	-	-
	Cargo (Ind)	-	0.300		-	-	-	-	-	-
	Cargo (Cap)	-	-	-	0.180			-	-	-
Safety/Accidents (User Service)	HS|RS (Car)	-	-	0.050	-	-	-	-	-	0.040
	HS|RS (Bus)	-	-	0.050	-	-	-	-	-	0.040
	HS|RS (Train)	0.150	-	-	-	-	-	-	-	0.040

Weight		Stakeholders								
		Users				Transport Service Operators			Infrastr. Manager	Government
		Induced Demand		Captured Demand		Rail		Other Modes	Rail Manager	
		HS|RS	Cargo	HS|RS	Cargo	Operator HS|RS	Operator Cargo			
	HS|RS (Air)	-	-	0.050	-	-	-	-	-	0.040
	Cargo (Ind)	-	0.240	-	-	-	-	-	-	0.060
	Cargo (Cap)	-	-	-	0.140	-	-	-	-	0.060
Spare Capacity (Operation)	HS	-	-	-	-	0.030	0.010	-	0.030	-
	RS (Pt)	-	-	-	-	0.030	0.010	-	0.030	-
	RS (Sp)	-	-	-	-	0.030	0.010	-	0.030	-
	Cargo	-	-	-	-	0.010	0.070	-	0.030	-
Service (Operations)	HS	-	-	-	-	0.030	0.010	-	0.030	-
	RS (Pt)	-	-	-	-	0.030	0.010	-	0.030	-
	RS (Sp)	-	-	-	-	0.030	0.010	-	0.030	-
	Cargo	-	-	-	-	0.010	0.070	-	0.030	-
Traffic (Operations)	HS	-	-	-	-	0.030	0.010	-	0.030	-
	RS	-	-	-	-	0.030	0.010	-	0.030	-
Vehicle (Operations)	HS	-	-	-	-	0.035	0.010	-	-	-
	RS	-	-	-	-	0.025	0.010	-	-	-
	Cargo	-	-	-	-	0.010	0.060	-	0.030	-
Track (Operations)	HS	-	-	-	-	0.025	0.020	-	-	-
	RS	-	-	-	-	0.025	0.020	-	-	-
	Cargo	-	-	-	-	0.010	0.060	-	-	-
Staff (Operations)	HS	-	-	-	-	0.030	0.010	-	-	-
	RS	-	-	-	-	0.020	0.010	-	-	-
	Cargo	-	-	-	-	0.010	0.060	-	-	-
Facilities (Operations)	HS	-	-	-	-	0.030	0.010	-	-	-
	RS	-	-	-	-	0.030	0.010	-	-	-
	HS|RS	-	-	-	-	0.025	0.010	-	0.030	-
	HS|RS	-	-	-	-	0.025	0.010	-	0.030	-
Rail-Road Facilities (Operations)	HS|RS Cargo	-	-	-	-	0.010	0.070	-	-	-
Subsidies	HS|RS Cargo	-	-	-	-	0.010	0.010	-	0.010	-
Infrastructure (Assets)	Investment	-	-	-	-	0.010	0.010	-	0.200	-
Rolling Stock (Assets)	HS	-	-	-	-	0.024	-	-	-	-
	RS	-	-	-	-	0.024	-	-	-	-
	Cargo	-	-	-	-	-	0.030	-	-	-
Rail-Road Facilities (Assets)	Investment	-	-	-	-	0.001	0.030	-	0.140	-
Residual Value	Line	-	-	-	-	0.0004	-	-	0.005	-
	Rail-Road Facilities	-	-	-	-	0.0004	0.010	-	0.005	-
Infrastructure & Superstructure (Assets)	HS|RS Cargo	-	-	-	-	0.040	0.060	-	0.050	-
Rail-Road Facilities (Assets)	HS|RS Cargo	-	-	-	-	0.040	0.060	-	0.050	-
Network (External Effects)	HS|RS (Car)	-	-	-	-	-	-	-	-	0.040
	HS|RS (Bus)	-	-	-	-	-	-	-	-	0.040
	HS|RS (Train)	-	-	-	-	-	-	-	-	0.050
	HS|RS (Air)	-	-	-	-	-	-	-	-	0.040
	Cargo	-	-	-	-	-	-	-	-	0.060

Weight		Stakeholders								
		Users				Transport Service Operators			Infrastr. Manager	Government
		Induced Demand		Captured Demand		Rail		Other Modes	Rail Manager	
		HS|RS	Cargo	HS|RS	Cargo	Operator HS|RS	Operator Cargo			
	Cargo(Truck)	-	-	-	-	-	-	-	-	0.060
Environment (External Effects)	HS|RS (Car)	-	-	-	-	-	-	-	-	0.040
	HS|RS (Bus)	-	-	-	-	-	-	-	-	0.040
	HS|RS (Train)	-	-	-	-	-	-	-	-	0.040
	HS|RS (Air)	-	-	-	-	-	-	-	-	0.040
	Cargo (Ind)	-	-	-	-	-	-	-	-	0.060
	Cargo (Cap)	-	-	-	-	-	-	-	-	0.060

Pt: Portugal; Sp: Spain; Ind: Induced demand; Cap: Captured demand

*Convenience is only a utility measure

The set of discrete decision variables are selected in order to define the appraisal. The Table 5.3 presents the selection of variables and its variation range which are fundamental to describe the mixed traffic rail line in appraisal.

Table 5.3 Decision variables

Decision Variables	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day	14	6[Portugal]	36[Spain]	0* | 11
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		0.058
	Variation range applied (%)	±50% | ±20% | ±10%			±5% | ±10% | ±15%
Discount	Discount offered by the manager to the rail operator (%)	0% | -10% | -20%			
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)			

* zero cargo frequency

Frequency represents the number of trains per day for each service considered for the two passenger's services (long-distance - HS and regional high-speed - RS) and the cargo service. For the passenger's services, it is assumed that the values proposed in RAVE demand studies are computed in order to guarantee that all passenger demand estimated for the services are considered. This means that the regional high-speed service needs 6 trains per day to meet all passenger demand in Lisbon-International link and the Spanish service (International-Madrid) needs 36 trains per day to meet the respective demand. A sensitive analysis is performed for the cargo services, regarding the introduction of cargo in the high-speed rail line. This a scenario considers no cargo service available in the line (i.e., value of zero for the cargo's frequency). Moreover, another scenario considers a discrete number of trains per day. The cargo service frequency is computed based on the minimum number of daily trains needed to carry all cargo estimated by RAVE for this line – i.e., 11 trains per day. Cargo frequencies are established according to the reference demand proposed on RAVE studies. The cargo trains have a capacity of 344 tons, set according to Janic studies (Janic, 2007) and the number of working days are considered 300 days/year. The frequency values stress the rolling stock need in the beginning of the operation (2015). The rolling stock acquisition – in fixed time periods - follows the demand studies, in order to ensure that all the demand estimated for HS, RS and Cargo services is carried out during the project lifespan.

The fares represent the trip value (by passenger-km or tonne-km) to be charged to users. The fare values change according to an elasticity curve defined both for passengers and cargo and described in Table 5.3 as the variation range applied. The variation range articulates passenger fares to the value of demand and are defined on *Modelo Integrado de Procura de Passageiros* (Steer Davies Gleave, 2007) and according to the European Investment Bank Appraisal (European Investment Bank, 2005), as stressed in section 4.8.4, Price Elasticity of Demand. For example, if the HS fare varies -50%, it means that the scenario appraises a fare of 0.0695€/pkm resulting in a demand increase of 20%. The same happens for the other passenger's variation range values.

Regarding cargo fare, the variation range is based on the elasticity studies made by (Beuthe et al., 2001). The variation range applied is the one that represents the total cost variation for a NST-R type 9 and considering the longest distance by rail. Moreover, it has been adapted, based on the passenger's elasticity curve, in order to consider a larger range of values. As it happens with passenger fares, the range of values is described by the modeled variation range. As example, if the cargo fare varies -15%, it means that the scenario appraises a fare of 0.0495€/tkm, resulting in a demand increase of 23%.

The discount result from the evaluation performed and defined for this research. The discount varies between 0 (no discount assigned), -10% or -20%. The discount is offered to passengers and cargo operators, in order to assess the profitability of the operation.

Rate of return is used for calculating the return on the investment. The value is based on previous studies performed by other methods of analysis and used as a reference value. The rate of return is assumed to be 0.5%, for the attributes related to Investment - infrastructures, rolling stock, and rail-road facilities, the rate of return is assumed to be 0.5% (European Investment Bank, 2005). Regarding all other costs (User Service, Operation, Maintenance or External Effects) the rate of return is assumed to be 1.0%.

Given all this, the model generates a set of possible designs which are the combination of the decision variables with the attributes weighting and the related utility curves. Each solution is then analyzed in terms of costs and utility, given each stakeholder's perspective and the combination of the selected decision variables, according to the pre-defined scenario. The costs are calculated according to the net present value (NPV) of the Lisbon-Madrid high-speed rail line project life cycle cost considering a life period of 40 years. The designs tested include all the pre-defined investment where the overall equipment and infrastructures and the required logistic freight facilities investment are comprised.

As example, the final cost regarding the stakeholder *User Cargo* related to induced demand is determined according to *(5.1)*:

$$\mathrm{Cost}\left(\mathrm{User}_{\mathrm{Cargo}}^{\mathrm{Induced\,Demand}}\right)_j = \sum_{i=0}^{T} \frac{\mathrm{Cargo}_j^{\mathrm{Induced\,Demand}} \times \left(\mathrm{ServiceValue}_j \times d - \mathrm{TravelTime}_j \times h - Safety_j \times d\right)}{(1+r)^i}$$
$$T = 40 \text{ year}$$
$$r = 1.0\% \ (\mathrm{User})$$
$$d = \mathrm{distance}\,(\mathrm{km}) \qquad (5.1)$$
$$h = \mathrm{time}$$

The demand is composed by the sum of the induced and captured traffic. The induced demand represents the demand generated given the existence of a new transport mode and the captured demand is composed of the traffic diverted from other modes. The present equation only estimates the costs related to *Induced Demand Cargo*. The equation integrates the sum of the important attributes of this stakeholder that were selected according to the options defined and displayed in Table 5.2.

The cost equation *(5.1)* does not considered the Convenience attribute stressed in Table 5.2 because this attribute is only assigned as a utility measure regarding the performance of the system, for all the selected stakeholders. The attributes considered were fully described in Chapter 4. The cost result regarding the *Induced Demand Cargo* translates the *Cargo User* concern about their willingness-to-pay for this service. The equation *(5.1)* accomplishes the attributes: Service Value (cost), Travel Time (benefit) and Safety (benefit). Service value is related to the price to pay for a trip. Then, travel time represents the travel time reduction regarding the use of rail services and is determined as the time difference saved by the induced cargo demand, with and without project. Finally, safety is related to the probability that rail users have in suffering accidents when compared to other modes. The rate of return, r is assumed to be, 1.0%, for cost related with User Service.

The cost and utility relation for each design solutions evaluated is then plotted in the tradespace. The tradespace, assessed by the stakeholder, combines the life cycle cost with the utility for each design solution (tradespace point) and resulting in a cloud of points. The different tradespaces reflect the different point of views that each stakeholder has regarding the Lisbon-Madrid high-speed rail line.

As defined in Chapter 3, it is mandatory to evaluate the tradespace in order to find a common solution that fulfilled all the stakeholders' ambitions. The solution accomplishes the evaluation of the expectations regarding the evaluated scenario and presents the trade-off of the resulting design, accessed through the *Pareto Front* together with the tradespace result of the selected stakeholders.

5.3 Scenario Analysis

The scenario analysis present the MATE-T performance in order to evaluate the introduction of cargo in the Lisbon-Madrid high-speed rail line. Different scenarios are tested and evaluated regarding a selection set of decision variables. In order to understand the suitability of cargo transport in the Lisbon-Madrid high-speed rail line, the different scenarios evaluated are described. The appraisal follows a step-by-step evaluation of the decision variables, in order to understand the feasibility of the method.

5.3.1 Reference Scenario

In the reference scenario, the investment is appraised given a static evaluation of the decision variables selected. This means that all decision variables are fixed and turned into constant values as presented in Table 5.4.

Table 5.4 Reference values

Fixed Values	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day	14	6[Portugal]	36[Spain]	11
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		0.058
	Variation range applied (%)	-			-
Discount	Discount offered by the manager to the rail operator (%)	-			
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)			

The goal of analyzing this scenario is to show how the reference scenario selects the design solution, since, for the sake of simplicity, all decision variables are fixed.

5.3.2 No Cargo Investment

The present scenario appraises the investment, as formulated by RAVE. Meaning that RAVE considers that the line is only operated by passenger services and a fixed number of trains run the line per day. The scenario also considers a range of fares defined for the passenger high-speed services related to demand. In the no cargo investment scenario, no investment in cargo facilities is assumed. Table 5.5 summarizes the constant values and the decision variables applied.

Table 5.5 Zero cargo investment decision variables

Decision Variables	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day (fixed)	14	6 Portugal	36 Spain	-
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		-
	Variation range applied (%)	±50% | ±20% | ±10%			-
Discount	Discount offered by the manager to the rail operator (%)	0% | -10% |-20%			
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)			

5.3.3 Cargo Scenario

The cargo scenario evaluates if the extra investment performed in cargo facilities and in cargo infrastructure, given the fixed number of trains, changes the cost results. The decision variables, Table 5.6, evaluate the selected range of fares, given the defined variation range and the possible discount applied to the rail operation values paid by the operator to the Rail Manager, in order to use the infrastructure.

Table 5.6 Cargo scenario decision variables

Decision Variables	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day (fixed)	14	6 Portugal	36 Spain	11
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		0.058
	Variation range applied (%)	±50% | ±20% | ±10%			±5% | ±10% | ±15%
Discount	Discount offered by the manager to the rail operator (%)	0% | -10% | -20%			
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)			

5.3.4 Cargo Frequency Variation Scenario

The cargo frequency variation evaluates the scenario performance regarding the assessment of a new decision variable. The cargo frequency appraises the changes that the different range of frequencies has in the project. Table 5.7 presents the selection of three different cargo frequencies, selected to evaluate the model reaction, given the introduction of a new assessment level. The evaluation accomplish the necessity to buy different rolling stock quantities versus the capacity to deliver more or less cargo, given the selected fare.

Table 5.7 Cargo frequency variation decision variables

<table>
<tr><th rowspan="3">Decision Variables</th><th rowspan="3">Definition</th><th colspan="4">Variable type
(discrete choice)</th></tr>
<tr><th rowspan="2">Long-Distance High-Speed (HS)</th><th colspan="2">Regional High-Speed Service (RS)</th><th rowspan="2">Cargo Service</th></tr>
<tr></tr>
<tr><td>Frequency</td><td>Number of trains per day</td><td>14</td><td>6 (Portugal)</td><td>36 (Spain)</td><td>6 | 11 | 14</td></tr>
<tr><td rowspan="2">Fares</td><td>Reference value paid by the user to the operator (€/pkm; €/tkm)</td><td>0.139</td><td colspan="2">0.083</td><td>0.058</td></tr>
<tr><td>Variation range applied (%)</td><td colspan="3">±50% | ±20% | ±10%</td><td>±5% | ±10% | ±15%</td></tr>
<tr><td>Discount</td><td>Discount offered by the manager to the rail operator (%)</td><td colspan="4">0% | -10% | -20%</td></tr>
<tr><td>Rate of Return</td><td>Return on the investment (%)</td><td colspan="4">0.5% (Investment)
1.0% (User, Operation, Maintenance, External Effects)</td></tr>
</table>

5.3.5 Attribute Scenario

The attribute scenario changes the stakeholder's attribute assessment and changes the overall evaluation performed. The present scenario considers the Rail Manager to be fully responsible for vehicle operations of, as he used to receive part of this operation cost as revenue and the rail-road operation costs are split between Rail Operator HS|RS as illustrated in Table 5.8.

Table 5.8 Attribute selection

<table>
<tr><th colspan="2" rowspan="3">Attributes</th><th rowspan="3">Applied to</th><th rowspan="3">Units</th><th colspan="4">Users</th><th colspan="3">Transport Service Operator</th><th rowspan="3">Rail Manager</th><th rowspan="3">Government</th></tr>
<tr><th colspan="2">Induced Demand</th><th colspan="2">Captured Demand</th><th rowspan="2">Operator HS|RS</th><th rowspan="2">Operator Cargo</th><th rowspan="2">Other (s)</th></tr>
<tr><th>HS|RS</th><th>Cargo</th><th>HS|RS</th><th>Cargo</th></tr>
<tr><td rowspan="2">Operation</td><td>Vehicle</td><td>Cargo</td><td>€/train.km</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td></td><td>x</td><td></td></tr>
<tr><td>Rail-Road Facilities</td><td>Cargo</td><td>€/t</td><td></td><td></td><td></td><td></td><td></td><td>x</td><td></td><td>x</td><td></td></tr>
</table>

The decision variables related to the scenario are presented in Table 5.9.

Table 5.9 Attribute scenario decision variables

Decision Variables	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day (fixed)	14	6 Portugal	36 Spain	11
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		0.058
	Variation range applied (%)	-			±5% | ±10% | ±15%
Discount	Discount offered by the manager to the rail operator (%)	0% | -10% | -20%			
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)			

5.3.6 Operation Fees Scenario

The operation fees scenario is formulated from the same decision variable used in the attribute scenario (Table 5.9) and evaluates the Lisbon-Madrid line investment if the operation fees, set out in Chapter 4, all supported by the stakeholder Rail Manager. This means that Rail Operators only care about the user's revenues and rolling stock acquisition. The result is presented as follows.

5.3.7 Investment Funds Scenario

The Lisbon-Madrid high-speed rail line business model is supported by financial support provided by European Funds or Bank loans. The Investment Funds Scenario follows the business model and evaluates the line's assessment and the stakeholder's reaction given the financial support of 85% regarding line – infrastructure and superstructure, and rail-road facilities investment. The decision variables considered regarding the investment funds decision variables are presented in Table 5.10.

Table 5.10 Investment funds decision variables

Decision Variables	Definition	Variable type (discrete choice)			
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)		Cargo Service
Frequency	Number of trains per day (fixed)	14	6 Portugal	36 Spain	11
Fares	Reference value paid by the user to the operator (€/pkm; €/tkm)	0.139	0.083		0.058
	Variation range applied (%)	-			±5% | ±10% | ±15%
Discount	Discount offered by the manager to the rail operator (%)	0% | -10% | -20%			

Decision Variables	Definition	Variable type (discrete choice)		
		Long-Distance High-Speed (HS)	Regional High-Speed Service (RS)	Cargo Service
Rate of Return	Return on the investment (%)	0.5% (Investment) 1.0% (User, Operation, Maintenance, External Effects)		

5.4 Results

The results present the evaluation regarding each tested scenario and defined according to the cost (positive values and revenues (negative values). The tradespace accessed by each stakeholder, the table of results and a graphical analysis of the design solution selected is presented in the following sections. The tradespace presents the cloud of designs appraised by each stakeholder. These are followed by the *Pareto front* assessment, which selects the best designs in each tradespace and compares the designs in order to select the common one. Then, the table of results displays the Cost and Utility values selected by the common design solution and the utility relaxation by stakeholder. The Cost values are the net present values regarded and the 'reference cost' represents the Cost resulting from the reference scenario, in 2011's prices. The Utility of the Reference Scenario is also displayed in the table of results in order to compare the reference scenario with the one in appraisal. Besides, results also present a k value utility relaxation performed in order to access the compromised design, as well as the utility distance (Δ Utility) to the highest utility design selected in each *Pareto front*, regarding the scenario in study. Finally, there is a display of a graphical analysis given the 40 year (2007-2045) of life cycle analysis of the selected design, valued by stakeholder, called lifecycle histogram (year vs. cost). In order to have a broader view of the design solution, and since there is no defined management model, the stakeholder Manager and the stakeholder Government are merged in order to evaluate the opinion of the stakeholders that most financially invest and support the investment performed.

5.4.1 Reference Scenario

Once the decision variables are all fixed, stakeholders cannot assess different designs according the current scenario. Thus, the tradespace analysis is represented by one single design common to the 9 stakeholders and there is no need to apply a *Pareto front* analysis. The Table 5.11 presents the design solution.

Table 5.11 Reference scenario results

Stakeholders		Cost (10^9 €)	Utility
Induced Demand	HS|RS	0.405	0.597
	Cargo	0.112	0.658
Captured Demand	HS|RS	-7.084	0.493
	Cargo	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	-1.793	0.675
	Rail Operator Cargo	0.588	0.668
	Other Modes	3.058	0.523
Infrastructure Manager	Rail Manager	4.516	0.617
Government		-6.769	0.589

Frequency (#)				Fares			Discount
HS	RS (Pt)	RS (Sp)	Cargo	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)	0
14	6	36	11	0.139	0.083	0.058	

The results demonstrate the will of the stakeholders involved regarding the fixed decision values. All stakeholders have a high utility expectation regarding the solution, since the utility value is always higher than 0.45. The stakeholders who benefit from this scenario are presented by the Captured Demand HS|RS and Cargo, Rail Operator HS|RS and Government. All the other stakeholders have costs related to this scenario. The Induced Demand cost proves that the travel time and the safety/accident benefits, regarding the selected demand are not enough to overcome the high fare selected. The revenue from Captured Demand reflects that the rail fares and the travel time reduction defined can compete with other transport modes. The Rail Operator HS|RS revenues translate that the operation revenues are enough to support passenger operation. On the other hand, the revenues from cargo operation are not enough to support the Rail Operation Cargo costs. The Other Modes present the demand loss from the other transport modes that compete with the future Lisbon-Madrid rail link. The Rail Manager cares about the investment cost. As a consequence, it is difficult that this stakeholder presents benefits, given the huge cost involved with high-speed rail investment. Finally, Government only cares about the safety/accident and externalities, which are always presented as ‘virtual’ benefits related to the use of the Lisbon-Madrid rail line.

The utility result stresses the analysis of the stakeholder preferences, but do not represent the right performance of the stakeholder’s needs. The utility presented is the result of a single utility curves aggregation. The life cycle histogram, Figure 5.1, supports the result and presents the annual cost during the lifespan of the investment (2007-2045) by the stakeholder.

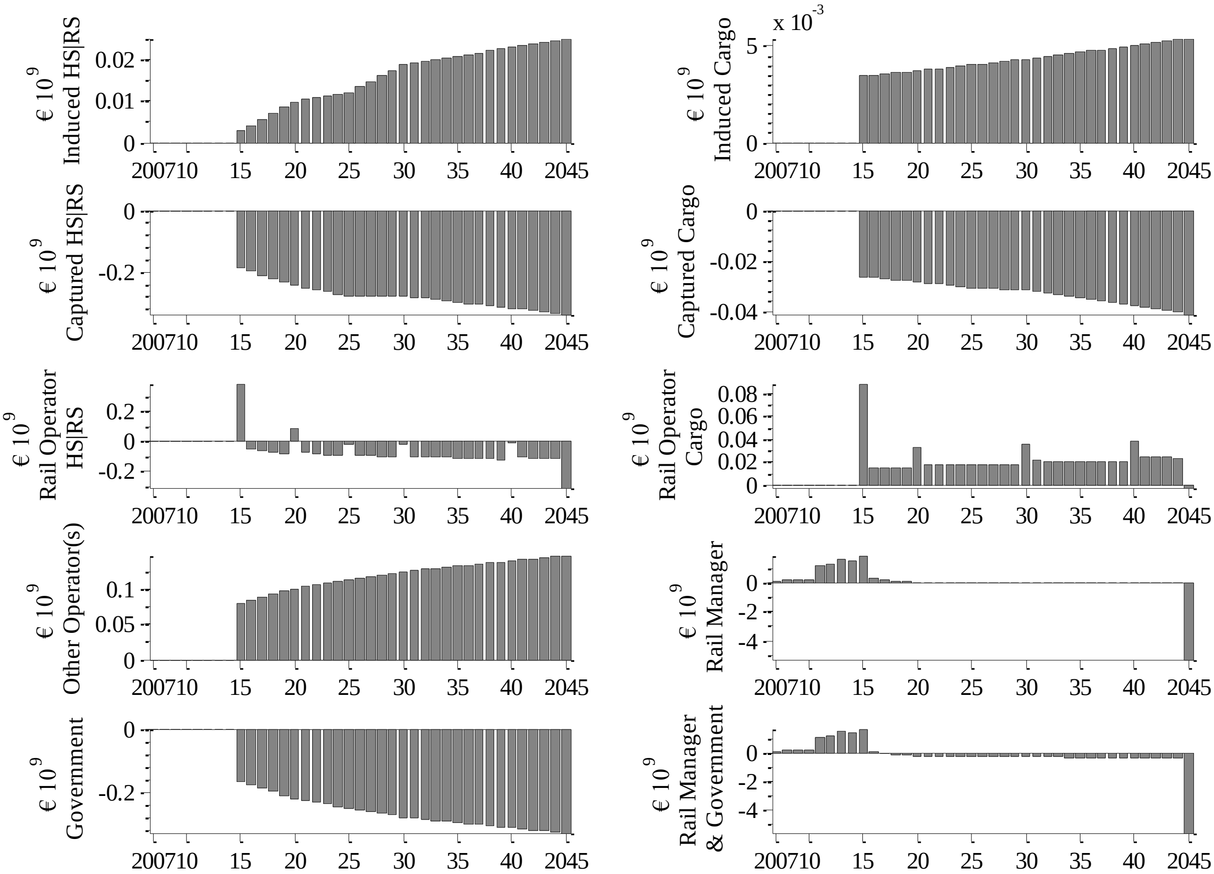

Figure 5.1 Reference scenario life cycle histogram

The life cycle histogram reflects the costs (negative values) and benefits (positive values) of the solution in y-coordinate, evaluated by year. Induced Demand (HS|RS and Cargo) presents a cost solution that grows given the demand increase by year. The Captured Demand shows the revenues (benefits) from the traffic demand captured from the other modes. The Rail Operator (HS|RS and Cargo) shows the investment performed with rolling stock (high bars) during the lifespan, the training costs and the annual operating costs associated to rail operation. At the end (2045) the residual value regarding the rolling stock purchase is displayed. Other Operator(s) present the annual costs related to the loss of demand. The Rail Management displays the initial investment cost (2007-2015), the related annual management cost and at the end of the period (2045) the residual value given the investment performed. Government presents the result of the annual benefits from the externalities and benefits. Finally, the last histogram merges the Rail Manager with Government considerations which translate the analysis between the investment costs and the appraisal benefits of the current scenario.

5.4.2 No Cargo Investment

The combination of all variables, from Table 5.5, result in 147 possible designs, as can be seen in the tradespace in Figure 5.2. The no cargo investment scenario assumes that all passenger demand is served and there is no investment in cargo (rail-road facilities and cargo rolling stock). The model compares the selected frequencies with fares and discounts offers (regarding payment values by the operator).

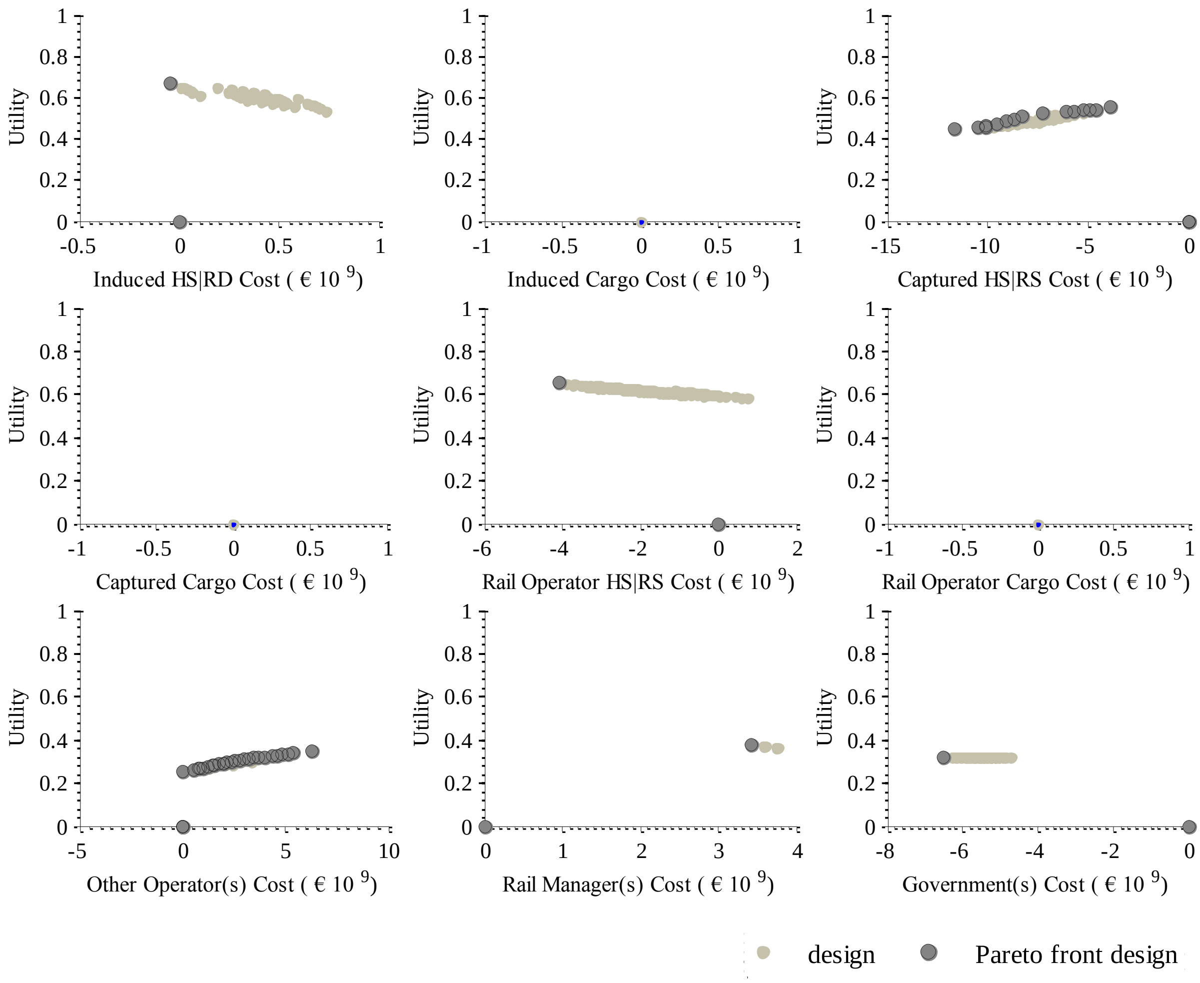

Figure 5.2 No Cargo investment tradespace

The tradespace reflects the antagonist solutions that each stakeholder has regarding the solution in appraisal. Because the cargo variable has not been selected, there is no designs accessed in the tradespaces related to it. Moreover, the different amount *Pareto front* designs selected is related to the number of design variables evaluated by the defined stakeholder, together with the *Pareto front* evaluation performed.

In order to find the compromise design the translation of the *Pareto front* is applied. Given the translation of the *Pareto front*, the compromised design solution presented in Table 5.12 is found. Table 5.12 also presents the design solution costs and utility values and also the loss of utility that each stakeholder expresses regarding the design solution.

Table 5.12 No cargo investment results

Stakeholders		Cost (10^9 €)	Utility	k	Δ Utility	Reference Cost (10^9 €)	Reference Utility
Induced Demand	HS|RS	-0.045	0.667	0%	0.00	0.405	0.597
	Cargo	-	-	-	-	0.112	0.658
Captured Demand	HS|RS	-11.674	0.443	0%	0.11	-7.084	0.493
	Cargo	-	-	-	-	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	0.767	0.579	15%	0.07	-1.793	0.675
	Rail Operator Cargo	-	-	-	-	0.588	0.668
	Other Modes	6.310	0.344	0%	0.00	3.058	0.523
Infrastructure Manager	Rail Manager	3.422	0.379	0%	0.00	4.516	0.617
Government		-6.501	0.316	0%	0.00	-6.769	0.589

Frequency (#)			
HS	RS (Pt)	RS (Sp)	Cargo
14	6	36	-

	Fares		
	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)
	0.0695	0.0415	-
Δ Fare	-50%	-50%	-
Δ Demand	20%	20%	-

Discount
0

The results show that the compromised solution is selected given the loss of utility, in 15% of the stakeholder Rail Operator HS|RS. The Rail Operator HS|RS presents one of the highest utilities, and its *Pareto front* is represented by one single design. The translation of the *Pareto front* is a line that has a much lower degree of sensibility than if the *Pareto front* was presented by an equation. However, the design search looks for the first common design that meets the stakeholder demands. Rail Operator HS|RS loses its income (benefits of 4.061x10^9€) for the sake of meeting a common solution.

The comparison with the reference scenario shows that, for all stakeholders, the utility varies given the existence of cargo investment. That is, the stakeholders effectively change their preferences and ambitions regarding the scenario in analysis. The results also present Cost differences among scenarios. The evaluation of the Lisbon-Madrid rail line without cargo is translated by Induced Demand HS|RS benefits contrarily to what happens in reference scenario. The opposite happens with Rail Operator HS|RS that presents a cost result given the current appraisal. The cost variation among scenarios is the result of the selected decision variables.

The design solution is defined with the support of the decision variables associated to the present scenario. The variables, given the selected design, consider the reduction of the HS and RS fares in -50%, which reflect a demand increase in 20%. The design solution does not select any discount. The fare results translate the user's ambition regarding lower fares and the discount stresses the compromises solution between Rail Manager and Operators.

Figure 5.3 presents the cost amount per year regarding the design solution. The stakeholder Induced HS|RS and Captured HS|RS features negative solutions (cost), which translate passenger benefits regarding the combination of fares, travel time and safety evaluation. The Other Operator(s) also presented negative values (costs). The costs are the result from the loss of passengers demand and fares transferred to the new mean of transport. Rail Operator(s) and Rail Manager(s) display the investment performed during the lifespan together with the routine cost operation, which are not enough to face the investment performed. The end of the life cycle is presented as a residual value benefit. The Government, which only cares about external benefits together with safety issues may be merged with Rail Manager and turn viable the Lisbon-Madrid line investment.

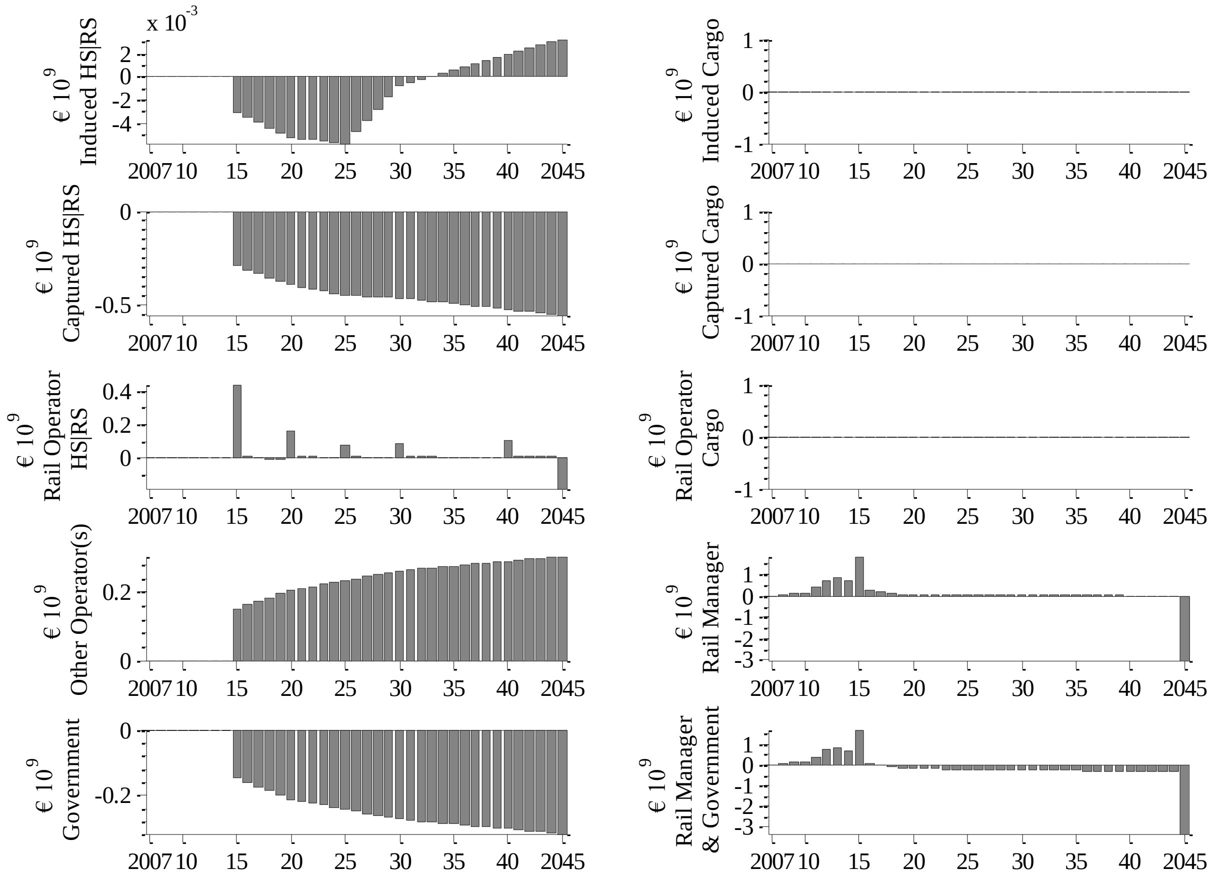

Figure 5.3 No cargo investment life cycle histogram

5.4.3 Cargo Scenario

In cargo scenario a fixed frequency of 11 cargo trains per day is assumed that together with the decision variables selected, resulting in possible designs in 1029, presented in the tradespace, Figure 5.4.

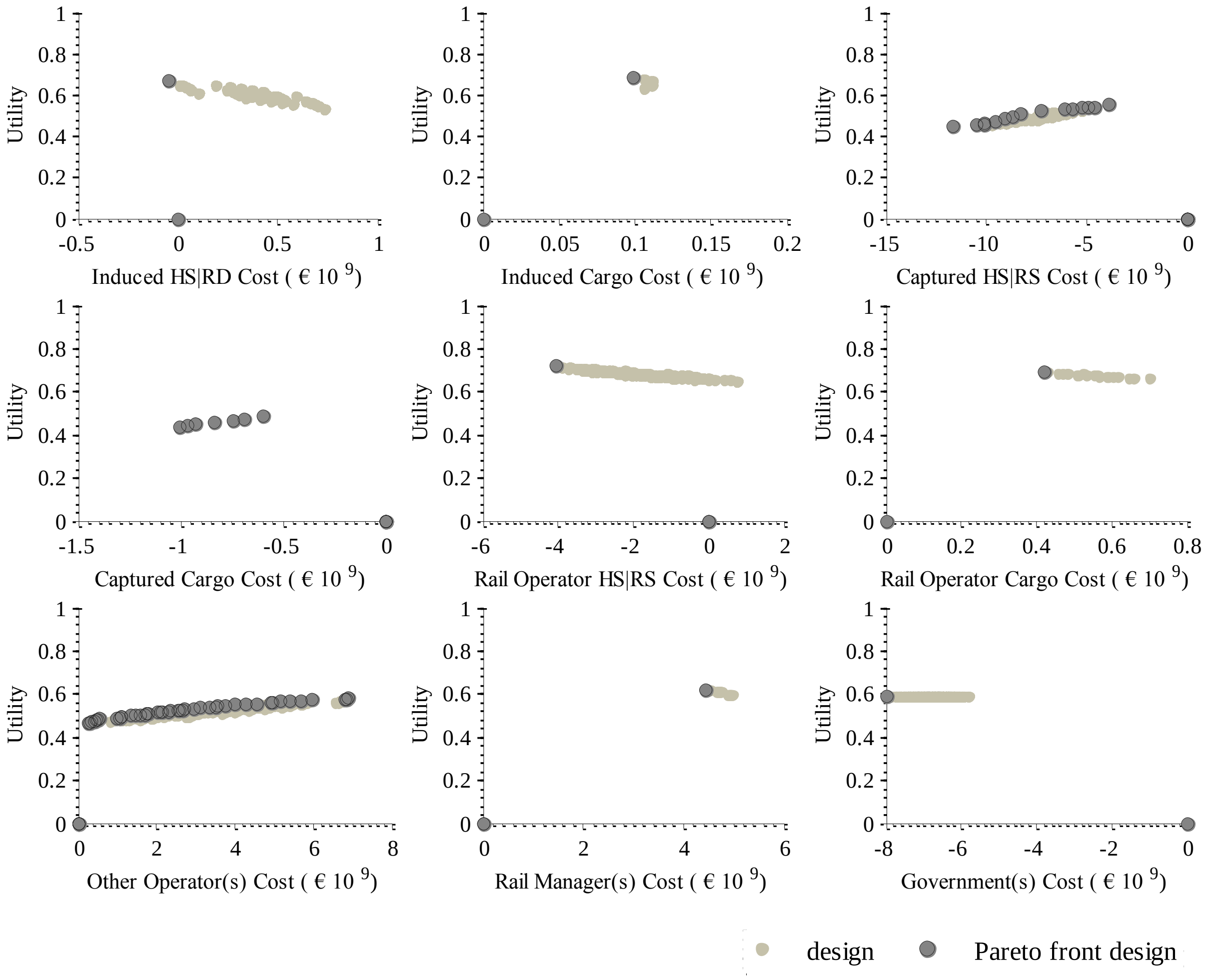

Figure 5.4 Cargo scenario tradespace

The tradespace shows the difference regarding the cargo investment in the Lisbon-Madrid line. Since the tradespace registered more than one possible design solution by stakeholder, the study of the tradespace, is required by a translation of the *Pareto front*. The results of the compromised design solution are presented in Table 5.13.

Table 5.13 Cargo scenario results

Stakeholders		Cost (10^9 €)	Utility	k	Δ Utility	Reference Cost (10^9 €)	Reference Utility
Induced Demand	HS|RS	-0.045	0.667	0%	0.00	0.405	0.597
	Cargo	0.099	0.684	0%	0.00	0.112	0.658
Captured Demand	HS|RS	-11.674	0.443	0%	0.11	-7.084	0.493
	Cargo	-1.005	0.434	0%	0.04	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	0.767	0.644	11%	0.07	-1.793	0.675
	Rail Operator Cargo	0.701	0.657	6%	0.04	0.588	0.668
	Other Modes	6.885	0.578	0%	0.00	3.058	0.523
Infrastructure Manager	Rail Manager	4.533	0.617	0%	0.00	4.516	0.617
Government		-7.981	0.589	0%	0.00	-6.769	0.589

Frequency (#)			
HS	RS (Pt)	RS (Sp)	Cargo
14	6	36	11

	Fares		
	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)
	0.0695	0.0415	0.0495
Δ Fare	-50%	-50%	-15%
Δ Demand	20%	20%	23%

Discount
0

The compromised solution is accessed given the utility relaxation of the Rail Operators. The relaxation presented is not at all out of place as Rail Operators take part on a long list of considerations about the system, not only related to rolling stock investment but also to the routine operation of the line. Moreover, Rail Operators are the intermediaries between Users and Manager, regarding fares (decision variable) in order to find a compromised value that satisfies all the interested ones. According to the present scenario, the compromised selected fare represents a reduction in 50% regarding HS|RS reference fare, and a reduction of cargo fares in 15%. As a result, the demand increases for all modes. The fare selection translates the User's willingness to pay regarding the service. The evaluation does not select any discount value regarding the operation.

The comparison to the reference scenario shows a fare range evaluation (decision variables) regarding the fixed fare by the reference scenario. Induced demand HS|RS and cargo present a higher utility when compared to the reference scenario. This is related to the demand increase stressed in the results. Moreover, the design solution turns the Induced demand HS|RS cost (benefits of $0.045x10^9$€) profitable. Regarding Rail Operator, this scenario reflects a decrease of the utility values and an increase in the assessed costs. Rail Manager and Government presents the same utility selection but the introduction of cargo services and the related investment in both rail-road facilities increase the Costs. The difference in costs are related to the demand appraisal and the selected fare. Given the results, the cargo scenario does not demonstrate the profitability given the introduction of cargo in the Lisbon-Madrid high-speed rail line. The life cycle histogram, Figure 5.5, supports the reflection analysis.

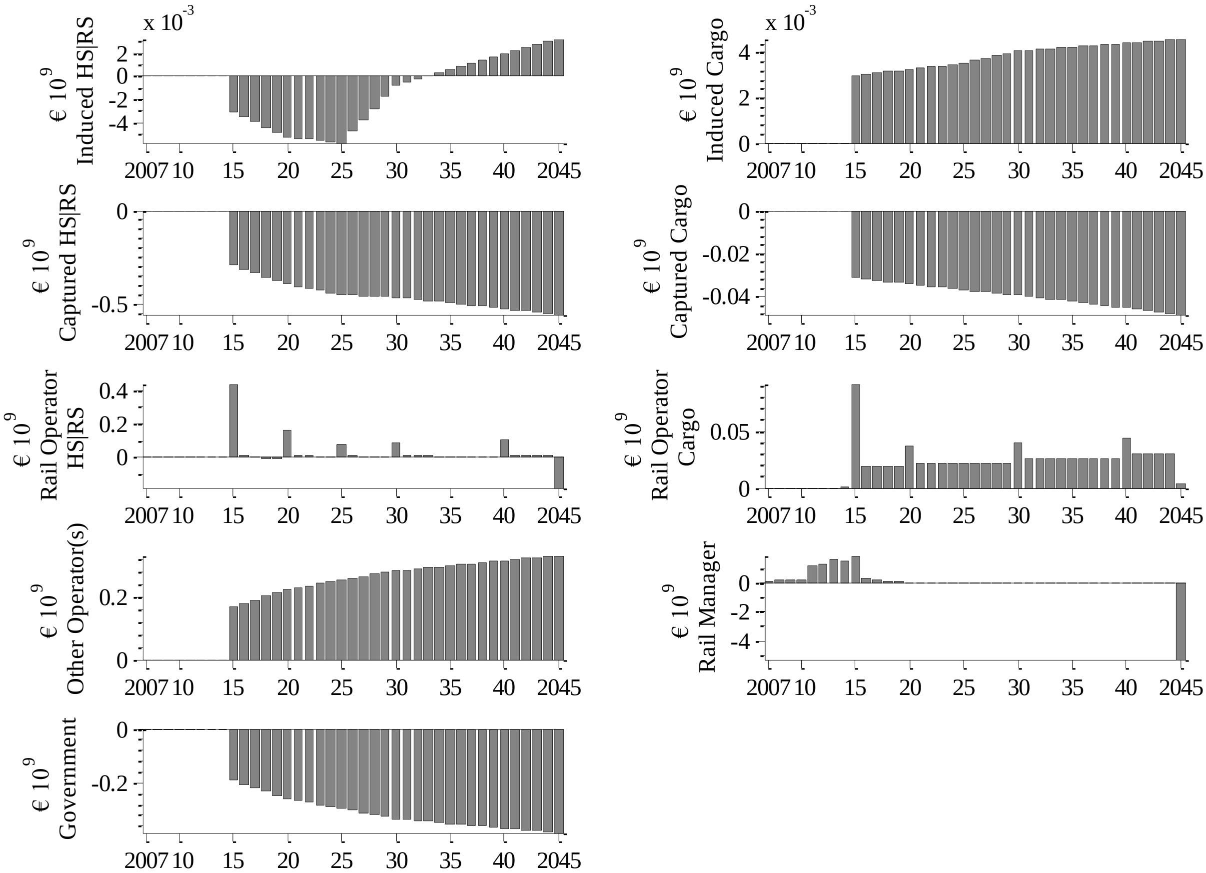

Figure 5.5 Cargo scenario life cycle histogram

The stakeholders that invest in the Lisbon-Madrid line want to have profit given the performed investment. The design solution presents the huge investment costs faced by the Rail Manager – who faces the investment without any Fund or European Investment Bank support. The Rail Manager income is not enough to face all the extra investment performed in cargo facilities and the annual required maintenance. The Rail Manager’s income results from the values charged to the Operators regarding the line in use.

Regarding the stakeholder Rail Operator, the analysis is similar. The revenue from the fares is not enough to cover the rolling stock purchase or to pay for the operation values regarding the use of infrastructure to the Rail Manager and still honor the obligations with staff. No transport operator invests in a service that presents costs since the beginning (and before) of its operation without any break even perspective.

5.4.4 Cargo Frequency Variation Scenario

The scenario evaluates the introduction of a frequency decision variable. The cargo frequencies selected are tested together with the already elicited decision variables. The evaluation results in a tradespace with 2087 designs assessed by the stakeholder, as presented in Figure 5.6.

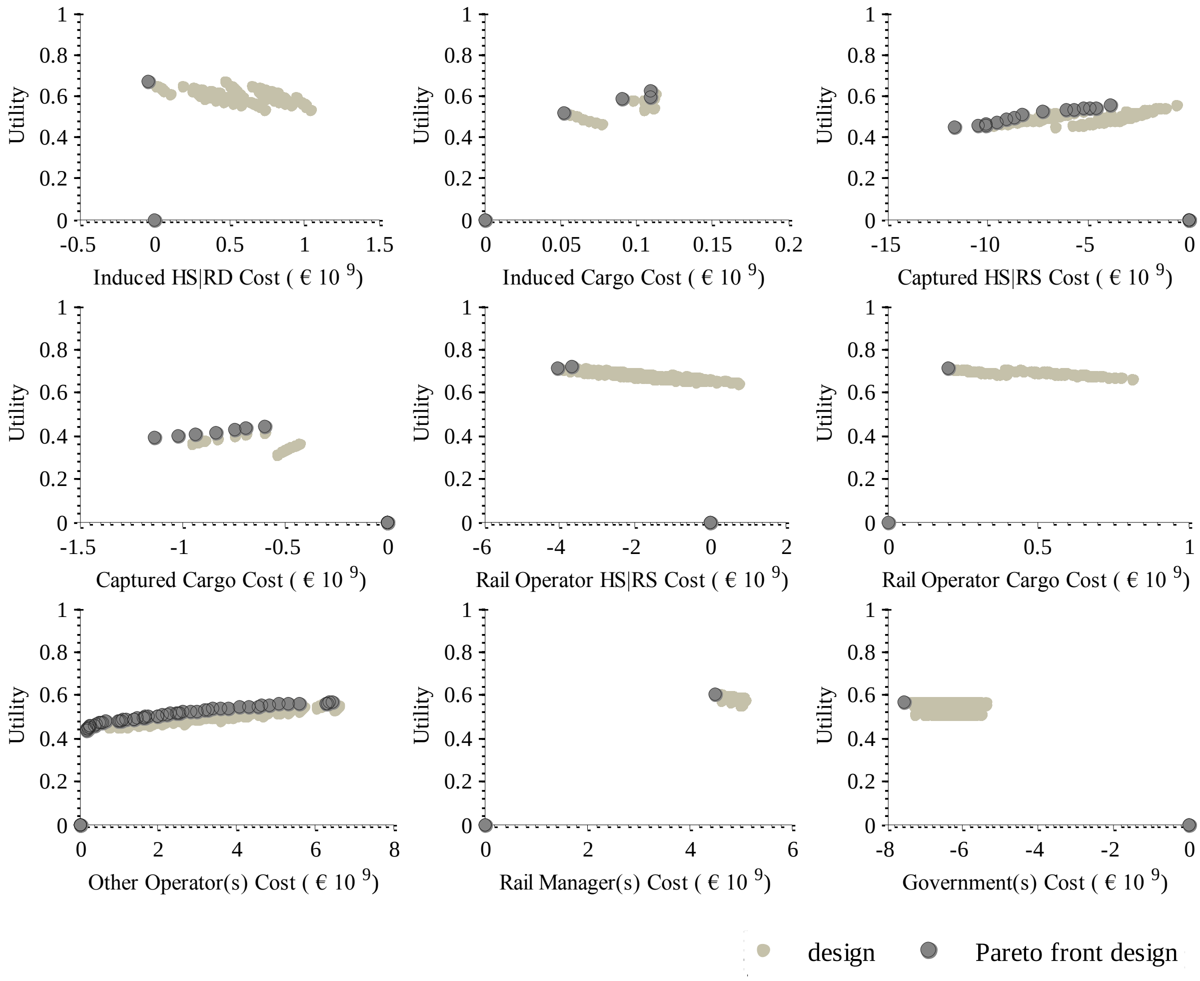

Figure 5.6 Cargo frequency variation tradespace

The *Pareto front* selects the designs with the best Cost-Utility relation. All tradespaces have different design assessment and, as a consequence, different *Pareto front* designs. The Induced Cargo Cost Tradespace is an example of this assessment. The tradespace presents 4 designs in the *Pareto front*. Two of them have similar costs but different utility, as compared to the neighborhood and have been selected as the best ones. Given the proximity, the representation is not as defined as the *Pareto front*s from the other tradespaces. The relaxation of the *Pareto front* results in a common solution represented in Table 5.14.

Table 5.14 Cargo frequency variation results

Stakeholders		Cost (10^9 €)	Utility	k	Δ Utility	Reference Cost (10^9 €)	Reference Utility
Induced Demand	HS|RS	0.475	0.667	0%	0.00	0.405	0.597
	Cargo	0.109	0.624	0%	-0.02	0.112	0.658
Captured Demand	HS|RS	-6.631	0.443	0%	0.08	-7.084	0.493
	Cargo	-1.135	0.392	0%	0.00	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	0.708	0.643	14%	0.10	-1.793	0.675
	Rail Operator Cargo	0.816	0.664	7%	0.05	0.588	0.668
	Other Modes	6.443	0.568	0%	-0.01	3.058	0.523
Infrastructure Manager	Rail Manager	4.619	0.605	0%	0.00	4.516	0.617
Government		-7.579	0.565	0%	0.00	-6.769	0.589

Frequency (#)			
HS	RS (Pt)	RS (Sp)	Cargo
14	6	36	14

	Fares		
	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)
	0.0695	0.0415	0.0495
Δ Fare	-50%	-50%	-15%
Δ Demand	20%	20%	23%

Discount
0

The results stress the introduction of the variable cargo frequency in the analysis. The model had to appraise all the possible designs regarding the defined frequency range. The compromised solution is assessed given the utility relaxation of the Rail Operators. Rail Operator HS|RS has to relax 14% and Rail Operator Cargo needs to relax 7%. Again, Transport Services Operators are the ones that have to relax their attributes' assessment in order to find the compromising solution. The relaxation is also related to the Fares' evaluation. This means that the selected preferable fare is the lowest evaluated within all modes. As a result, there is an increase of the demand values evaluated. The design solution also points to the selection of a different cargo frequency – 14 cargo trains per day. However, even with the losses pointed out by results the decision variable Discount (discount offered by the manager to the rail operator) is not accessed.

The comparison between cargo frequency variation scenario and the reference scenario underline differences regarding the cost and the utilities selected. The major ones are related to Transport Service Operators and to Rail Manager. Given the increase of cargo frequencies, the utility relaxation translates the huge net present costs (2011 prices) of the stakeholder Rail Operator HS|RS given the solution design. Likewise, Rail Operator Cargo also increases Cost as a result of the purchase of additional rolling stock, staff and maintenance operations associated to the increasing number of trains. Other Modes evidence, once again, the demand transference between modes. Finally the stakeholder Government presents the gains (negative costs) related to the increase in rail demand.

The design solution still does not invite the investment by the possible Rail Manager or Rail Operators since the result only stresses the huge costs faced with the performed investment. The life cycle histogram illustrates, in Figure 5.7, the annual evaluation of the selected design.

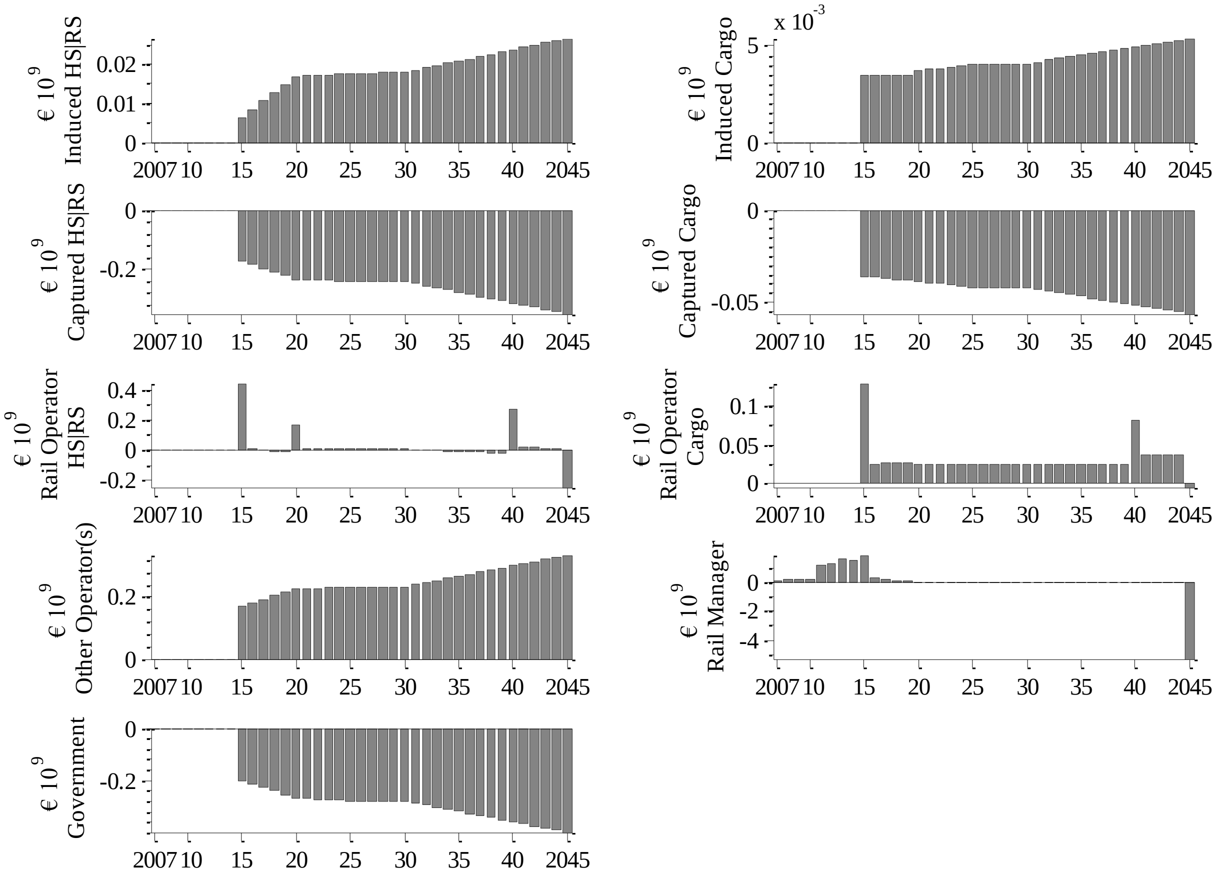

Figure 5.7 Cargo frequency variation life cycle histogram

The Induced and Captured demand present different revenues given the willingness to pay for the trip and the mode transference selected. Rail Operators, in the beginning of operations, need to purchase rolling stock and provide the staff with instructions, as illustrated. Then, during half of the lifespan, the revenues are enough for Rail Operators HS|RS to overcome costs, but the necessity to buy more or new rolling stock change the financial balance

The lifespan analysis of the Rail Operator HS|RS show that excluding the cost related to the acquisition of new rolling stock, the revenues are enough to support the annual cost related to the passenger's operation. On the other hand, the revenues from Rail Operator Cargo are too low to support the cargo operation in the line, regarding the present scenario. Rail Manager histogram reflects its huge front costs and the low management cost. In the end of the time the residual value benefit related to the line and cargo facilities is demonstrated. Finally, the graph from the stakeholder Government returns the overall benefits (negative costs) of the line operation.

5.4.5 Attribute Scenario

Given the changes performed in the stakeholder's appraisal, the tradespace comprised 21 possible designs assessed by stakeholder, as presented in Figure 5.8.

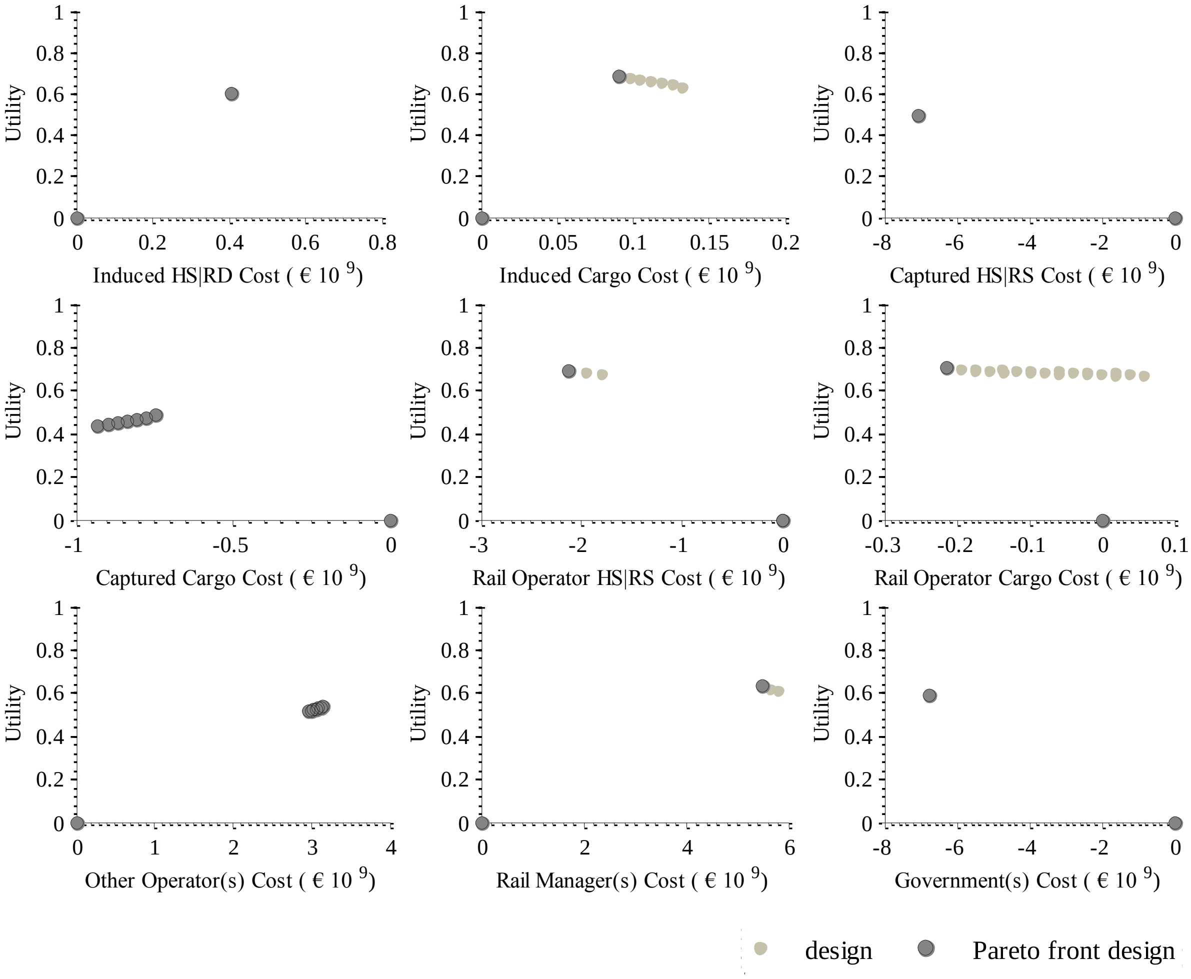

Figure 5.8 Attribute scenario tradespace

The compromised solution stresses the utility relaxation by the stakeholder, as shown in Table 5.15.

Table 5.15 Attribute scenario results

Stakeholders		Cost (10^9 €)	Utility	k	Δ Utility	Reference Cost (10^9 €)	Reference Utility
Induced Demand	HS|RS	0.405	0.597	0%	0.00	0.405	0.597
	Cargo	0.091	0.684	0%	0.00	0.112	0.658
Captured Demand	HS|RS	-7.084	0.493	0%	0.00	-7.084	0.493
	Cargo	-0.930	0.434	0%	0.00	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	-2.121	0.689	2%	0.00	-1.793	0.675
	Rail Operator Cargo	0.017	0.680	4%	-0.02	0.588	0.668
	Other Modes	3.151	0.534	0%	0.00	3.058	0.523
Infrastructure Manager	Rail Manager	5.800	0.610	4%	0.02	4.516	0.617
Government		-6.769	0.589	0%	0.00	-6.769	0.589

Frequency (#)			
HS	RS (Pt)	RS (Sp)	Cargo
14	6	36	11

	Fares		
	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)
	0.139	0.083	0.0495
Δ Fare	0%	0%	-15%
Δ Demand	0%	0%	23%

Discount
-20%

The design solution is selected given the relaxation of the Rail Operators together with Rail Manager. The relaxation achieved by this three stakeholders is minimal and reflects the changes made in the cargo attribute evaluation. The Rail Operator HS|RS, as well as the Government, has a positive value cost against the choices made. The design solution also points to the discount of 20% offered by the manager to the rail operator, and the selection of the lowest cargo fare variable (0.0495 €/tkm). The lowest fare choice is related to Demand Cargo ambitions in relation to their willingness to pay for the service. That is, the Demand Cargo ambition is to minimize the fare for a given trip.

The comparison to reference scenario shows similarities regarding induced and captured cost and utility values. Rail Operator HS|RS presents higher revenues and Rail Operator Cargo presents lower costs, given the similar utility values. Other Modes also show comparable cost and utility values with the reference scenario. Regarding Rail Manager, it has a higher cost given the annual management increment caused by the over-maintenance costs and discounts offered.

The lifespan evaluation is translated by the life cycle histogram presented in Figure 5.9.

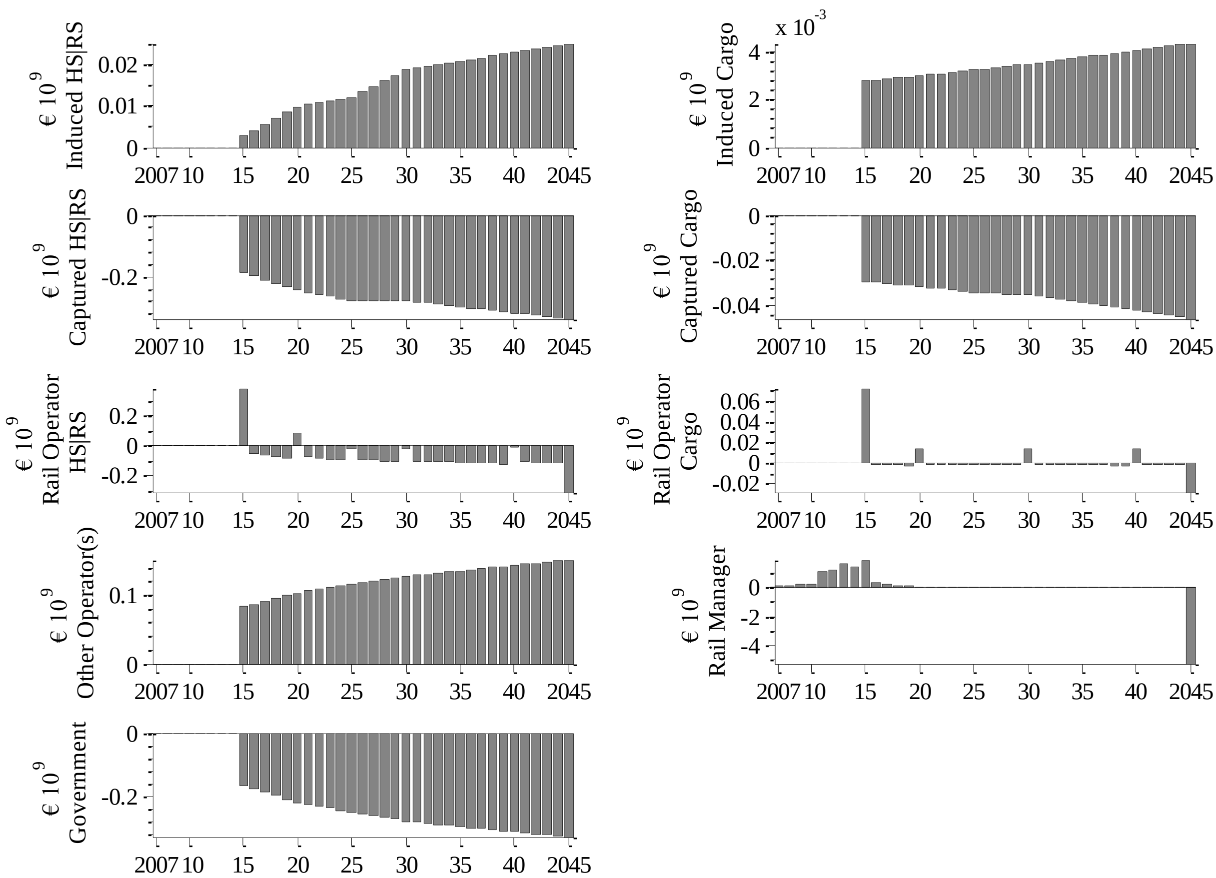

Figure 5.9 Attribute scenario histogram

The histogram scenario presents an improved possibility of investing in the operation of Lisbon-Madrid rail line, given the Rail Manager support. Demand graphs relates demand issues to fares and travel time benefits. Rail Operator HS|RS shows that the investment to perform is mainly in the beginning of operation (2015) and then the revenues are enough to support the operation, decreasing given the necessity to buy rolling stock. The same happens to Rail Operator Cargo. However, the revenues are lower and the value is associated to rolling stock increase. The rolling stock residual value is illustrated in the end of Rail Operators time line (2045).

5.4.6 Operation Fees Scenario

The operation fees scenario evaluate 21 possible designs presented in the tradespace, Figure 5.10.

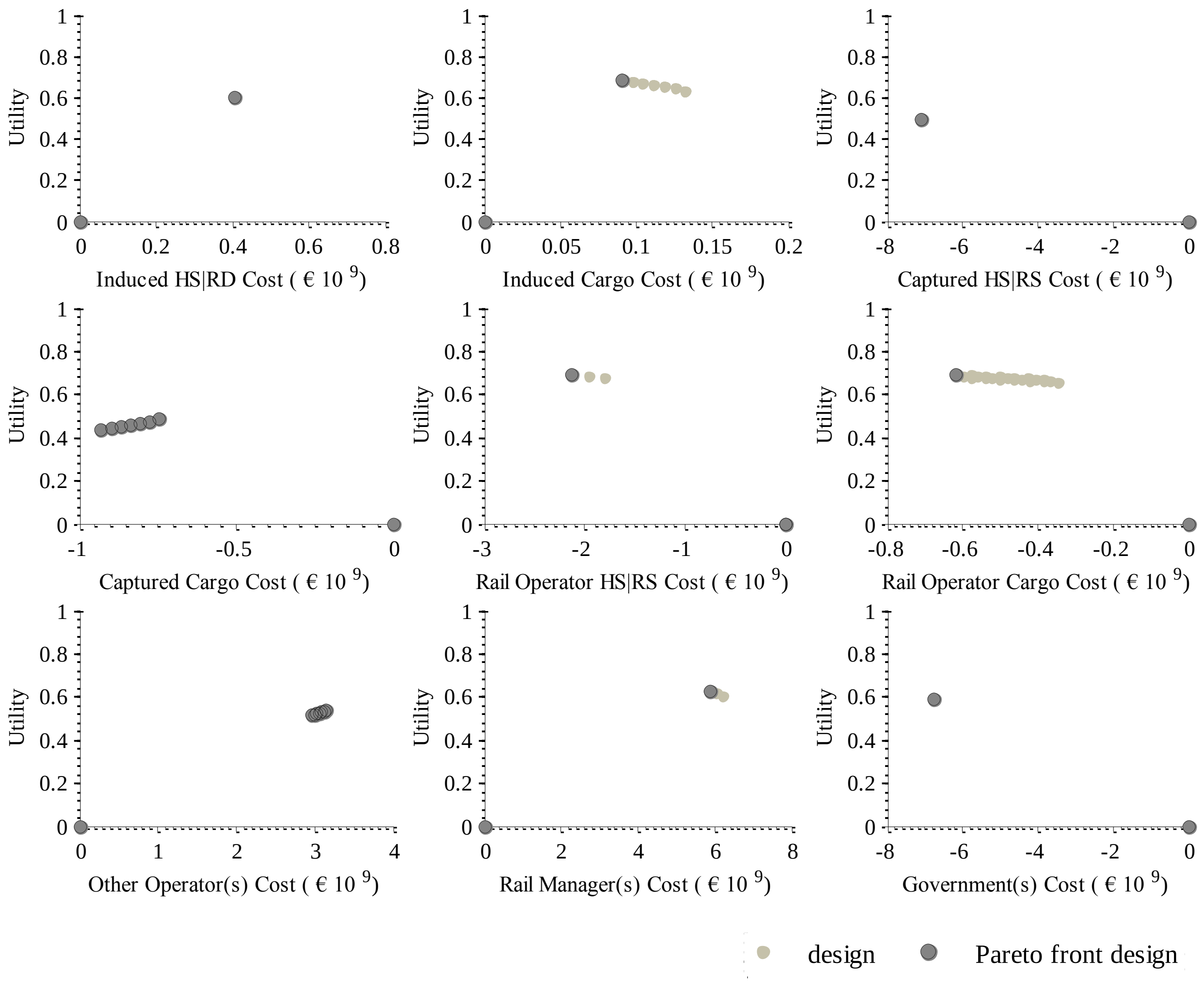

Figure 5.10 Operation fee scenario tradespace

The relaxation of the *Pareto front* is performed in order to evaluate if there is a compromised design that satisfy the ambitions of all stakeholders present in the appraisal. Given the initial assumptions, it is not possible to find any common design that correspond to the changing of the attribute preferences concerning the operation fees. That is, there is no understanding between stakeholders. The comparison to the reference scenario is not a feasible option, due to the changes made in the attribute's elicitation.

5.4.7 Investment Funds Scenario

The combination of the decision variables results in a tradespace with 21 designs per stakeholder and presented in Figure 5.11.

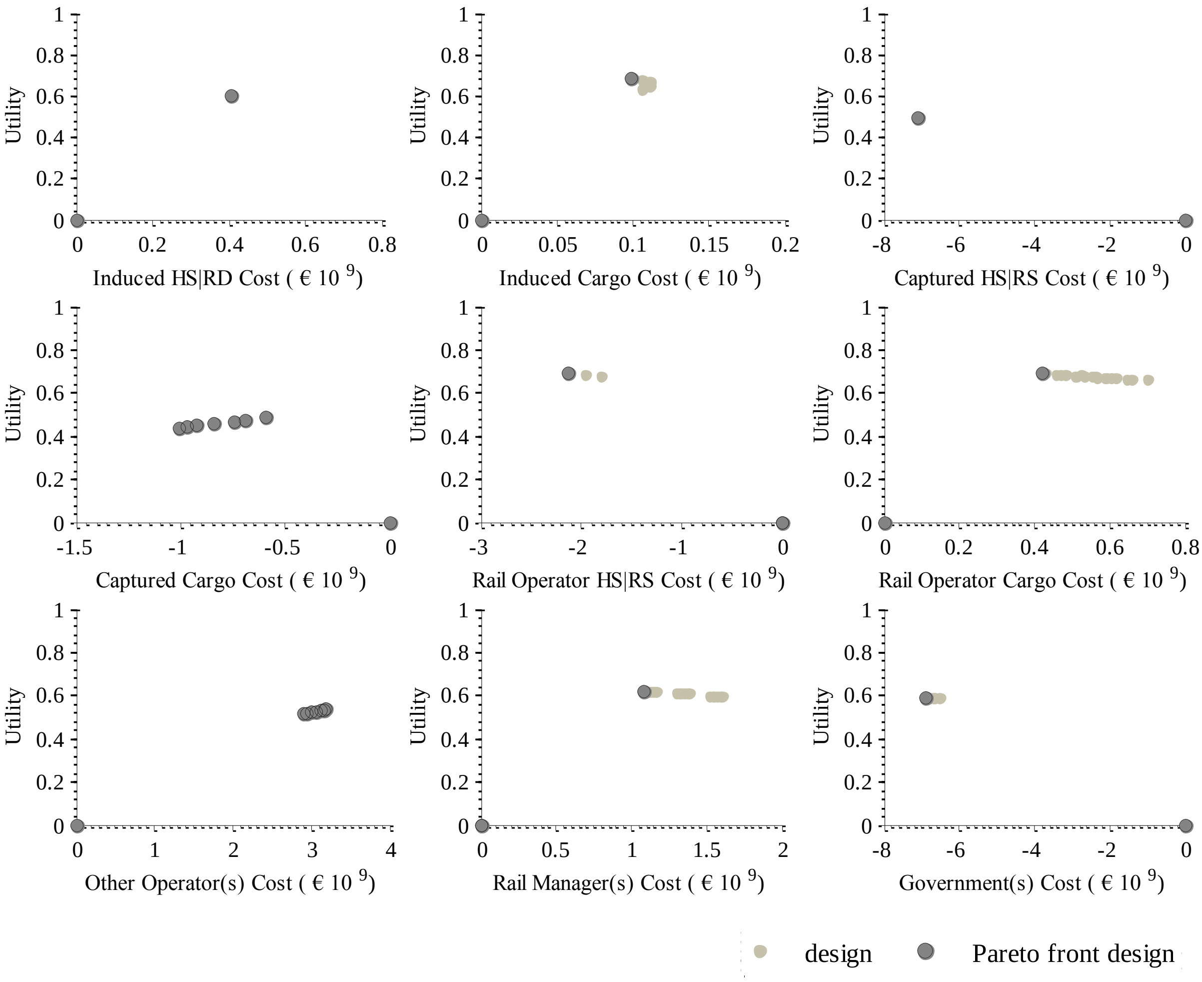

Figure 5.11 Investment funds tradespace

At the first sight there are no relevant tradespace chances. The *Pareto front* evaluation relates the designs among tradespaces in order to find the compromised solution presented in Table 5.16.

Table 5.16 Investment funds results

Stakeholders		Cost (10^9 €)	Utility	k	Δ Utility	Reference Cost (10^9 €)	Reference Utility
Induced Demand	HS|RS	0.405	0.597	0%	0.00	0.405	0.597
	Cargo	0.099	0.684	0%	0.00	0.112	0.658
Captured Demand	HS|RS	-7.084	0.493	0%	0.00	-7.084	0.493
	Cargo	-1.005	0.434	1%	0.00	-0.837	0.458
Transport Service Operators	Rail Operator HS|RS	-2.121	0.687	1%	0.00	-1.793	0.675
	Rail Operator Cargo	0.595	0.671	4%	0.02	0.588	0.668
	Other Modes	3.189	0.534	0%	0.00	3.058	0.523
Infrastructure Manager	Rail Manager	1.605	0.597	4%	0.02	4.516	0.617
Government		-6.897	0.589	0%	0.00	-6.769	0.589

Frequency (#)			
HS	RS (Pt)	RS (Sp)	Cargo
14	6	36	11

	Fares		
	HS (€/pkm)	RS (€/pkm)	Cargo (€/tkm)
	0.1390	0.0830	0.0495
Δ Fare	-	-	-15%
Δ Demand	-	-	23%

Discount
-20%

The compromised design is only selected given the utility relaxation of both Rail Operators, together with Captured Demand Cargo and Rail Manager. The common solution is selected given the 4% utility relaxation of Rail Operator Cargo and Rail Manager and 1% utility relaxation of Rail Operator HS|RS and Captured Demand Cargo. The compromised design also selected the lowest cargo fare evaluated – 15% less regarding the reference scenario, with an increase of 23% regarding cargo demand values and the assumption of a discount of 20% relating to operation taxes. The comparison to the reference scenario allows to verify that only the Rail Manager faces the most significant cost difference, supported by the loans. The investment fund offered is reflected in the cost differences presented by the Rail Operators.

The life cycle histogram supports the analysis of the selected design, as presented in Figure 5.12. The present design solution reflects a scenario closer to the preconized by RAVE for the Lisbon-Madrid high-speed rail line without cargo. That is, Rail Operator HS|RS costs are positive and supported by the passenger fare selected. The costs are mainly related to the initial costs in order to start the operation – rolling stock and staff, and fulfil rolling-stock necessities during the operation life cycle. The Rail Manager, given the investment fund loan, reduced its front costs and the operation revenues became enough to support the line management actions. Moreover, if the Rail Manager costs are merged with the benefits resulting from the Government externalities, the merge is translated into a profitable rail line due to the investment opportunity. Nevertheless, the cargo operations still face costs, even with the discount offered by the manager to the rail operator, which translates the lack of the operation profitability.

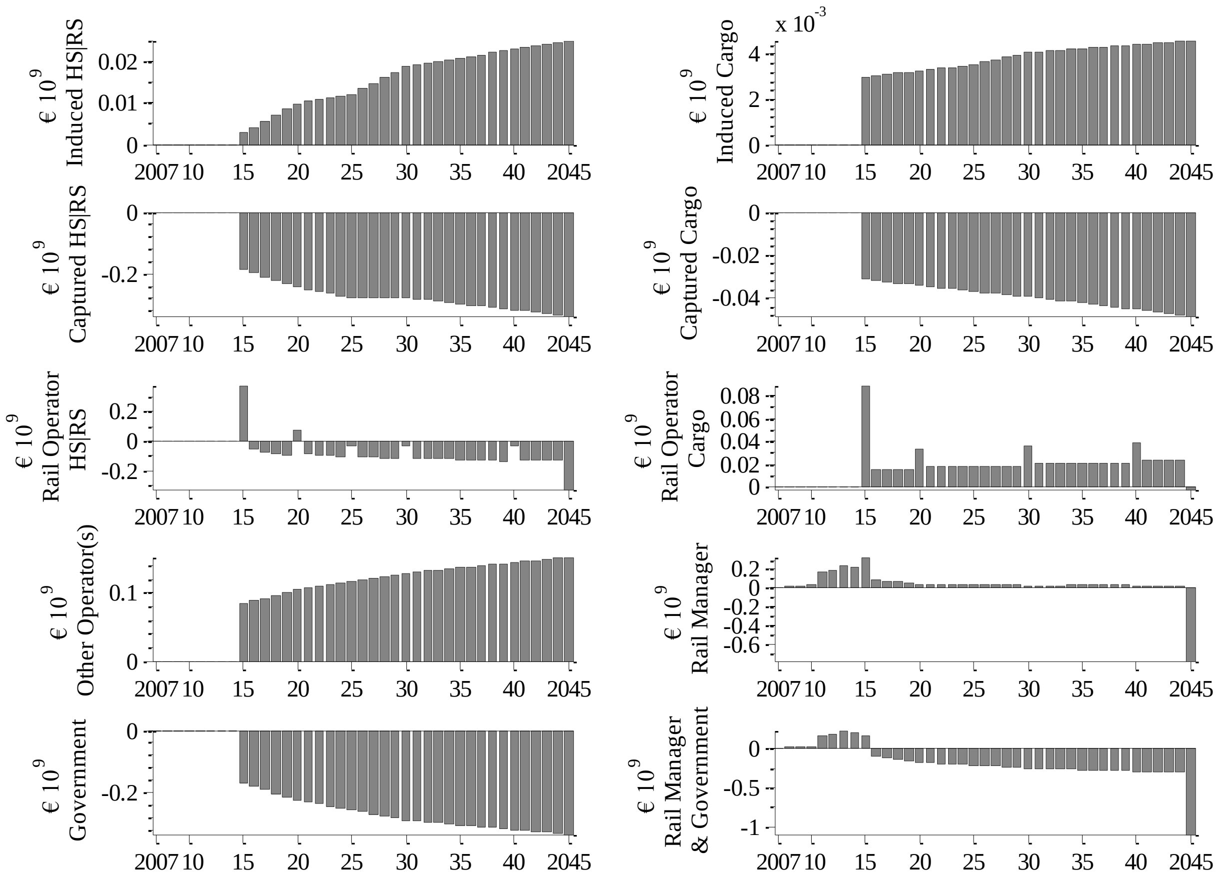

Figure 5.12 Investment funds life cycle histogram

Given the present scenario, it is possible to reflect on the result, given the fares fixation. The design comparison is demonstrated in Table 5.17.

Table 5.17 Analysis of the investment fund fares

Stakeholders		Cost (10^9 €) *fix. fares*	Utility *fix. fares*	Cost (10^9 €)	Utility
Induced Demand	HS|RS	0.405	0.597	0.405	0.597
	Cargo	0.112	0.658	0.099	0.684
Captured Demand	HS|RS	-7.084	0.493	-7.084	0.493
	Cargo	-0.837	0.458	-1.005	0.434
	Rail Operator HS|RS	-1.793	0.675	-2.121	0.687

Stakeholders		Cost (10^9 €) *fix. fares*	Utility *fix. fares*	Cost (10^9 €)	Utility
Transport Service Operators	Rail Operator Cargo	0.588	0.668	0.595	0.671
	Other Modes	3.058	0.523	3.189	0.534
Infrastructure Manager	Rail Manager	-2.647	0.618	1.605	0.597
Government		-6.769	0.589	-6.897	0.589

Table 5.17 displays the comparison between a fixed design assessment (fix fare) and a design with multiple decision variables. In order to find a common design, the scenario needs to relax the overall utility (regarding the fixed fares solution). The losses are undertaken by the Rail Manager that, given the choice of a lower fare, does not get enough revenues to face the line assets. However, given the fare increases, the Rail Manager sees the net present cost (in 2011 prices) to be turned into a revenue (negative cost). Nevertheless, even with the increase of cargo fares, it is not enough to turn the operation profitable. The net present cost of the Operator Cargo remains negative. The related life cycle histogram is presented in Figure 5.13

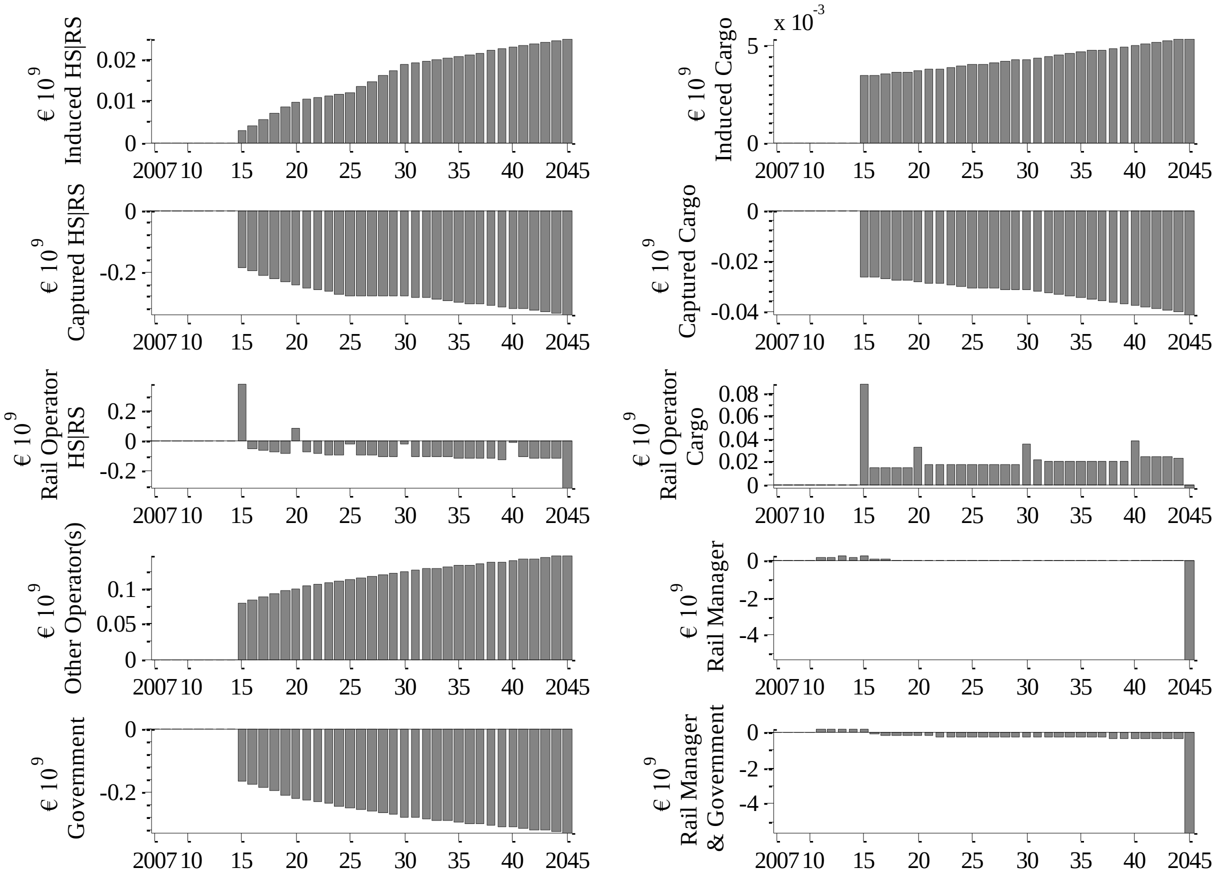

Figure 5.13 Investment funds life cycle histogram

5.5 Conclusions

The reason to use the MATE method adapted to complex transport systems is its ability to deal with project evaluation considering preferences and motivations considering each interest group (Ross, 2003). This chapter presents the MATE-T performance in order to evaluate the introduction of cargo in the Lisbon-Madrid high-speed rail line. Different scenarios are tested and evaluated regarding a selection set of decision variables. The variables assess the frequencies (based on RAVE demand studies), the fare variation, the discount applied to the fees paid by the operator to the rail manager (in order to turn the operation more attractiveness to operators) and also the assessment based on the rate of return on the investment. The appraised scenarios can be described as follows:

- Analysis of a reference scenario with fixed decision variables (frequencies, rates, operation discount and rate of return) considering the investment performed in the rail-road platforms,
- Analysis of the scenario considering the high-speed rail line without cargo investment, that is, rail-road facilities;
- Analysis of the extra investment performed, line update and rail-road facilities investment in the Lisbon-Madrid high-speed rail line;
- Analysis of the scenario considering the variation of the cargo service frequencies;
- Analysis of the attribute scenario that changes the stakeholder’s attribute assessment;
- Analysis of the line investment considering the support of investment funds.

The presented results are the product of the following ‘starting’ conditions:

- The data in the assessment is based on the studies performed by RAVE for the line investment and also for cargo and passenger demand;
- The data assessed were modeled and adapted given the considerations set out in Chapter 4;
- The uncertainty about the business and operation model led to the consideration of four different stakeholder groups: Operation HS|RS, Operation Cargo, Rail Manager and Government.
- Two rail-road facilities, one in Portugal and one in Spain were considered to support the cargo investment in the Lisbon-Madrid line. Even though, there is information about the feasibility of the introduction of cargo in the Lisbon-Madrid line, which can never be load or unload in the defined passenger stations, such as Oriente (Lisbon) or Atocha (Madrid). Thus, the considered rail-road facilities do not follow any business model.
- The investment costs and the costs related to operation and management are mainly supported by the Rail Manager and Operators, as confirmed by the costs of these stakeholders in the results. This also relates with the undefined business model stressed by the data accessed and the model defined for the present case study.

The different scenarios considered should be seen as a test performed to the investment options and to the operations considered, since they appraise the solution given different perspectives and interests. The method proves to be very sensitive to the evaluation performed by each stakeholder to its attribute group (weight) and how the utility curves are modeled. Different attributes, weights or utility curves cause the rise of different solution scopes which can be difficult to compare. The change of attributes, weights or utility curves cause the rise of different solution scopes which can be difficult to compare. Thus, it is essential to have a robust database to support the dynamic interaction with the selected stakeholders, in order to assess the significance of interest and attributes selected. An example is the stakeholder ‘Other Modes’, included in the analysis to assess the demand losses in other modes of transport.

The solutions show that the costs associated to cargo introduction are mainly reflected in the Rail Manager and Cargo Operator. The Rail Manager manages the line and rail-road investment, leaving to the Cargo Operator the rolling stock charges and the operating costs both on line and rail-road facilities. Given the different scenarios presented, the last one is the one that closely reflects the aspired investment. The scenario focus on the financial support related to the line construction (and the estimated investment for the rail-road facilities), considering the European Economic Community support, as example. This financial support is essential for the Rail Manager income based on the selected solution (negative cost, at 2011 prices). The scenario considers that the Rail Manager’s unique interest in the investment performed and the investment return. The benefits of the investment represented by the externalities of the solution (i.e. environmental impact) are the main concerns of the stakeholder Government. The merge of these two stakeholders can be an advantage for the assessment. However, it is mandatory to define the scope of action of each one. On the other hand, the Operator Cargo has a low profitability since it has to care about costs related to rolling stock acquisition and the operation costs of the rail-road platforms. As a result, this restricts the choice of cargo operations by any rail operator who intends to compete with other modes of transport.

Therefore, several other scenarios can be implemented in this case study such as a more specific analysis of the rates applied, especially in rail-road platforms and the development of different business models for lone operation and intermodal platforms. Despite the results, the introduction of cargo in the Lisbon-Madrid high-speed rail line should be seen as a complementary and strategic operation option with other operators (road, sea, etc.) which can benefit from a more integrated business model.

Finally, from the MATE-T application the following inferences and recommendations can be underlined:

- The MATE-T major advantage against other cost-benefit methodologies is the concern of different stakeholder perspectives in a single analysis. The analysis tries to model the stakeholder’s concerns about the project and its business model, allowing the inclusion of interests that are not only monetarily quantifiable, producing a set of solutions that enable a more balanced investment decision, given all related stakeholders.

- The MATE-T code should be improved to accomplish mode decision variables according to the selected stakeholders, in order to turn the analysis more effective. That is, the increasing number of the decision variables is easily reflected in a calculation time longer than one week precluding analysis of the solution, as with traditional methods.
- A routine calculation to define the optimal solution should be developed by a calculation tool that encompasses the growing number of stakeholders with different *Pareto front* assessments and different utility relaxation measures by stakeholder. The process is presently carried out by a simple evaluation and there was no generated robust code for this purpose.

Given all this, cargo investment in the Lisbon-Madrid high-speed rail line is feasible and the Cargo Operation, even with the costs stressed in the appraised scenarios, could be a strategic investment that cargo companies might not want to lose. Nevertheless, rail cargo operations investment is seen as a front line action in the rail revitalization. With an adequate operating investing and a strategic business plan, the Lisbon-Madrid high-speed cargo line can promote the modal shift in favor of rail. This fulfils the TEN-T ambition by improving the interoperability of the rail network and helping many transport enterprises to use the rail infrastructure as a support of their daily activities.

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6 CONCLUSIONS

This thesis addresses a model to support strategic decisions of significant investments in the transportation field. The model allows the prediction of the impacts of a project in order to assess the feasibility of the technical decisions and to support intermediate and final decision-makers through the process of investment evaluation. The range of transportation projects is very diverse and a widespread of points of view and consequences should be evaluated. Projects might involve different transportation facilities, control systems, services and fares. Similarly, projects can be designed and evaluated from the perspective of the community that is being served or from the perspective of the operators of the service and the facilities. The model proposes a support tool applied to the future Lisbon-Madrid high-speed rail line especially with respect to the introduction of cargo in this type of line.

The materialization of the thesis is spread throughout the chapters and in this sense a reminder is necessary considering the subjects approached and treated. Chapter 1 presents the main objectives related to the introduction of cargo in the Lisbon-Madrid high-speed rail line. This decision could support a better modal distribution, both for passenger and cargo, changing the present hegemony of roads in the Iberian Peninsula, mainly on the Portuguese side. In addition, the Lisbon-Madrid link is connected to major freight routes, which are integrated and interoperated in the Trans-European network and could support the mobility increase and competitiveness of the ports, airports and logistic systems and consequently act as the backbone of transport services.

Chapter 2 describes the development of several high-speed rail systems around the world together with the usual appraisal methodology of the investment. This chapter also presents the different approaches performed by different countries that selected the railway system and the high-speed technology as an investment option. Traditional appraisal methods such as cost-benefit analysis or multi-criteria analysis are addressed.

Chapter 3 presents the study methodology. The presented methodology deals with the multiple and conflicting objectives given the support of multi-criteria decision-making methods and is based on Multi-attribute

Tradespace Exploration method (MATE) developed by SEAri-MIT. A description is made for a specific application of MATE in a case of complex transport systems in order to support decision-making in transport investments, called MATE-T. The method is applied to the future Lisbon-Madrid high-speed rail line in order to evaluate the line investment and the suitability for carrying goods in the daily operations, using the free slots left by the passenger services. The strength of this method is its capacity to evaluate the interests of a range of stakeholders and find an optimal solution that best fits the overall interests given the support of a *Pareto front* applied to the resulting tradespaces.

Chapter 4 renders an overview of the Lisbon-Madrid high-speed line project that was suspended due to the economic crisis. The use of the high-speed rail shortens cargo service travel times and the use of the European gauge network offers the possibility for longer trips. The research is held by several studies that state that the Lisbon –Madrid passenger demand expected is not enough to support all the investment cost. Therefore, the investment in cargo-rail services can provide a critical link in the national intermodal freight transport system, serving not only trucking and maritime shipping industries, but also supporting the Portuguese intermodal trade and global competitiveness.

Chapter 5 is a display of the results from MATE-T application. As stated, the work done addresses the feasibility of the introduction of cargo on the operation of this line, assessing the costs throughout different phases, in order to contribute to a more conscientious decision-making process. The analysis stresses the model's effort to solve the problem for different considered scenarios and find the best solution considering all stakeholders' expectations and concerns, given the decision variables selected. There are reasons to state that cargo operation, supported by a structured business model could be a viable option in order to support the investment's profitability. Moreover, the results also present the investment performed in two rail-road facilities to support cargo operation, which are seen as a cargo strategic investment. This chapter presents the main inferences and it is possible to say that the main objectives of the thesis were achieved once it became possible to define an evaluation system, MATE-T, to treat the feasibility of the investment in complex transport infrastructures by the analysis of the Lisbon-Madrid high-speed rail connection case, taking the passenger and cargo operations into consideration as well as all the impacts on the several potential stakeholders (government, infrastructure manager, operator, other transport modes operators and society).

The main contribution of the work relies on the demonstration of the strengths of MATE-T against other cost-benefit methodologies, specially the possibility to add other stakeholders or attributes or even define different decision variables for a given case study and the capacity to select an optimal solution given the range of stakeholders involved. The analysis tries to model the stakeholder's concerns about the project and its business model, allowing the inclusion of interests that are not only monetarily quantifiable, producing a set of solutions that will enable a more balanced investment decision, given all stakeholders related. Besides, it is also possible to update the tool regarding different decision variables or considering different stakeholders or attributes which turn the evaluation more or less restrictive. However, it should be underlined that an increasing number of decision variables are easily reflected in the calculation time making it longer than one week precluding analysis of the solution, as with traditional methods.

The following steps should enhance the possibility to carry on the analysis considering different economic or financial appraisals (as the impact of adding cargo directly from the seaport of Sines, or evaluate the airport connection to the system) or allowing different subsidization models. The use of the methodology on other environments in the field of transport systems should also be considered, due to its ability to identify the key indicators of interest for modeling more detailed project evaluations.

In addition, it is important to define a more robust procedure to determine the optimal solution such as a calculation tool that encompasses the growing number of stakeholders with different *Pareto Front* assessments and different utility relaxation measures by stakeholder.

The applicability of MATE-T is not restricted to the case treated within this research. With the right stakeholders characterization and consideration, and the proper analysis scenarios it is possible to apply MATE-T to other transport solutions, such as airport suitability, bus rapid transit (BRT) solution or even the analysis of a metro light rail system. A first insight about MATE-T applied to the Coimbra metro light rail system has been already designed in order to evaluate the feasibility of the studied branches. Thus, MATE-T application can be a real option to hold investment decisions since it is supported by reliable information and stakeholders with viable decision variables.

Finally, it is believed that the present thesis offers an important contribution to transportation planners and transportation authorities, as well as political entities in the decision making process destined to deal with huge investments in the transportation system.

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