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GOODS TRAFFIC ON HIGH SPEED RAILWAY LINE BETWEEN LISBON AND MADRID

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Abstract Evaluation of different alternatives within the same transport mode is necessary for the identification of the "best" or most "preferable" means. Evaluation of alternative modes is necessary while looking for a "preferable" transport option in markets, where competition and complementarities may take place.

Keywords High Speed Rail, Conventional Rail, Portugal, MATE

1. INTRODUCTION

Mobility of persons and goods is an essential component for the competiveness of European services. Mobility is also an essential citizen's right. The goal of the European Union's sustainable transport policy is to ensure that our transport systems meet society's economical, social and environmental needs, as highlighted by the mid-term review of the 2001 White Paper (EC, 2001).

Investing in high speed rail is a central planning decision. The national government decides on the introduction of a new rail technology which will allow trains running at a average speed of 300-350 kilometers per hour (though the average commercial speed is substantially below the maximum technical feasible speed). At the beginning of 2008, there were about 10000 kilometers of new high speed lines in operation around the world and in total (including upgraded conventional tracks), more than 20000 kilometers of worldwide rail networks that were devoted to providing high speed services. (Rus, 2008)

In the past decades, the planning and development of transport systems had become a very complex task. In particular, dealing with diverse and conflicting technical, technological, operational, socio-economical and environmental objectives – widening the range of possible solutions and involving numerous participants in the decision-making process (Janic, 2003) (Guiliano, 1985) (Haimes, 1985) (Speling, 1984). Some of the very complex transport projects with respect to decision-making have been the high-speed transport systems in Europe. These systems are represented by the high speed rail. The decision- making process in this system has been complex for various reasons:

- High speed transport systems have been expected to both compete and collaborate with each other, particularly in high-density transports market-corridors, taking into consideration, their integration in the Trans-European Transport Networks (TENs) (EC, 1998a) (EC,1998b);
- High speed transport systems have been expected to significantly affect the micro- and macro-spatial, socio-economical and political development of a particular region across Europe;
- High speed transport systems have particularly been expected to enhance future globalization, internalization and integration of regional and national economies and societies;
- High speed transport systems have been identified as promising options for a further sustainable development of the European transport sector in terms of an increase in safety and security and reduction of air pollution, noise and land-use on the one hand and support for a growing transport demand on the other.

The Trans-European Network (TEN-T) plays a crucial role in securing the free movement of passengers and goods in the European Union.

Different methodologies may be applied to evaluate alternatives, in order to have the most properly answer regarding the complexity of this means of transport. High speed systems operated with different transport modes. Such an evaluation may be carried out for existing (operating) and non-existing (planned) alternatives.

The main objective of this paper is to discuss some characteristics of a methodology applied to the study of the line Lisbon-Madrid to deliver freight on a high speed rail system.

The main scope of this study began with the following questions: is it feasible for the sea port of Sines to perform the role of an important sea port hub for the Iberian Peninsula? Is it reasonable to introduce traffic merchandise on high speed rail lines in technical and economical terms? This analysis will be done, in first approach, by the use of MATE (Multi-Attribute Tradespace Exploration) analysis to a simplistic formulation of the problem. The analysis is intended to be expanded within the PhD work that will be done in the next two years using more and better information about all of the features and organizations involved.

The structure of this paper is as follows: Chapter 2 provides a brief overview of high speed rail in Europe. Chapter 3 provides an overview of selected case study for mixed use high speed rail in Portugal. Chapter 4 introduces the concept of MATE and its applicability in this case study. Chapter 5 summarizes the preliminary insights and suggests future work. Chapter 6 lists references from the main text.

2. HIGH SPEED RAIL IN EUROPE

High speed rail is currently regarded as one of the most significant technologies in transportation development in the second half of the 20th century.

Railway technology is particularly popular in the European Union. High speed rail projects of the European member's countries are financially supported by the European Commission. "Revitalizing the Railways" (EC, 2001) is the new motto in European Transport policy. Both introducing competitive railway industry and giving priority to public investment in the rail network (Rus, 2008). The 7th Research Framework Programme, covering the from 2007 to 2013, is an opportunity for the European Union to match its research policy to its ambitions in terms of economical and social policy by consolidating the European Research Area. In order to achieve this objective, the Commission hopes to increase the European Union's annual spending on research, thereby generating more national and private investment in this field. The Cooperation Programme aims at stimulating cooperation and improving links between industry and research within a transnational framework. The aim is for Europe to gain and consolidate leadership in key research areas. The program will have nine themes, which are to be managed autonomously, but will be complementary in terms of implementation. One of them is related to rail transport. (EU, 2007)

Investing in high speed rail is one of the front line actions to revitalize the railways. The ultimate objective is to change modal split in passenger transport, with the aim of reducing congestion, accidents and environmental externalities.

High speed rail trains require high speed infrastructures, meaning that new dedicated tracks need to be built at a cost substantially higher than the conventional rail line. Infrastructure maintenance cost is similar to the conventional rail line, however, the building cost and the acquisition operation and maintenance cost of specific rolling stock make this transport alternative an expensive option.

The profitability of the high speed rail is very sensitive to the full price that is incurred when there is a need to choose between different alternatives. Before high speed rail is introduced, various options have to be looked at, such as road viability and air transport which are clearly chosen in viability to distance. This mode of transport competes with air and road transport within some very specific distances and it is also considered as a substitute to feeder air services and to main hub airports (Banister & Givoni, 2006). High speed rail investment competes with car in distances up to 300 kilometers and with air in the range of 300-600 kilometers. These distances are coarse references as the particular conditions of accessibility (access and egress time, parking conditions, security control, etc.) are frequently more easily determined than the travel time itself.

The construction of a safe, modern and integrated railway network is one of European Union's major priorities. Economical integration and rapid growth in trade have transformed the European Union needs.

In order to service this integrated market, railways must become more competitive and offer high-quality and door-to-door services without being restricted to national borders. All in all, at the end of the 1980's emerged the idea of Trans-European Networks (TEN), in connection with the proposed integrated single market. Figure 1 shows the European ambitions with regard to shortening travel times inside Europe. The introduction of high speed rail services results in spatial and socio-economical impacts. This figure shows the European rail network and train travel time in 1993, 2010 and 2020, after the implementation of the high speed network.

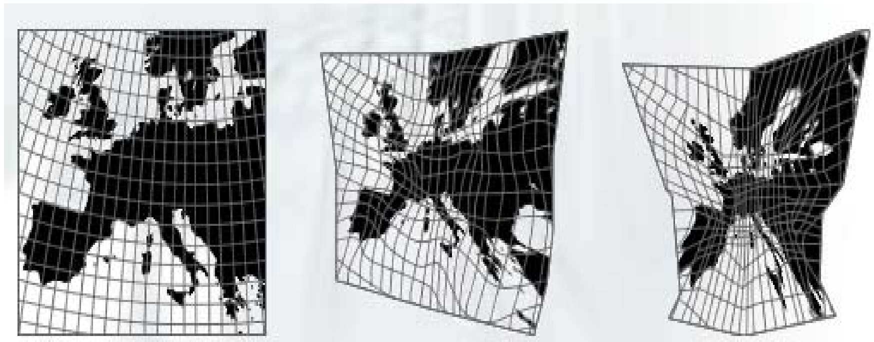

Figure 1 - Trans-European Network (Vickerman, 1997)

European policymakers believed that it made little sense to talk about an integrated market, with freedom of movement of goods, people and services, without providing transportation, energy and telecommunications networks that linked the regions making up that market. Furthermore, they believed that construction of these networks would help economic growth and employment (EC, TEN-T Network, 2009).

The TEN-Transportation (TEN-T) guidelines included a list of 30 priority projects which were declared to be of European interest. In these projects are included all means of transport and it is expected to decrease the average “distance” between European Capitals, which calls for a wider high-speed network. The main goal is to improve cohesion competitiveness and market with freedom of movements for goods, people and services but also relieving congestion of the main European axis.

Nowadays there are high speed rail services in more than 15 countries (figure 2), and the network is still growing at a very fast pace in many more: it is expected to reach 25000 kilometers of new lines by 2020 (UIC, 2005a).

Figure 2 - HSR Network 2020 (UIC)

2.1. HSR definition

The rail industry considers "high speed" just a technical concept related to the maximum speed that could be reached by trains running on a particular track segment. The European Council Directive 96/48 specifically established that the high speed infrastructure comprised three different types of lines:

- Specially built high speed lines equipped for speeds generally equal to or greater than 250km/h;
- Specially upgraded conventional lines, equipped for speeds in the order of 200km/h;

- Specially upgraded conventional lines, which have special features as a result of topographical, relief or town-planning constraints, in which the speed must be adapted to each case (less than 200km/h).

However, speed has not always been the best indicator for the characterization of a high speed system, since commercial speed in many services is often limited due to urban areas or topographical constraints.

Although high speed rail share the same basic engineering principles as conventional railways – both are based on the fact that rail provides a very smooth and hard surface in which the wheels of the train may roll with a minimum of friction and energy consumption – they have also technical differences. For example, from the operational point of view, their signaling systems are completely different: whereas traffic on conventional tracks is still controlled by external (electronic) signals together with automated signaling systems, the communication between a running HSR train and the different blocks of tracks is usually fully in cab-integrated, which removes the need for drivers to see lineside signals (Campos, Rus, & Barrón, 2007).

2.2. Freight in Europe

The lack of quality assurance for freight services, particularly for international services involving several railway undertakings on the same route, has a negative impact on the attractiveness of rail transport. This includes poor interoperability, lack of mutual recognition of rolling stock and products, weak coordination of infrastructure and interconnection of systems, and the problem of single wagon loads (EC, Transport, 2007).

According to the European Commission, these problems explain why rail market share has been steadily declining. In effect, between 1995 and 2005, rail freight increased slower than average transport growth. It was even slightly lower than freight development in inland waterways.

According to the Commission, this aversion to rail transport is due above all, to reliability and quality problems. Significant progress has been made in recent years in generally revitalizing the railways. Many of the obstacles in the way of an integrated European railway area have been gradually removed, for instance, the high-speed networks of Thalys and Eurostar, or the creation of corridors for freight services, such as the one between Rotterdam and Genoa (Eurostat, 2007).

However, European railways still face considerable challenges if they are to maintain their current share of total traffic volume (passengers and freight), and increase in medium term. The opening of rail freight markets, based either on community legislation or national initiatives, has resulted in increased market entry in recent years, although on a very modest scale. However, in the area of rail passenger transport the opening up of the market is still far from reality. In the long term, competition should force an improvement in quality, but the actual process of opening up the European rail freight market is too slow.

The mixed high-speed models, not only for passengers, but also for freight, allow a more intensive usage of high speed rail infrastructure. Since trains of significantly different speeds cause massive decreases in line capacity, mixed-traffic lines are usually reserved for high speed passengers during the daytime, while freight trains run at night.

3. HSR IN PORTUGAL

Portugal, following the steps of other European countries, will begin the construction of a new high speed line. To implement this project the Portuguese government empowered RAVE (Rede Ferroviária de Alta Velocidade, S.A.) with the development, coordination of project and studies necessary for the planning, construction, financing, provision and operation of a high speed rail line in Portugal as well as the feasibility of a connection to the Spanish line in standard gauge (critical to integrate Portugal with the rest of Europe).

The development of a high speed rail is viewed as a structural element for country development that will contribute to country homogenization, country image and rail sector modernization. The high speed rail reverses the long term decline in rail transportation with a new product that is commercially profitable for average distance. The main purpose is to reduce travel time, increase reliability and comfort.

Until now freight is not a target revenue segment for HSR, it has been seen as a secondary strategy. Portugal wants to change this vision, and implement freight deliver on the Lisbon-Madrid line.

The rail infrastructure in Portugal (figure 3), nowadays needs some improvements and rehabilitation. In this way it will be possible to improve a modern, sustainable and efficient means of transport, increase mobility and increment the competitiveness of its sea port, airports and logistical system. With this huge investment it will be possible to contribute to a better distribution both for freight and passengers, changing the current supremacy of roads. This new high speed line will also improve the internal connection and will represent the main bone of the Portuguese transport system. The new transport system will work together with the existing conventional line and roads, the principal sea and land ports and also with the national airports.

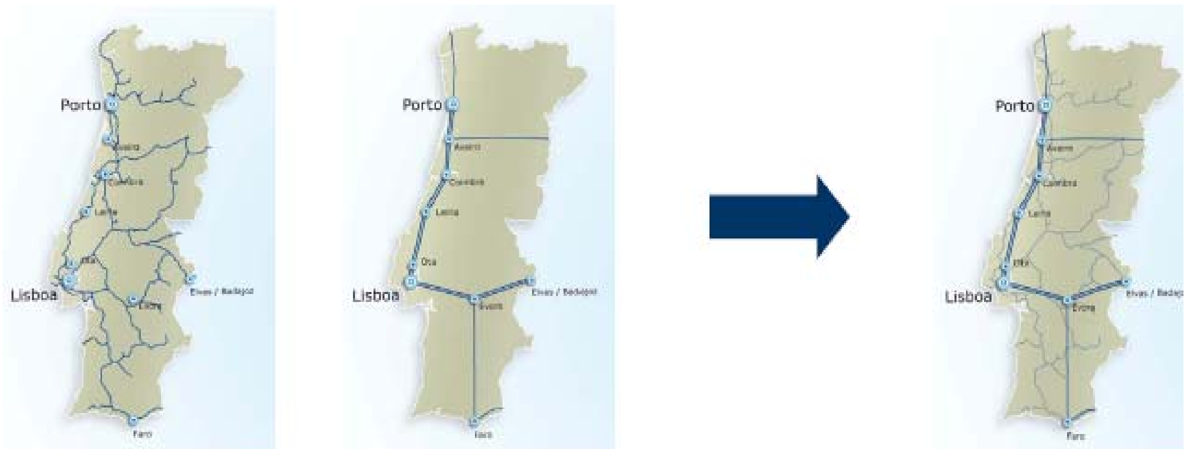

Figure 3 - Portuguese Network over time (RAVE, 2008)

The scope of this study is centered on the line between Lisbon and Madrid with the possible connection to the sea port of Sines (figure 4), and the introduction of freight to the same passenger line.

Figure 4 - Lisbon-Madrid connection (Portuguese side) (adapted RAVE,2008)

3.1. Investment plan

As it has happened in several rail infrastructures in Europe, the railway project investment is high and the operating cash flow is not sufficient to cover the investment cost. RAVE, the entity that is responsible for the project has the mission to manage the financial operation.

The business model established (MOPTC, 2009) is based on public-private partnership (PPP), 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;
- Minimize overall funding cost;
- Maximize the amount of debt financing;
- Ensure good quality of service.

3.2. Lisbon-Madrid Connection

The objective of the high speed line between Lisbon and Madrid is to have a travel time of 2h45m for direct connections between the two capitals and improve the connection between Évora and Lisbon to 30 minutes. To achieve this objective, the 34 kilometers between Lisbon and Poceirão will be covered in less than 10 minutes. The extension of the project will be 640km, 203 of which will be in Portuguese territory. The travel speed will between 120 – 350 km/h, regarding the use of this line not only for passengers but also for freight.

The lifecycle investment will be made over a period of 40 years and will include: the project, construction, financing, maintenance and provision of all rail infrastructures.

4. CASE STUDY ANALYSIS

4.1. Multi-Attribute Tradespace Exploration Applicability

The motivation for this research began with the discovery of the MATE (Multi-Attribute Tradespace Exploration) method and its applicability in the development process for products.

The MATE method has been selected for the purpose of identifying the preferable options for high speed study. This method classifies the options into a ranking and allow for the establishment of a trade-off between a countable number of criteria. Thus, fully ranking the current alternatives, this has been an approach absent in traditional rank-based methods.

The MATE process itself can be described (Ross, Hastings, 2005) as a process with the following steps:

- Need identification;
- Architecture-level exploration and evaluation;
- Design-level exploration and evaluation;

The goal of the method (figure 5) is to create a system that fulfils some need while efficiently utilizing resources within some context. The context surrounds the entire endeavor, including the roles of participants and their domain influence. The Stakeholder role includes influence over the definition and evaluation of the needs. The Funder role includes influence over the allocation of the resources. The Decision Maker role acts as the gatekeeper of needs and resources, determining whether to pursue a system development effort. The Design role includes influence over the definition of the system, while efficiently utilizing resources and fulfilling needs, as determined by the Decision Maker (Ross, 2006).

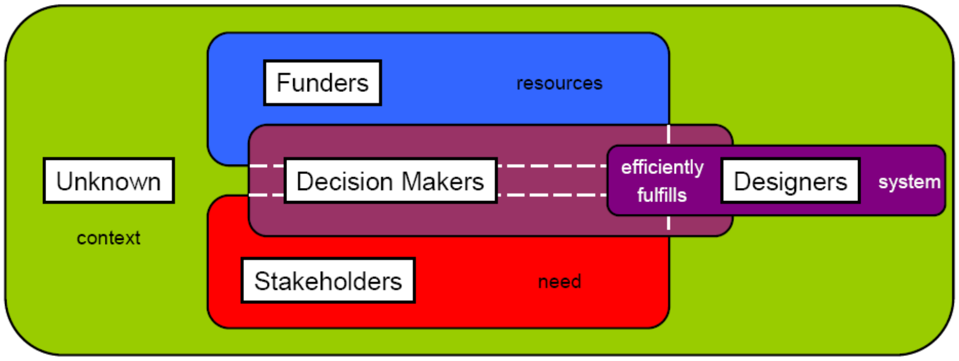

Figure 5 - The goal of design (Ross, 2006)

4.2. Stakeholders

According to Sussman (2000) stakeholders are organizations and individuals that may not be users of transportation, explicit suppliers of service or goods to transportation organizations, but vitally concerned with transportation enterprises and their operating and investment practice. Another assumption according to the same author is that the general public is in a very real sense, a stakeholder in the transportations enterprise. There is a relationship between transportation and economic development and quality of life – all interests are of great interest to the general public. So, to a greater or less extent, everybody is a stakeholder in transportation.

In Europe various interest groups may be involved in decision-making related to the development and implementation of a high speed transport system. In general, these may be users (passengers), system operators, the public, semi-public and private investors, policy makers at local (regional), national (country) and international (European) level and local community members. All these groups may hold different preferences and different objectives with the respect to the performance of particular high speed systems. Investors in transport infrastructure (public, semi-private and private), and manufacturers of rolling stock; guidance and control systems; facilities and equipment; may expect higher and faster returns on investment. Further, policy-makers at different levels may expect a contribution to global improvement in the efficiency of the transport sector and the economy in general, whereas community members may expect local socio-economic benefits nearby their homes; such as new jobs and improved spatial accessibility in the region where they live in.

In this case study the stakeholders chosen were the most important decision-makers, the ones that have a direct or a strong indirect influence over the allocation of resources for the project during the lifecycle time. Portugal and Spain, the countries that will split and use the infrastructure, the European Union and Private Investors are the ones that will provide the economic and financial support, where the stakeholders are chosen. In order to simplify the analysis, the stakeholders' decision will be different for passengers and for freight analysis (investment, operation, schedules, load types, etc.).

4.3. Attributes

In order to model this project it is necessary to have resources. These resources are the concerns, expectations and objectives that stakeholders have regarding the project. They must be explicitly determined through interactions with decision makers.

Each decision-maker has a set of objectives. In this case study, a metric for meeting objectives will be called attributes. An attribute (Ross, 2003) is a decision maker-perceived metric that measures how well a decision maker-defined objective is met. According to the same author, the characteristic of an attribute includes its definition, units and range from least to most acceptable values.

Due to the fact that this is a transportation study, decision-makers have a massive list of objectives, multiple objectives, and therefore a set of attributes. Keeney & Raiffa (1993) defined the attribute set as a complete, operational, decomposable, non-redundant, minimal, perceived and independent.

An example set of attributes from the high speed rail study are in table 1.

Table 1 - Attributes

Attributes	**Definition**	**Range**	**Units**
Total Project Cost[1]	Total cost of the engineering, planning, infrastructure, construction, stations, border connection and vehicles from Lisbon/Sines – Madrid.	$[8\text{-}30]*10^6$	€
Portuguese Cost Share	Share of project cost that Portugal has to allow.	[40-100]	%
EU Cost Share	Share of project cost that the EU will provide to this link	[5-50]	%
Spain Cost Share	Share of costs related to the border connection provided by Spain.	[30-35]	%
Private Investor Contribution	Contribution given by the private investors to this project. The financial support will be shared with some private investors.	[45-70]	%
Maintenance Cost [2]	Maintenance cost per kilometer	$[30\text{-}35]*10^3$	€/km

[1] The construction cost of a new high speed rail line are marked by the challenge to overcome the technical problems which avoid reaching speeds above 300 km per hour, such as roadway level crossing, frequent stops or sharp curves, new signal mechanisms and more power electrification systems. Building new HSR infrastructure involves three major types of costs: planning and land costs, infrastructure building and superstructure costs (UIC, 2005)

Operation Cost [3]	Operation cost per kilometer	$[18\text{-}43]*10^6$	€/km
Portuguese Cost Share Operations	Operation cost share related with the trans-border train line and the border connection stop	[25-70]	%
Spanish Cost Share Operations	Operation cost share related with the trans-border train line and the border connection stop	[25-70]	%
Net Travel Time	Travel time without stops	[38-384]	Min
Number of Stops	Total number of stops	[3-8]	#
Overall Travel Time (Passengers)	Overall travel time related to passenger trains	[0-10]	Min
Overall Travel Time (Freight)	Overall travel time related to freight trains	[0-30]	Min
Level of Coordination	Quality of coordination related to the border connection. The scale runs from the least amount of coordination (1) to a friendly and cooperative atmosphere between the Portuguese and Spanish side (5).	[1-5]	
Max Throughput	Maximum load possible to travel per day in the entire line		ton/day
Max Capacity	Maximum capacity for passengers per day		pass/day
Loads Transference	Ease of transference cargo from the train to trucks or from the land port. 1 means the difficulty to load/unload and 5 is the best scenario with perfect conditions to transfer.	[1-5]	
Risk	Associated to the private investors. Denotes the best or worst ability to invest their money in this	[1-9]	

[2,3] The operation of high speed rail services involves two types of costs: infrastructure maintenance and operation costs, and those related to the provision of transport services using the infrastructure. Operating costs includes costs of labor, energy and other material consumed by the maintenance and operation of the tracks, terminals, stations, energy supplying and signaling systems, as well as traffic management and safety systems.
Some of these costs are fixed and depend on operations routinely performed in accordance to technical and safety standards. In other cases, as in the maintenance of tracks, the cost is affected by the traffic intensity; similarly, the cost of maintenance, electrical traction installation and the catenaries depend on the number of trains running on the infrastructure.
The operating cost of high speed rail services vary across rail operators depending on the specific technology used by trains and traffic volumes. (Rus, 2008)

	project.	
Security[4]	Level of risk applied to this mean of transport	[1-5]
Prestige	Prestige referent to the line. Measured on a scale, 1 (worst case) to 5 (very satisfied).	[1-5]

After the attributes have been determined, the utility function, which captures the perceived value under uncertainty for each attribute, can be elicited. The single attribute curve is shown in figure 6, it represents the single utility curve for the number of stops.

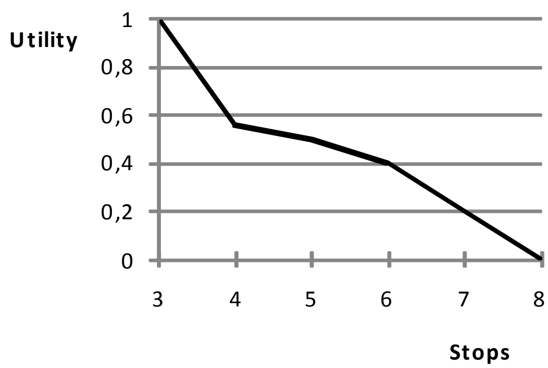

Figure 6 – Single attribute utility curve

A multi-attribute utility function can be formed, aggregating the single attribute utility values into a single decision metric (Ross, 2006). In order to calculate it, Keeney and Raiffa (1993) defined the multi-attribute function as:

$$KU(\underline{U})+1=\prod_{i=1}^{M}\left[Kk_iU^i\left(X^i\right)+1\right],\ where\ \ K+1=\prod_{i=1}^{M}\left[Kk_i+1\right]$$

4 Measuring transport security - and comparing it with other countries - is not clear cut, for there are different ways of measuring it. One method is to simply count the number of accidents and divide it by the total population, to arrive at, for example, the number of deaths per million inhabitants.

and $U(\underline{X})$ is the multi-attribute utility function, K is a normalization constant, k_i is the relative weight for attribute X^i and $U^i(X^i)$ is the single attribute utility function for attribute X^i.

Table 2 summarizes the attributes that stakeholders care about:

Table 2 - Stakeholder opinion

Attributes	**units**	**Portugal**	**European Union**	**Private Investors**	**Spain**
Total Project Cost	€	x	x		
Portuguese Cost Share	%	x			
EU Cost Share	%	x	x		
Spain Cost Share	%	x			x
Private Investor Contribution	€	x		x	
Maintenance Cost	€/km	x			
Operation Cost	€/km	x			
Portuguese Cost Share Operations	%	x			
Spanish Cost Share Operations	%				x
Net Travel Time	min	x			x
Number of Stops	#	x			
Overall Travel Time (Passengers)	min	x	x		x
Overall Travel Time (Freight)	min	x	x		x
Level of Coordination	[1-5]	x	x		x
Max Throughput	ton/day	x			
Max Capacity	pass/day	x			
Loads Transference	[1-5]	x			x
Risk (for private investor)	[1-9]			x	
Security	[1-5]	x			
Prestige	[1-5]	x			

The multi-attribute utility value represents the satisfaction of a decision maker. These functions are defined over the range of 0 to 1. A utility value of zero corresponds to an attribute at its least acceptable level; a utility value of one corresponds to an attribute at its best level, beyond which no additional value is perceived. Figure 7 shows the utility-cost tradespace for a design.

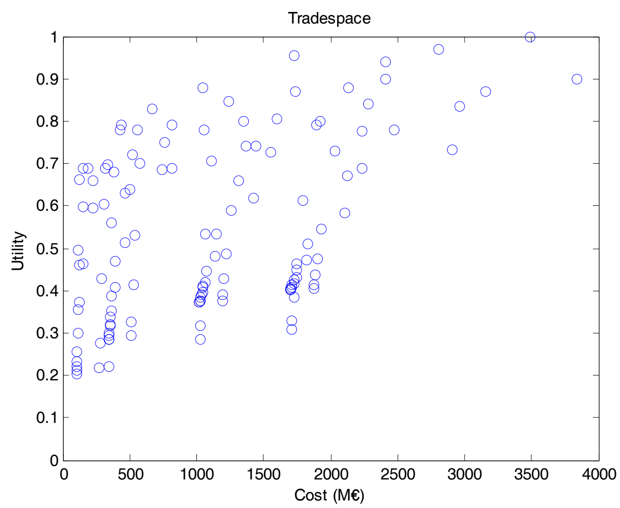

Figure 7 – Utility-cost tradespace

4.4. Design Variables

According to Ross (2006) a design variable is a designer-controlled quantitative parameter that reflects an aspect of concept, which taken together as a set uniquely defines a system or architecture design. The design variables are the key quantitative tradable parameters.

In this case study the design variables and its units are expressed in table 3.

Table 3- Design Variables

Design Variables	**Definition**	**units**
Network Routing	Different route options that can be chosen	Discrete choice
Rail Type	Ability to deliver freight regarding to a cost-benefit choice of technology	HSR, Conventional
Loads Conventional	Maximum load for conventional track	ton/axle
Loads HSR	Maximum load for High-Speed Rail tracks	ton/axle
Train Capacity	Technical specifications envisaged by the manufacture and the specific internal configuration agreed with the buyer.	Dependent on the brand
Land Port Location	Better location regarding shipping and unshipping loads regarding trains and trucks.	Feasible Locations
Border Land Port Location	International connection.	Articulation between two sides
Number of connections /stops	Number of stops and stations in the Portuguese line	[1…5]
HSR Link to Sines	Connection to Sines. If there is connection will be defined as 1, and 0 means conventional connection	[0-1]
Cost share Portugal	Project Cost supported by Portugal	%
Cost share EU	Project Cost subsidized by the European Union	%
Cost share Private Investor	Project Cost contributed by the Private Investors	%
Cost share border port with Spain	Spanish cost from border connection	%
Cost share operations Portugal	Portuguese cost related to operations	%
Investment in good border interactions	Qualitative scale to measure the integration between Portugal and Spain in the border connection.	[1…5]

The design variables define the concept modeled. This concept is what will differentiate the possible architectures. Design vectors will define the tradespace in study. These variables tend to represent the characteristics of the system and they usually rise by a brainstorming process.

4.5. Design Value Matrix

According to figure 8, after the design variables are determined, a system model is created in order to assess how various combinations of design variables perform in terms of attributes.

The model shows the attributes elicited from decision makers from the columns. Proposed design variables are placed in the rows. Qualitative effects are captured through allocating a 1, 3 or 9 to each row representing the amount of impact that design variable is expected to have on each attribute. In this way, the designers can be assured that each attribute has at least one driver, and can help determine which design variable to focus on, thus creating more value (Ross, 2006).

		Attributes																				
		Total Project Cost	Portuguese Cost Share	European Union Cost Share	Spain Cost Share	Private Invester Contribution	Maintenance Cost	Operation Cost	Portuguese Cost Share Operations	Spanish Cost Share Operations	Net Travel Time	Number of Stops	Overall Travel Time (Passengers)	Overall Travel Time (Freight)	Level of Coordination	Max Troughput	Max Capacity	Load Tranference	Risk (for private investor)	Security	Prestige	
Design Variable	Network Routing	9	0	0	0	0	1	3	1	0	9	9	1	1	3	0	0	9	3	9	9	67
	Rail type	9	0	0	0	0	9	9	0	0	9	9	1	9	0	9	9	9	3	9	9	103
	Loads Conventional	9	0	0	0	0	9	9	0	0	0	0	3	9	9	9	9	1	0	0	0	67
	Loads HSR	9	0	0	0	1	9	9	0	0	0	0	3	9	9	9	9	1	0	0	9	77
	Train Capacity	9	0	0	0	0	9	3	0	0	9	0	1	0	0	0	0	0	0	0	9	40
	Land Port Location	1	0	0	0	0	0	3	0	0	9	3	3	0	0	0	0	9	3	0	0	31
	Border land port location	3	0	0	9	0	0	0	9	9	0	3	0	0	9	0	0	9	0	0	0	51
	Num connections/stops	9	9	0	0	0	9	9	0	0	9	9	9	0	0	0	9	9	0	3	0	84
	HSR link Sines	9	9	0	0	0	9	9	0	0	9	0	1	9	0	9	0	9	3	0	3	79
	Cost share Portugal	0	9	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
	Cost share European Union	0	0	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
	Cost share Private Investor	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	18
	Cost Share Border Port with Spain	0	0	0	9	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	18
	Cost Share Operations with Portugal	0	0	0	0	0	0	0	9	1	0	0	0	0	0	0	0	0	0	0	0	10
	Investment in good border interactions	0	0	0	0	0	0	0	0	0	0	0	0	9	9	0	0	0	1	0	3	22
		67	27	10	18	12	55	54	19	19	54	33	22	46	39	36	36	56	22	21	42	

Figure 8 - Design-Attribute DVM

4.6. Epoch Variables

The system lifecycle is used to characterize the phases of a system during its lifespan, from initial concept to end of life. System lifecycle processes are beneficial to the designer for organizing the various activities required to design, develop, and operate a system. The system lifecycle is comprised of phases that have defined end points, but these are typically based on the resources available to complete a set of phase activities (Ross, Rhodes, 2008).

Epoch-Era Analysis is an approach for conceptualizing system timelines using natural value centric timescales, whereas the context and expectations define the timescales. The full lifespan of system is referred to as the System Era, which can be decomposed into Epochs. An Epoch is a period of time for which the system has fixed context and fixed value expectations. Each epoch is characterized by static constraints, available design concepts, available technology, and articulated attributes.

For this analysis the epoch variable chosen are shown in table 4:

Table 4- Epoch Variables

Epoch Variables	Definition	units
Demand level	Demand for freight	ton/year
Demand level	Demand for passengers	pax/year
Economic situation of EU/World	Economic scale: 1 denotes a global economic recession, shortage of capital, public investment are in fierce competition with each other. Level 5 the economy is booming and the public investment is available.	[1-5]
Portuguese Economy	Economic State of the Portuguese Economy. Level 1 denotes economic recession, shortage of capital, public investment are in fierce competition to each other. In Level 5 the economy is booming and public investments are available.	[1-5]
Spanish Economic situation	Economic State of Spanish Economy. Level 1 denotes economic recession, shortage of capital, public investment are in fierce competition to each other. In Level 5 the	[1-5]

	economy is booming and public money for investments is available.	
Threat level	Level of threat from 1 (worst) to 5 (no threat)	[1-5]

During each epoch in the system era, as it is shown in figure 7, path analysis can be conducted, utilizing an accessibility matrix generated by the tradespace exploration process. This process denotes which designs in the tradespace are reachable from another design that already exists in the tradespace by application of a transition rule (Ross, Hastings, 2006).

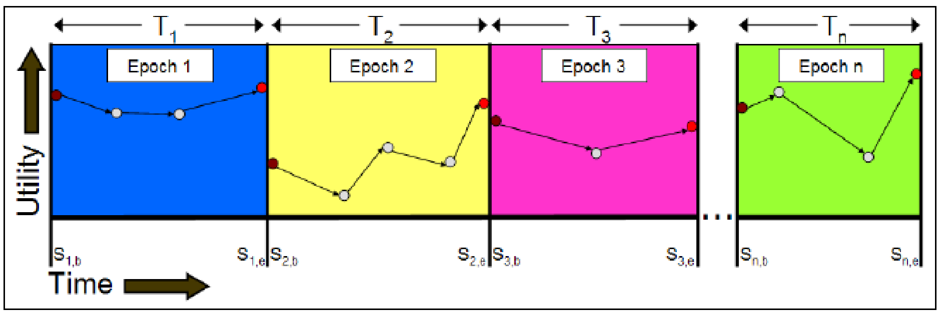

Figure 9 - Example of Epoch String to form System Era (Ross, Rhodes, 2008)

The use of Epoch-Era Analysis, as part of tradespace exploration, provides a means for the natural extension of static views to the dynamic view that is essential for designing systems for changeability.

4.7. Tradespaces

To develop the MATE idea, the notion of tradespace is fundamental. The tradespace analysis includes not only the space of the design but also the space of attribute trades.

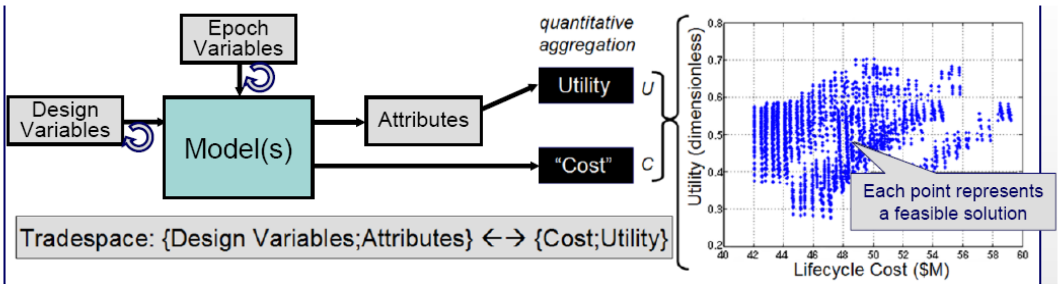

Figure 10 - Tradespace analysis (Ross, Rhodes, & Hastings, 2009)

The main objective is to find the highest utility at a given cost level. This is done through the Pareto frontier of solutions. The decision maker is allowed to decide the most appropriate trade off resource. As an example, it will be possible to know regarding all design variables how many stops will be required do to the design of the line or the financial resources.

This method is useful not only to find the 'best' solution but to find the 'best' decision about the set of alternatives in the study. The main value is the stakeholders have the opportunity to give their true opinion about what they most care about and evaluate the design variable in the study.

5. CONCLUSION

The reason for building a new high speed rail infrastructure depends on its capacity to generate social benefits which compensate for the construction, maintenance and operation costs. Decisions to invest in this technology have not always been based on sound economic analysis. A mix of arguments, besides time savings–strategic considerations, environmental effects, regional development and so forth– have often been used with inadequate evidence to support them.

Whether high speed rail investment is socially profitable depends on the local conditions, which determine the magnitude of costs, demand levels and external benefits such as reduced congestion or pollution from other modes. Given the costs, the expected net social benefit of the investment in high speed rail relies heavily on the number of users and its composition (diverted and generated passengers) and the degree of congestion in the corridor affected by the investment. High speed rail projects require a high volume of demand with enough economic value to compensate for the high cost involved in providing capacity and maintaining the line. Not only does the number of passengers have to be high, but there has to be, a great amount of willingness-to-pay for the new facility. The users who will greatly benefit form the benefits to the HSR are those who are frequent travelers.

High speed rail investment does not only save time but also increases the capacity for passengers as well as for freight, both by providing capacity itself and by freeing existing routes. In those routes characterized by serious bottlenecks, the opportunity to upgrade the existing services is a factor which may well increase the added value of high speed rail.

The applicability of this approach to the high speed rail lines will help to understand the feasibility of the whole project.

5.1. Future Work

After the huge step taken regarding the data acquisition, the future work is related to the real applicability of MATE approach to this system. Mate is intended to provide high level architecture guidance, concept generation and concept evaluation.

The applicability of MATE in this case study will require a more detailed and specific analysis of the whole process. This process will be related not only with the conceptual system engineering design but also with all the unarticulated propositions from transportation systems engineering.

MATE approach has been seen as an important area of ongoing research. With this methodology it is possible to define and improve all important preferences and concerns from the different stakeholders. Improve or change their preferences through the project and include or modify the scope of the project. Tradespace analysis may be used as a quantitative tool in order to evaluate benefits, cost, and risk of alternatives chosen but also technical capabilities. This tool will also be useful to explore the implications of policy uncertainties and changing value perception.

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