MSc in Railway Systems Engineering and Integration

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Planning Very High-Speed Railway for Southeast and South regions of Brazil

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Knowledge, study and science, if they do not provide awareness, uneasily face the challenges of reality and will only serve the mystical and oppressive ends. In contrast, knowledge must make men more aware of the causalities which have made them as they are, so as to continue. They must be generators of new knowledge.

(Freire, 1972)

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Executive Summary

The development of a Very High-speed Railway (VHSR) is a complex and long-term matter involving many requirements and issues. If it is not being managed correctly, the adoption of VHSR will be stiffed. The present dissertation is structured to address four main objectives stated by the author as follows: *Identify* the forces driving VHSR and the barriers to the successful development of passenger rail transport through the capital cities of Brazilian Southeast and South region to solve transport capacity problems and to enhance the efficiency of the economy; *Evaluate* critically some of the models and frameworks relevant to supporting a "Transport Board" in coping with VHSR technology; *Explore* the Brazilian transport and socio-economic database and outline the practices related to design, operation and management of VHSR, including inducement and barriers, and *Formulate* recommendations on "Transport Board" design issues.

The author then present a description about what are the influences on users that make them chooses which transportation mode and address the question of when very high-speed railways take advantages over other modes in order to justify the development of a passenger railway on the proposed corridor. There also are comments regarding an idealised planning for passenger railway and its activities in order to guide the design process.

A briefly reviews of the background and the evolution of very high-speed rail services and the competing MagLev technology where conclusions about railway system based on magnetic levitation technology is, in fact, technically feasible but queries regarding its long-term reliability and safety aspects still need to be proved; whereas, the very high-speed rail is based on well known technologies and is thus likely to represent a lower technical risk.

The details of how Brazil is geographically and economically was taken in account for identifying drivers and constraints of corridor between Belo Horizonte and Porto Alegre. It was characterised that the major cities are located relatively equidistant to each other, with major destinations situated 350 km or more from São Paulo.

It was characterised that São Paulo – Rio de Janeiro is the busiest route where there is greater commuting of 5.8 million of passenger per year by coach and air together. Other routes that can also be highlighted are São Paulo – Belo Horizonte where there are over 2.3 million of passengers per year and São Paulo – Curitiba where greater than 2.2 million of transference annually between both cities by coach and air together. The route from São Paulo to Porto Alegre has also had a greater traffic about 1.9 million of passenger per year flight by airplane. Moreover, it was also concluded that there are likely to be requests for a number of intermediate stops along the route (Blumenau, Joinville, Registro, São Jose dos Campos, Resende) to foster local economic development and augment of traffic.

The existing transport network in Brazil has clearly capacity deficits and there are bottlenecks that lead to the development of a high quality system linking all major cities. However, the author contends that a very substantial enhancement of the capability if a passenger railway network is developed. Based on the research undertaken and evidence from other countries, the author suggests that the development of conventional railway network in Brazil could be a great business case.

Finally, the development of high-speed line between Belo Horizonte and Porto Alegre will deliver a railway link the capital states of south and southeast region and strategic cities along the corridor. The population comprises roughly 100 million inhabitants (IBGE, 2007a). In addition, the states that compose both aforementioned regions bring together more than 70% of the Brazilian GDP, where are also located the highest developed region and installed more than 75% of the industries of the country (IBGE, 2007b). Therefore, the proposed route operated by passenger railway transport may facilitate cross-boundary travel for commuting, leisure and business.

Table of Contents

List of Figures

List of Tables

Glossary of Terms

Term	Meaning / Definition
AC	Alternating Current
ALL	America Latina Logística
ATP	Automatic Train Protection
AVE	Alta Velocidad Española
BAHP	Brazed Aluminium Honeycomb Panels
BOT	Build – Operate – Transfer
BR-116	Acronyn for Brazilian Federal Road and number
CBTU	Brazilian Company of Urban Trains
CFRP	Carbon Fibre Reinforced Plastic
CPTM	Companhia Paulista de Trens Metropolitanos
DC	Direct Current
Dieese	Inter-Union department of statistic and socio-economic studies (Departamento Intersindical de Estatística e Estudos Socioeconômicos)
EMS	Electromagnetic Suspension
FMI	International Monetary Fund
IBGE	Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)
ICE	InterCity Express
INCOSE	International Council of Systems Engineering
LGV	Ligne Grande Vitesse
MagLev	Magnetic Levitation
MetroRio	Metro of Rio de Janeiro
MG	Acronym of Minas Gerais State
MRBH	Metropolitan Region of Belo Horizonte
NIMBY	Not In My Back Yard
NR	Network Rail
PM	Project Management
PMC	Curitiba city council
PPP	Public-Private Partnership

Term	Meaning / Definition
PR	Acronym of Paraná State
RAMS	Reliability, Availability, Maintainability, and Safety
RGI	Rail Gazette International
RJ	Acronym of Rio de Janeiro State
RPM	Railway Project Management
RS	Acronym of Rio Grande do Sul State
SC	Acronym of Santa Catarina State
SE	System Engineering
SP	Acronym of São Paulo State
SuperVia	Concessionaria de Transporte Ferroviário S.A.
TGV	Train à Grande Vitesse
TLA	Three Letter Acronym
Trensurb	Company of Urban Trains of Porto Alegre S.A.
UIC	International Union of Railways
UNDP	United Nations Development Report
UoB	University of Birmingham

1 Introduction

1.1 Background

The rapid process of change in every sphere of life is perhaps the most visible aspect of the post modern age. The technological developments have been enormous in the past quarter century. The social, demographic and economic features of the world are also changing rapidly. Due to advances in medical technology the average life expectation of the individual has increased. The economic prosperity and rise in per capita income have made the cost of travel affordable for common man. That means greater mobility of people across the world.

All these changes demand a lively, dynamic, efficient, reliable and sustainable transport network. The role of transport in the success of modern societies is becoming critical, to say the least. No society can cope with the emerging process of change without having a strategic vision for inter-modal transport solutions. Railways as the most sustainable mode of transport from the standpoint of climate change and global environmental concerns have even more relevance in the modern age.

Railways have seen some dramatic developments in the sector of High-speed Rail (HSR) worldwide. The expansion of existing corridors in Europe and Japan and the opening of several new lines in Asia demonstrate the high interest in many nations for HSR in order to provide effective transport, safe mobility, lower time journeys and consequent socio economic benefits.

In Brazil, the virtual disappearance of intercity rail passenger services and past failures to invest in the rail network led to a situation where about 70% of all freight and about 95% passenger movement are undertaken by road. As a result of policies of low investment in freight and passenger railways between the most important state capitals has led to a massive increase of vehicles on the roads and growing capacity constraints in the transport networks.

The increasing movement of people and products at the local, regional and national levels has placed extreme demands on transportation systems. Railways should be the backbone of the transport system; the Brazilian Federal Government has been studying the feasibility of introducing trains at higher speeds along the corridor between São Paulo and Rio de Janeiro using part of existing network and a dedicated new line for very high-speed operation.

1.2 Research Focus

The building of a Very High-speed Railway (VHSR) is a complex and long-term matter involving many requirements and issues. If it is not being managed correctly, the adoption of VHSR will be stiffed. For example, there have been concerns over VHSR networks as urban structure when linking large urban centres, access to alternative modes, the size of the network and the frequency of stops, together with the influence of regional geography on the design (Vickerman, 1997). System Engineering (SE) applications have been exhausted mentioned by INCOSE studies which points to in better cost and schedule performance and increased the suitability to stakeholders' need, have already been exausted. Bianco and Majo (1991), Lopez Pita (2001), Kostadinovic and Cvetanovic (2001), Hourcade (2000), and Koller (2003) concluded that the long-term effects of high-speed railways are ultimately favourable to environmental concerns and safe mobility instead of funding problems. The changes to social structure caused by the influence of high-speed railways have been pointed out by Amano et al. (1991) and Morichi et al. (2002).

Specifically, within the context of higher education, the objectives of this research are to: Identify the forces driving VHSR transport and the barriers to the successful development of passenger rail transport through the capital cities of Brazilian South-Eastern and South region. Evaluate critically some of the models and frameworks relevant to supporting a "Transport Board" in coping with VHSR technology. Explore the Brazilian transport and socio-economic database and outline the practices related to design, operation and management of VHSR, including inducement and barriers, and Formulate recommendations on "Transport Board" design issues.

1.3 Overall research aim and individual research objectives

The purpose of this thesis is to analyse the need to construct an express railway link from Belo Horizonte to Porto Alegre in order to bring together all aspects of railway systems engineering and to integrate all the elements into the route. In Figure 1.1 illustrates the link previously mentioned. Moreover, it will evaluate and compare as much of the existing VHSR literature as possible, to present an accurate and current picture of High-speed Rail installations and proposals, as well as other applications of High-speed Rail.

The author examined the engineering and operational feasibility of high-speed rail using steel wheel on steel rail technology. A rail passenger transport is needed for the following reasons: the saving in travel time, customer satisfaction, edge over other modes of transport, as competition with air traffic in regard to speed and more convenience, since unlike aeroplanes air because it goes to the heart of city, energy efficient, environmentally friendly, to have a sense of pride and confidence, demand and capacity.

Figure 1.1: Belo Horizonte – Porto Alegre corridor (Google Earth)

1.4 Methodology

The author's methodology was to survey a range of literature with a view to understanding the technology, cost, and benefits of the existing high-speed railways worldwide. A critical analysis was carried out in relation to the increasing demand for mobility and the currently perceived capacity of the existing modes – rail, road and air – in order to determine what lessons could be learnt and whether these lessons can be applied in the context of the corridor Belo Horizonte to Porto Alegre through the most important cities such as Rio de Janeiro, São Paulo, Curitiba and Florianópolis.

1.5 Dissertation Structure

The dissertation has been structured as follows: the first page provides an Executive Summary and section 1 is the Introduction, with a brief description of the research focus and methodology applied in the course of the document. The author then uses section 2 to present a brief description regarding the choice of transportation mode addressing the question of when very high-speed railways have advantages over other modes, ideal planning for a passenger railway and its activities in order to guide the process, IDEFØ as a tool for modelling of decisions and actions of organisations or systems, the need for forecasting demand models, and the strengths and weaknesses of forecasting modes used for transport. The author then introduces very high-speed railways and briefly reviews the background to and the evolution of very high-speed rail services and the competing MagLev technology, System Engineering and project management as another tool to manage and control the whole life cycle of the project.

The author outlines briefly in section 3 details of how Brazil is arranged geographically into states and regions as well as of its economic production and the distribution of its industries around the country. The corridor between Belo Horizonte and Porto Alegre is explained in section 4 and this section also leads to a discussion of the applicability of very high-speed railways and the specific plans for Brazil.

In Section 5, the author presents a summary of the technical aspects involved in very high-speed systems such as the limiting factors of speed goes up, the rolling stock characteristics that bring about benefits in terms of savings on energy consumption or improved ride, and the sorts of traction power used by different countries, and their features.

In Section 6, the reader finds an overview of very high-speed rail applications in key countries worldwide. This explains the impact of the physical and population geography of the case study countries on the introduction of very high-speed technologies.

Last but not least, section 7 summarises the author’s findings and recommendations regarding very high-speed railways. This is followed by the main conclusions, in section 8.

2 Literature Review

2.1 Transportation Planning

2.1.1 Background

The ancients were used to the benefits of having a system of transport; the Romans, were celebrated for their elaborate system of roadways, e.g. the Appian Way, that delivered connectivity and augmented the interaction between people and regions. Thus, transportation has been closely related to the evolution of civilisation and its socio-economic growth.

In order to reduce traffic congestion and enhance the socio-economic activities between the capital states of the southeast and south regions of Brazil, the author became interested in suggesting a way forward for the planning and development of a further system of transport. Papacostas and Prevedouros (2005) describe a transportation system as 'consisting of the fixed facilities, the flow entities, and the control system that permit people and goods to overcome the friction of geographical space efficiently in order to participate in a timely manner in some desired activities'.

Wang (2008) states: 'Transportation, while promoting economic development, is highly dependent on resources. It occupies a large quantity of land and energy, and also brings serious environmental pollution', and 'all factors need to be unified systematically and interestedly, in particular, the impact of restrictive conditions, by optimizing the allocation of transportation resources, and establishing a resource-saving, environment-friendly, adaptable, and multi-modal transport network, to enable the balance between the aggregate supply and demand of transportation, and the satisfaction with its basic demand and the aggregate demand in economic and social aspects with minimum resources and environmental costs'.

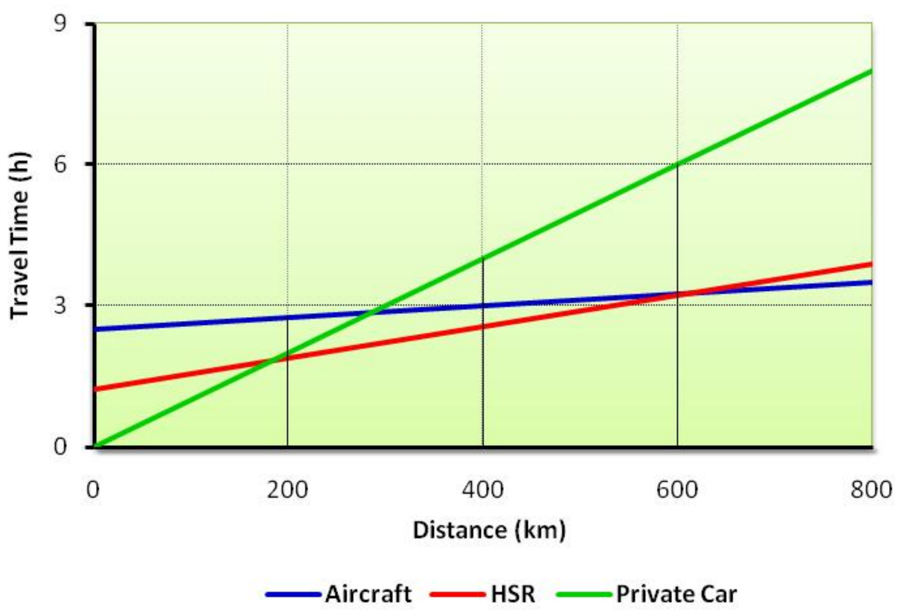
Both definitions clearly talk of the needs for the development of planning for transportation to meet the balancing of a wide range of conflicting requirements imposed by the complexity of transportation systems and the interests of society. Therefore, because a set of major interrelations between the diverse components existing in the transport system demonstrates the necessity of planning in an organised and methodological manner, the author advocates that there is a case for using system engineering tools in order to help in the controlling of critical points described by the V-life cycle theory.

2.1.2 Choice of Mode

The choice of mode for long-distance travel is highly dependent on the sensitivity of the traveller with respect to time and cost. By and large, business travel is time-sensitive and leisure travel is price-sensitive, whereas travel for personal reasons may be either time-sensitive or price-sensitive, or both (Papacostas and Prevedouros, 2005). The basic attributes of each mode are schedule, speed, cost, and perceptions regarding the service offered.

First, schedule and speed prescribe the ability of the mode to serve passengers at the times they want and at the speed they require; for example, a same day round-trip from São Paulo to Rio de Janeiro where the distance between the two cities is about 437 km can be accomplished by air or road travel. Next, cost is a major consideration for most passengers. For a given distance rail and bus are the least expensive, followed by private car or rented car, and with air travel coming last as the most expensive means of travel. Last, perceptions of passengers regarding the overall service offered by a particular mode compared with other modes also affect the choices they make. Therefore, the rail mode must offer as high a level of amenities as air. Moreover, setting cost aside, the competitiveness of modes can be judged by their ability to provide a fast service from origin to destination on a door-to-door basis.

Figure 2.1 Comparisons of modes of intercity transportation



The typical travel-time components adopted for rail and air transportation are as follows: access and wait time equal to 1.2, 2.5 and 0h were assumed for high-speed rail, air travel and car; respectively, along with the assumed time durations. Figure 2.1 compares the three modes of intercity transportation. The average of main haul speeds was assumed as: 100 km/h for a passenger car, 300 km/h for high-speed rail, and 800 km/h for a subsonic jet aircraft.

For travel of less than 200 km the private car provides a faster journey than other modes. That is because the private car has greater typical travel-time. For distances ranging from 200 km to 600 km VHSR is the fastest mode and for distances higher than 800 km air is more efficient even if there is dedicated high-speed rail.

In conclusion, since the distance between the major Brazilian urban centres is considerably lower than 450 km, the development of an affordable and good-value railway passenger transport system will deliver to users a new opportunity of mode choice and it may lead to change in transport market share in Brazil.

2.1.3 Planning Railway Transport

Planning is an essential attribute when a huge capital-intensive long-term project is required. The development of a VHSR for passenger transport in the Southeast and South regions of Brazil requires substantial activities that must be carried out in order to meet diverse requirements such as reliable and safe transport, time and fare competitiveness, reduced operational cost and maintenance life-cycle cost, and environment within an appropriated cost-effective.

The author therefore suggests the planning process for a new passenger rail link proposed by Harris and Godward (1992); see Figure 2.2, where the activities of planning railway transport are composed of six main areas which can occur simultaneously: policy issues, demand estimation, engineering issues, operability issues, environmental issues, and appraisal. However, the author also points out that there is a need for a planner to have considerable creativity in remoulding or generating activities within the proposed planning in order to obey the constraints imposed on a project in terms of time and budget (Richardson, 1999)

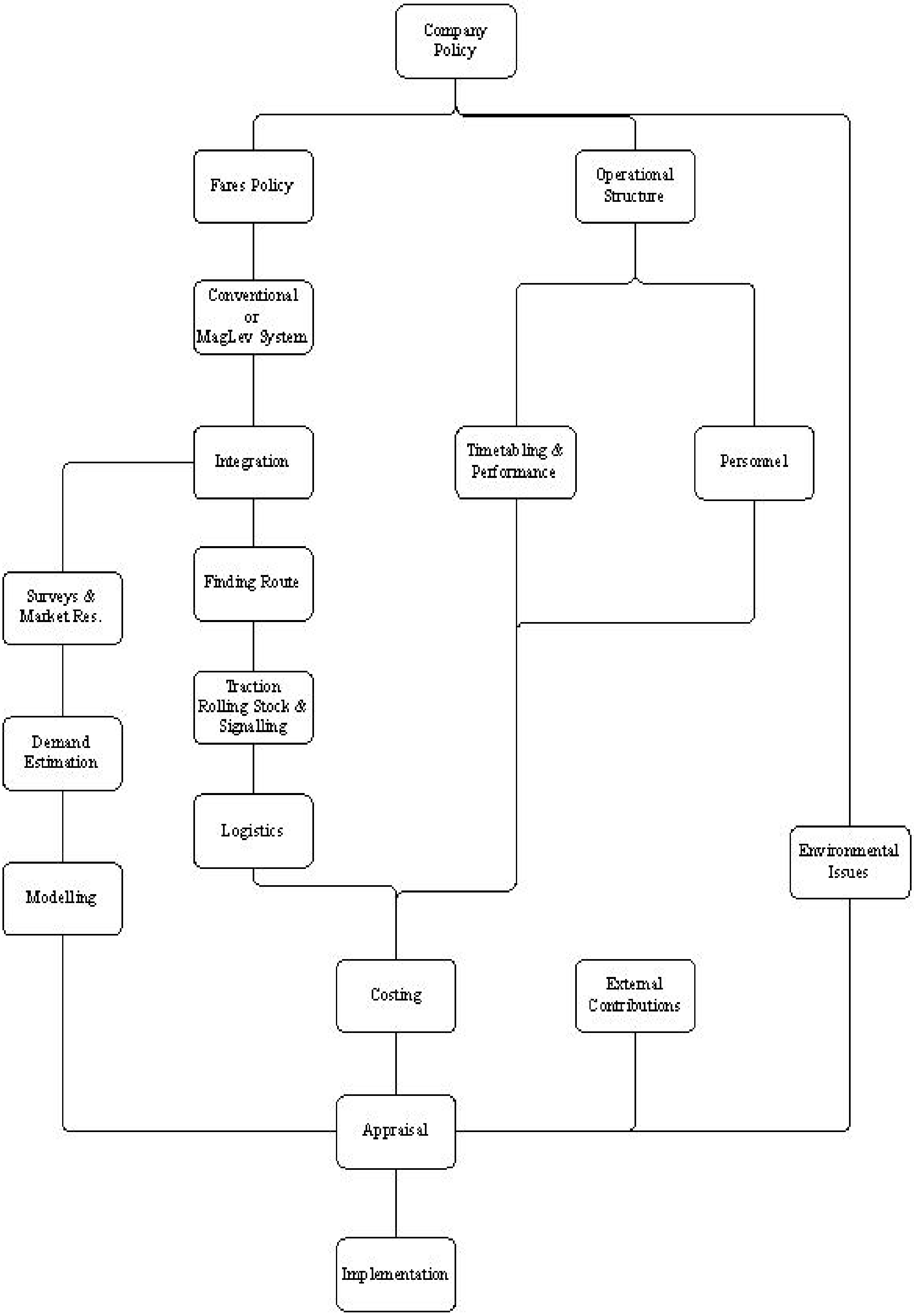


Figure 2.2: Phases of planning passenger railway (Harris and Godward, 1992)

The first area of activity which is important in the railway passenger system is the fare policy. In order to survive and make profits on the rail market, leaders must be aware of price policy and price elasticities in their strategies for running VHSR if they want to be winners in this market (Harris and Godward, 1992). The second area is demand estimation strategies. A number of key concepts underlie transport planning, and one of the most important of these is that travel is a derived demand and is the means of meeting the user's needs (Harris and Godward, 1992). Time and money are spent in order to travel and therefore Generalised Cost is indicated as an useful theory for measuring of travelling in order to recognise different aspects of travel behaviour (Harris and Godward, 1992). Next, engineering issues such as technology must be borne in mind to deliver system performance, operational and maintenance flexibility, and high interoperability between sub-systems at reasonably priced manner. Third, the operation must be organised to maximise the existing assets in order to meet an affordable operational cost while meeting the user's requirements. Environmental aspect in railways must be managed in order to minimise the consequences of pollution, noise and vibration, visual intrusion, land take, and damage to the natural environment and archaeological landscapes (Harris and Godward, 1992).

2.1.4 IDEFØ

In order to minimise the conflicts and maximise the efficiency and safety performance between sub-systems and interfaces in complex systems, Williams (1998) and Roberts (2002) advocate the use of the Integrated DEFinition (IDEF) methodology. The IDEF techniques allow the modelling of decisions, actions and activities of an organisation or system where IDEFØ can be used as a function modelling method for analysing and communicating the functional perspective of a system.

As seen in Figure 2.2, railways systems underlay on a set of high complexity of activities and interactions that are performed simultaneously. Through the IDEFØ a creation of consistent and integratable models can be developed by partitioning the activities and interfaces into independently parts. As a result, the using of IDEFØ leads to progressively decompose the system from a high level description, where the model begun with an initial concept of what have to be done and the step-by-step development help insure the inclusion of all necessary activities.

Thus, the IDEFØ figure below is an example of the inputs, outputs, controls, and mechanisms for a new railway system that can be considered at the earliest planning stages. First, the controls in the form of laws, standards, and rules and regulations specify the conditions required for the function to produce correct outputs. Second, the demand for transport is the main input that will be transformed or consumed by the function to produce outputs. Next, resources and equipment, people and funds are identified as some of the means that support the execution of the function. Last, the transport unit, transport quality and transport value are the objects produced by the function (Schmid, 2006).

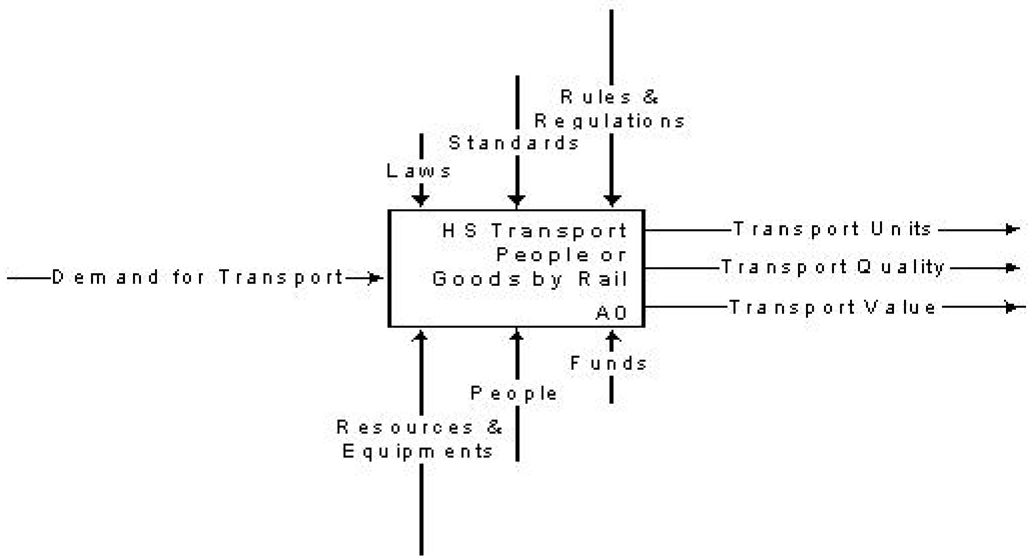


Figure 2.3: IDEFØ for high-speed transport (Schmid, 2006)

2.1.5 Travel demand forcasting

The Oxford dictionary defines the word forecast as '*a statement about what will happen in the future based on information that is available now*' and indeed the opening of a new VHSR requires an effort to foresee and anticipate the accurate consequence data of the mode of transportation adopted.

The major thrust of this section is to describe briefly '*demand estimation*' which Harris & Godward (1992) quoted as a prerequisite for various activities in the railway and which Profillidis (2006) stated to be the construction of a new railway line, revenue estimation, commercial and tariff policy as well as management strategies.

Table 2.1: Parameters of rail transport and their degree of influence (Profillidis, 2006)

Parameter	***Intercity Journey***	
	Business	Leisure
Travel Time	+++	+
Cost of travel	+	+++
Frequency of services	++	+
Quality of services	++	++
Punctuality	+++	+

Legend: +++High Influence, ++Medium influence, +small influence

The ability to judge and select a model that is appropriate for a particular application is considered to be one of the most important aspects in transport planning and is an arduous task. Diverse factors such as human nature and technological requirements may affect the selection of a model that is most suitable for meeting needs and requirements. For example, intercity journey travel time has a greater influence on business trips than leisure trips; while travel cost influences leisure trips more than business trips. Table 2.1 shows the parameters of rail transport and their degree of influence on business and leisure travellers on intercity journeys.

Diverse models are available to be applied to transportation planning. Papacostas (2005) organised the models according to such major components of travel behaviour as the decision o travel for a given purpose (Trip generation), the choice of destination trip (Trip distribution), the choice of travel mode (Mode choice), and the choice of route or path (Network assignment). Moreover, Profillidis (2006) classified the most applicable models for railway transport into three categories: qualitative, statistical, and qualitative. The Table 2.1 presents a comparative analysis of the performance of diverse methods applied in forecasting rail demand.

There is no suitable procedure for the systematic selection of one model that is most appropriate for meeting the needs and requirements of a particular planning task and therefore the use of a combination of two described models, as in Table 2.2, leads to improvement in the accuracy of results.

Table 2.2: Comparison of forecasting model performance (Profillidis, 2006)

		Quality Methods				*Statistical projection*	*Quantitative (casual methods)*		
		Executive Judgement	Market Survey	Delphi technique	Scenario Writing		Econometric	Gravity	Fuzzy
Suitable for forecasts till	1 year	H	H	H	H	H	H	H	H
	2~3 years	M	H	M	H	M – H	H	H	H
	5 years	L	M	M	M	M – L	H	H	H
	10 years	L	L	L	M	L	M	M	M
Special expertise required		H	M	H	H	M – L	H	H	H
Time required to conduct the forecast		L	H	L	M	L	H	H	H
Data requirements		M	M	M	M	H – M	H	H	H
Cost requirements		M	H	M	L	L	H	H	H

Legend:
H → High, M → Medium, L → Low

From short (1~2 years) to medium-term (5 years) forecasts, the use of statistical projection and quality methods become less reliable while quantitative methods keep the same quality. For long-term (10 years), the use of any forecast should be used only as an indication of what may occur because of the lesser accuracy (Profillidis, 2006).

As presented by the author, there are a number of technical approaches which can be used for forecasting demand. However, the gravity model may indeed be appropriate in the circumstances of this dissertation. It is especially the case where the dissertation covers not just demand forecasting issues but wider business planning ones (e.g. estimation of capital & operating costs).

As with any other model of the real world there are certain limitations. For example, the gravity model can be criticised because of its simplistic nature and lack of a behavioural basis that explains how individuals make choices among potential destinations and modes of transport in order to satisfy their needs. The model is reliant on k-factors for adjustment of possible discrepancies between the observed base trip-length frequency distribution and final friction factors (Papacostas and Prevedouros, 2005).

The author therefore applied some appropriated simplification of the model. For example, the lambda and alpha parameters are not included in less-sophisticated models, as the relationships may be linear, and the distance parameter is remarkably near 2. However, all models need calibration as mentioned. In order to estimate the impact of high-speed rail in this corridor, the author also gets data relevant to the multi-modal nature of the gravity model such as the main competitors are air, coach and car.

2.2 High-speed Railway Technology

2.2.1 Definition

High-speed Railways have been defined in varying ways by different authors but for Whitelegg (1993) the expression “high-speed” for trains or other guided vehicles means that they run at speeds over 200 km/h, up to 300 km/h; and “very high-speed” is used for systems travelling at speeds greater than 300 km/h.

The author, in order to facilitate the understanding of the reader and to avoid redundancy in description, has adopted the term ‘high-speed’ to describe operations with cruising line speeds between 200 km/h and 270 km/h and ‘very high-speed’, that is, for operations with cruising line speeds greater than 270 km/h. To illustrate this, the range about 270-300 km/h includes the AVE (Spain), ICE (Germany), Shinkansen (Japan), TGV operations in France and in Korea, and Taiwan. The second range includes the TGV Est (France) which operates up to 320 km/h and the German Transrapid MagLev System which reaches speeds of 450 km/h. Moreover, there are some lines that operate at speeds of 200 km/h but are nevertheless deemed to be high-speed lines.

2.2.2 High-speed Rail Systems

To meet the needs of augmentation of performance and capacity of railways, technologies have been developed and improved to cope with the targets. Actually, railways can use two sorts of technologies. The first is the existing conventional railway technology where trains rely on the point of contact of the wheel with the rail for traction and adhesion. This option has the advantage of being a mature technology and allows total integration with conventional rail lines. The emblematic high-speed lines such as the TGV (France), KTX (Korea), ICE (Germany) and the Japanese Shinkansen illustrate the preference for this option. The second option is to use a completely different method of guided transport. The one currently available is magnetic levitation (MagLev) where the movement of the vehicle can be controlled by an electromagnetic field along the guide-way. In this case the VHSR will be completely segregated from the conventional railways but it can become an interesting opportunity for regions where brand-new lines will be built. Both options are technically viable but more details and comparisons will be given in the next chapters.

2.2.3 Conventional Very High-Speed Rail

The first high-speed rail originated in Japan but the French TGV is further advanced. The Shinkansen network and the LGV/TGV system are the main drivers of conventional very high-speed rail systems worldwide. Furthermore, the Taiwan high-speed rail link between Taipei and Kaoshiung is a Shinkansen derivative with European track technology while the AVE (Spain), KTX (South Korea) and Eurostar (England/France/Belgium) are all derivatives of the LGV / TGV approach (Morimura and Seki, 2005a, Morimura and Seki, 2005b).

The infrastructure to accommodate conventional very high-speed rail must be designed with specific features in order to operate at speeds greater than 270 km/h over substantial distances and provide passenger comfort. For example, track design must be designed to eliminate successions of curves and sharp curves and steep gradients. All of these cause a reduction in performance, slower line speeds and increased energy consumption as well. Moreover, reducing the number of intermediate stops at relatively minor stations can improve journey times even further and save energy.

Other characteristics of very high-speed railways include traction power using 25 kV AC (50 or 60 Hz) overhead lines; although there are some countries such as Germany and Sweden where the trains are supplied with traction power about 15 kV, 16 2/3 Hz, low mass per axle, automatic train protection (ATP) and in-cab signalling, essential since it removes the need for drivers to observe line-side signals at very high-speed.

The Table 2.3 provides a limited overview of the commercial speeds1 obtained on the fastest dedicated high-speed rail routes worldwide. It may be worth highlighting that the maximum speed limit in France is about 320 km/h, and 300 km/h for other countries.

[1] The commercial speed includes acceleration and deceleration for stops, dwell-time etc. The associated line speed and top speed of the train have to be substantially greater, particularly where there are several stops.

Table 2.3: Commercial speeds of some VHSR worldwide according (RGI, 2007)

Country	**Route from – to**	**Distance (km)**	**Time (min)**	**Speed (km/h)**
France	Lorraine TGV – Champagne TGV	167.6	36	279.3
France	Valence TGV – Avignon TGV	129.7	30	259.4
Japan	Okayama – Hiroshima	144.9	34	255.7
France	Paris Lyon – Avignon TGV	657.0	154	255.6
Japan	Hiroshima – Kokura	192.0	46	250.4
International	Brussels Midi – Valence TGV	831.7	204	244.6
International	Brussels Midi – Paris Nord[1]	313.6	82	229.5
South Korea	Seoul Yongsan – Seodaejeon[1]	161.0	50	193.2
South Korea	Seoul Main – Daejon[1]	160.0	52	184.6

1. Runs in both directions

2.2.4 Very High-speed MagLev

The form of transportation whereby the vehicle is moved and supported without any mechanical contact, by electromagnetic forces alone, is termed MagLev; that is, magnetic levitation. Due to the absence of physical contact between the track and the vehicle when travelling at speed, the only friction present is that between the vehicle and the ambient air. Advantages can include greater speed and ride comfort when compared with transport systems that use wheels and rails.

The MagLev system has great acceleration and braking rates that can therefore cope with steep gradients, being limited only by the availability of power. MagLev systems do not suffer from the constraints created by limited adhesion between vehicle and infrastructure. The vehicle has less weight per seat as a result of the lack of bogies, pivots, and wheels that are the main heavy parts of conventional rolling stock. The major drawbacks are the system for switching routes and the difficulties of integration with existing networks.

There are two kinds of MagLev system: the German and the Japanese technology. The German system is based on magnetic attraction between electromagnets underneath the guide-way and upwards facing magnets on the vehicle and is known as the EMS (electromagnetic suspension) system. The Japanese EDS system depends on superconducting magnets in order to operate by repulsive forces, but it is still at the test stage while the German system is in limited public service in Shanghai, China, where an extension is currently being considered (Prosser, 2004).

Although promising from a purely technical perspective, very high-speed MagLev cannot yet be described as a mature technology where project risk is sufficiently low to embark on a large-scale implementation, such as the link between São Paulo and Rio de Janeiro. Apart from the short airport link in China (Shanghai) there are currently no commercial services using either the EMS or EDS technology.

2.2.5 Comparison between MagLev and Very High-Speed Rail Solutions

High-speed rail is in operation in various countries such as Japan, France, Germany, Spain, Italy and Korea and in all these countries it is being built on conventional railways. The MagLev technology is used in Japan and Germany only on test tracks and, as previously mentioned, in China on a limited operation scale, even though it has speed advantages over conventional railways. In order to facilitate the understanding of these findings, the author summarises a compilation of the key technical and functional differences reported by Prosser (2004) and Connor (2006) between conventional and MagLev high-speed transport technologies in Table 2.5.

The author also provides in Table 2.4 values that reflect energy and power use coefficients for different speeds as compared to 200 km/h for trains of the same aerodynamic shape and cross-sectional area (Connor et al., 2006).

Table 2.4: Energy and Power use coefficients (Connor et al., 2006)

Speed (km/h)	*160*	*200*	*225*	*270*	*300*	*330*	*450*
Speed (mph), rounded	100	125	140	168	186	205	280
Speed (m/s), rounded	44	56	63	75	83	92	125
Energy consumption*	0.64	1	1.27	1.82	2.25	2.72	5.06
Power Requirement*	0.51	1	1.42	2.46	3.38	4.49	11.39

*The values not include rolling friction and increased losses due to less efficient design.

Table 2.5: Characteristics of MagLev and conventional HSR (Connor et al., 2006)

Issue	***Very High-Speed Rail***	***Very High-Speed MagLev***
Performance	▪ Poor acceleration and braking; ▪ Upper limit to speed (about 500 km/h due to need for current collection).	▪ High rates of acceleration & braking; ▪ Top speed limited by alignment and aerodynamic resistance.
Civil Engineering	▪ Switching between lines straightforward; ▪ Long switches needed for high-speeds; ▪ Lines conventionally built at grade.	▪ Concrete or steel guide-ways; ▪ Normally elevated to reduce land take and to improve safety; ▪ Switching between lines relatively complex.
Safety	▪ Currently safest mode of land transport worldwide.	▪ Expected to be safer than high-speed rail due to almost total segregation.
Energy Efficiency	▪ Very good when compared with other modes; ▪ Energy use per seat km grows by square law as speed increases.	▪ Efficiency should be broadly similar to high-speed rail at speeds > 300 km/h; ▪ Energy use per seat km grows by square law as speed increases.
Operations & Capacity	▪ Generally good. Track and switching allows flexibility; ▪ Capacity limited at high-speeds due to poor braking.	▪ Poor flexibility; ▪ Capacity limited by the number of linear motor sections in guide-way.
Environment	▪ Route easier to integrate into built environment and landscape; ▪ Noise and vibration issues; ▪ Land-take is much lower than for motorways.	▪ Elevated guide-way visually more difficult to integrate into surroundings; ▪ Noise and vibration are lower; ▪ Land-take about the same as for high-speed rail or lower.
Reliability & Maintenance	▪ Track maintenance cost high for reliable operation although slab-track may address issue; ▪ System reliability reasonable but still needs to be improved; ▪ Relatively high vehicle maintenance costs.	▪ Guide-way maintenance costs expected to be lower although current design still requires regular adjustment; ▪ Reliability expected to be higher due to non-contact system; ▪ Very low vehicle maintenance costs thanks to low dynamic impact forces.
Integration & Interoperability	▪ Excellent integration with existing rail systems where routes into centres have sufficient capacity.	▪ It is difficult to link system physically with the existing networks due to lack of interoperability; ▪ Can use air-space of existing corridors.

2.3 System Engineering and Railway Project Management

2.3.1 Background

Railway projects tend to be far more expensive than budgeted or have been completed with substantial delays to the schedule. For instance, there was the Hallandsåsen tunnel between Malmö and Göteborg in Sweden, where chemicals in the grout used for sealing water inflows contaminated water supplies and tunnel workers and cattle were paralysed and had to be submitted for investigation. The Seoul–Pusan VHSR in Korea, modelled on the French LGV system, had to be postponed several times because of delays in construction and poor execution of some bridges. Another example was the Cologne–Frankfurt VHSR, where political interference in route design on Germany's prestige 'roller-coaster' high-speed line resulted in the construction of two intermediate stations serving a rural hinterland with very limited traffic demand (Connor et al., 2006).

As can be learnt through past examples, the author considers it necessary to characterise and manage the natural complexity of the rail mode and its implications in order to tailor the Systems Engineering (SE) and Project Management (PM) approach and cope with local challenges appropriately, as mentioned by Calvano (2004). Therefore, the following sections will present important characteristics of the complex systems nature of railways.

2.4 Complex Systems Nature of Railways

2.4.1 Natural Characteristics of Rail as a Mode of Transport

As mentioned previously, an understanding of the natural characteristics of VHSR increases knowledge of how to cope with unpredictable emergent behaviours that the dynamic complexity of the mode might introduce. In addition, particular operations and physical structures of the mode lead to a build-up of technical and organisational demands to deal with strengths and weaknesses in order to achieve dependability.

Therefore the author presents in Table 2.6 an overview of the four most significant and influential material (physical) properties or characteristics of the mode as portrayed by Schmid (2006). Managing these features may require the ability of organisations to analyse, identify, and predict key issues and form a modus operandi for coping with them.

Schmid (2006) also advocates that there are, in addition to these four, more significant ‘immaterial’ features of the mode such as: (v) High cost of assets, (vi) distributed staff, (vii) wide variety of skills, (viii) high variability of skills, (ix) direct customer contact, (x) instantly perishable products and (xi) high levels of political interference in decision-taking.

Table 2.6: Natural characteristics of railway mode (Schmid, 2006)

Properties → ↓ Aspects		(i) Motion restricted to single degree of freedom along track	(ii) Low coefficient of friction between wheels and rails	(iii) Stiff interface between wheels and rails	(iii) Distributed linear infra-structure subsystem
Strengths	S	• No steering required; • Predictable motion; • Narrow swept path; • Linked consists (trains); • High standard of safety; • Track-based power supply.	• Low rolling resistance; • Low rolling surfaces wear; • Efficient propulsion; • High speed operation; • Energy efficiency; • Energy recovery potential.	• Low energy dissipation; • High tonnages / period; • Low forces in track bed; • Predictable motion; • Smooth operations; • Potentially long track life; • Low wheel-rail damping.	• Product reaches customer; • Production process controllable throughout system; • External events rarely affect all of system; • Part opening of new routes; • Multiple feeding options.
Weaknesses	W	• Guidance function cost; • High route blockage risk; • Low network flexibility; • Complex route changes; • No collision avoidance; • Complex electrification; • Limited design options.	• Limited braking rate; • Low acceleration rate; • Seasonal adhesion variation; • Line of sight inadequate; • Low rolling surface wear; • Risk of slip and slide; • Torque control required.	• Stiff rolling interface; • Low inherent damping; • Noise & vibration issues • Cost of track & structures; • Cost of inspection; • High impact environment for all subsystems.	• Environmental impact affects strips of terrain; • Remote management of local problems difficult; • Voltage drop along route; • Many supply points needed.
Technical requirements	T	• Variable geometry elements; • Train position detection; • Locking of route elements; • Junctions & stations.	• Signalling system; • Adhesion control; • Artificial wear required; • Regular maintenance.	• Load rack design; • Testing & inspection; • Accurate maintenance; • Regular maintenance.	• Provision of redundancy; • Protective features (tunnels, galleries, fences etc.).
Operational requirements	O	• Timetabling & planning; • Modelling of train services.	• Path allocation to trains; • Stringent safety rules.	• Maintenance management.	• Scheduling of services; • Several layers of control.
Management tools	M	• Rigorous selection of staff; • Strict rulebook for all staff.	• Simulation of individual train behaviours.	• Technical understanding; • Strong procedures.	• Delegated authority; • Strong supervision.
Education and training	E	• Responsibility; • Staff competence.	• Environmental awareness; • Safety ethos.	• Strong engineering skills; • Safety ethos.	• Rule based behaviour; • Adaptive behaviour.

2.4.2 Defining and Measuring Complexity

Schmid (2006) described that Casti (1979) stated: ‘Basically, complexity refers to two major aspects of a system: (a) the mathematical structure of the irreducible component subsystems of the process, and (b) the manner in which the components are connected to form the system.’ Perrow (1999) suggests that complex interactions have the following characteristics: Proximity of parts and units that are not in a production sequence, presence of unfamiliar or unintended feedback loops, existence of indirect or inferential information sources and limited understanding of some processes. Such interactions allow a system to respond quickly to change; however, they also create substantial risks of accidents when combined with tightly coupled processes with time-dependent behaviour, invariant sequencing and little slack.

It is relatively easy to relate the context of the railway and its natural characteristics to Casti's and Perrow's views but both approaches offer only limited guidance on how to assess and control the nature of complexity in railways. McKechnie (1979) developed a framework with four determinants or dimensions of complexity, namely, heterogeneity, variability, interdependence and unanalysability. Schmid (2006) adopted the first three of these and added dispersion and longevity as dimensions that are particularly reflective of the rail mode. The five dimensions can be used to measure the level of complexity of a system, subsystem or process by assessing how different or heterogeneous it is in its composition, how often it has to adapt to a variable task or environment, to what extent it is interacting with other subsystems (and how reliant it is on their outputs), whether its component parts are co-located or widely distributed and whether the intended and de facto service life of component extends over several technology generations.

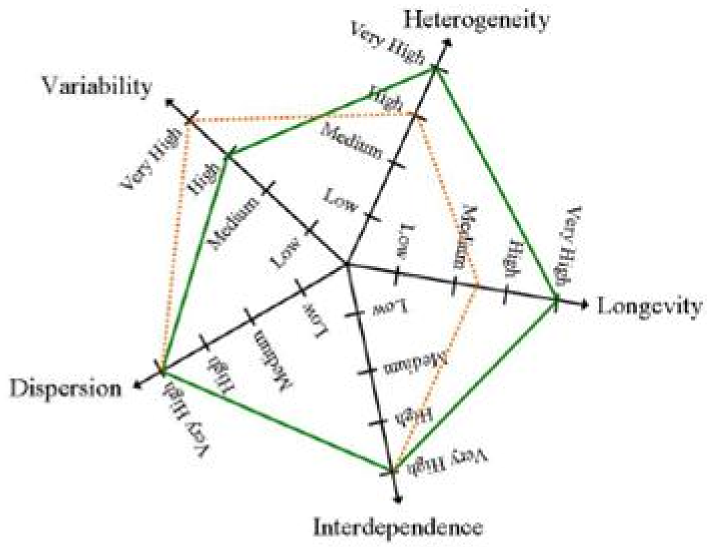


Figure 2.4: Dimensions of Complexity (Schmid, 2006)

The complexity of the railway creates substantial problems in managing the asset base, particularly in terms of creating, maintaining and representing the information about the infrastructure. Effectively, a very heterogeneous range of long-life assets is dispersed along the infrastructure of the network in a highly variable environment, with a high level of interdependence between different sub-systems, as shown in Figure 2.4. The full line in the figure represents the locus of the railway in about 1990 while the dashed line represents the emerging situation where the rapid pace of developments in computer technology leads to greater system variability and a shorter life-span.

2.5 Systems engineering and Project management applied to the railways

2.5.1 Systems engineering applied to the railways

The development of a new VHSR line in Brazil should take advantage of System engineering and Project management along its process to help ensure success in terms of performance requirements, management, time-scales, budget, maintenance, etc.

The VHSR system is composed of different systems which should be simultaneously performed in a dependable manner in order to deliver its purpose in terms of reliability, punctuality and safety in the transport of people and goods. However, a complex interaction lead to difficulties in meeting all requirements and providing the proper balance of system performance, life cycle cost, development schedule, and risk.

What is Systems Engineering? The author presents the INCOSE definition: ‘Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.’

Systems engineering is the implementation of efforts through an iterative process in order to: First of all, change an operational need into a description of system performance parameters and a system configuration. Next, integrate technical parameters and ensure interoperability of all the systems, including the physical, functional and logical, Third, integrate other factors to meet cost, schedule and technical performance objectives, together with targets to do with reliability, maintainability, safety, and human factors (Hayward, 1997). Thus, SE approaches are highly applicable to railway projects, since railways are complex systems, comparable to aircraft and advanced defence equipment.

2.5.2 Project management applied in railways

Project management was defined by Chew (2006) as ‘the application of knowledge, skills, tools and techniques to project activities to meet project requirements’. The applicability of this definition to VHSR leads to multidisciplinary activity to manage and integrate processes that will ensure a high level of systems integration.

A project, therefore, is a co-ordinated set of activities and tasks designed to achieve an objective by the development of physical, service or other capabilities, under conditions of defined schedules, budget, and performance criteria.

2.6 Railway Systems Engineering and Integration

Railway Systems Engineering and Integration, or RSEI, is concerned with managing the resources and processes required to build new railways and to enhance, renew and maintain existing railways in a safe, effective and efficient manner, while respecting the limitations and constraints imposed by the natural physical, operational and organisational characteristics of the rail mode of transport. Thorough systems engineering approaches, combined with good project management are more likely to lead to a successful railway operation than is commonly achieved using conventional project management approaches (Waboso, 2003). RSEI is not just about technologies, components, interfaces, know-how and processes. It is equally about developing people and their know-how so that they can carry out their tasks better and more effectively (Schmid, 2006).

3 Geography and Economy of Brazil

3.1 Geography of Brazil

3.1.1 Background

Brazil, officially the Federative Republic of Brazil is the fifth largest country by geographical area, the fifth most populous country with over 187.3 million inhabitants (IBGE, 2007a) and the fourth most populous democracy in the world. Despite being the fifth most populous country, Brazil has low population density and the majority of the population lives in the coastal area.

Figure 3.1: Brazil split into 5 regions

The Federation is formed by the union of the Federal District plus 26 States distributed into five main regions: Centre-West, North-West, Northern, South-East, and South (see Figure 3.1). The South-East region is the richest and most densely populated and has the country's two largest cities, São Paulo and Rio de Janeiro; while the South region is the wealthiest by GDP per capita (IBGE, 2007b) and has the highest standard of living in the country (UNDP, 2005).

The rail corridor suggested by the author should call at six terminal stations in the cities of Porto Alegre (Rio Grande do Sul State), Florianópolis (Santa Catarina State), Curitiba (Paraná State), São Paulo (São Paulo State), Rio de Janeiro (Rio de Janeiro State), and Belo Horizonte (Minas Gerais State).

3.1.2 Minas Gerais State

Minas Gerais lies almost wholly within the geologically ancient, mineral-rich uplands known as the Brazilian Highlands, a much dissected hilly upland reaching an elevation of about 790 metres above sea level. Only small sections of the southern and eastern parts are within the zone of the Great Escarpment that forms the eastern margin of the highlands. In the southwest, along the border of São Paulo, is the commanding range known as the Mantiqueira Mountains. The capital of Minas Gerais State is Belo Horizonte and located about 853 metres above sea level.

1.1.1 Rio Grande do Sul State

Porto Alegre is the capital of Rio Grande do Sul and located about 10 metres above sea level. The state occupies part of the Paraná Plateau, which is situated between 600 and 900m above sea level and composed of outpourings of basaltic lava solidified into sheets of rock known as diabase. It has been dissected into rolling hills by streams, but its margins are marked by steep cliffs and mountains which lie along the Atlantic coast.

1.1.2 Santa Catarina State

The Southern coastal state of Brazil is bounded to the north by the state of Paraná, to the south by the state of Rio Grande do Sul, to the east by the Atlantic Ocean, and to the west by the Misiones province of Argentina. It is one of the smaller Brazilian states. The capital is Florianópolis, located on the coastal Santa Catarina Island.

1.1.3 Paraná State

The Paraná state of southern Brazil is bounded to the east by the Atlantic Ocean, on the south by the state of Santa Catarina, on the southwest by Argentina, on the west by Paraguay, on the northwest by the state of Mato Grosso do Sul, and on the north and northeast by the state of São Paulo, Curitiba, the capital, in the eastern part of the state and located about 935 metres above sea level.

The State can be divided into five topographic zones, each running approximately northeast to southwest. Proceeding westward there is the coastal region, fringed with dunes and mangrove swamps and backed by the high mountain ranges of the Serra do Mar to the west. The Serra do Mar, rising to the peak of Serra da Graciosa about 1,888 metres, forms a watershed between the coastal region and the first of the three successive plateaux farther westward, each lower than the one before. The first plateau, which lies at a height of between 800 and 900 metres above sea level, is formed mainly of crystalline rock. On the western side of the first plateau, a cuesta (an escarpment with a steep slope on one side and a gentle slope on the other) rising to heights of from 1,050 to 1,150 metres marks the beginning of the second plateau. A basaltic scarp with a maximum elevation of 1,250 metres rises at the western border of the second plateau, forming the eastern edge of the third plateau, which slopes westward and downward until it reaches the fringes of the Paraná River.

1.1.4 São Paulo State

São Paulo has a coastline about 600 km long. The narrow coastal zone is broken by lagoons, tidal channels, and mountain spurs. It is bordered by the slopes of the Serra do Mar, on the edge of an extensive plateau with wide, grassy plains, about 460 to 920 metres above sea level. Isolated ranges of low elevation break the surface in places, but, in general, the undulating tableland slopes toward the Paraná River, the state’s western boundary. The capital of São Paulo State has the same name of state São Paulo and its elevation is 760 metres.

1.1.5 Rio de Janeiro State

The State of Rio de Janeiro has as capital the city of Rio de Janeiro. Most of Rio lies on a geological structure called Brazilian Crystal Basement; the rocks, gnaisses and granites. The entire state has a profile of mountains and depressions and it is divided in three morphologic frames: the coastal low lands (referred to as Baixada Fluminense), the coastal elevations and the highlands. The Baixada stretches all along the coast, with a large diversity of morphology (rocky mountains, beaches, dunes, lagoons, and other formations can be found in the shores of Rio). Furthermore, most of the State are located in highlands (often higher than 1000m), which resulted from the eruption of the several mountain chains which cover Rio de Janeiro. The chain which separates São Paulo from Rio is known as Serra do Mar; between Rio and Minas, it´s called Serra da Mantiqueira (the highest point of the State is Pico das Agulhas Negras - Black Needles Peak, located at Mantiqueira); the mountains receive other local denominations (like Serra dos Órgãos) across the State.

3.2 Economy of Brazil

3.2.1 Background

The economy of Brazil is ranked as the world's tenth largest at market exchange rates and the ninth largest in purchasing power as well as the largest national economy in Latin America (FMI, 2008). As a result of its economic growth and forecasts of economy by 2050, Brazil is regarded as one of the group of four emerging economies called BRIC (Sachs, 2005).

Figure 3.2: Industry concentrations (IBGE, 2002)

Up to 30.8% of the gross domestic product come from industries from cars, steel and petrochemicals to computers, aircraft, and consumer durables (IBGE, 2007b). Figure 3.2 presents how the industries are located and concentrated geographically. Metropolitan areas such as São Paulo, Rio de Janeiro, Curitiba, Campinas, Porto Alegre, Belo Horizonte, Florianópolis, Recife, and Fortaleza are foremost among the concentrations.

Brazil is the world's tenth largest energy consumer. Most energy consumption comes from renewable sources, particularly hydroelectricity and ethanol, or non-renewable sources, mainly oil and natural gas. Brazil will become an oil superpower, with massive oil discoveries in recent times (Petrobrás, 2008).

3.2.2 Minas Gerais

The metropolitan region of Belo Horizonte (MRBH) has a GDP of about R$ 62.3 billion. The economic production is highly concentrated in a few cities such as Belo Horizonte, Betim and Contagem which have about 84% of GDP in the metropolitan region (IBGE, 2007b). The trade and services sectors are very important for the MRBH and industry, the emphasis being on the metallurgical industry, cars, petrochemical and food. Moreover, the MRBH is also a centre of excellence in the areas of software and biotechnology.

3.2.3 Rio de Janeiro

The State of Rio de Janeiro has an economy based on extracted minerals such as oil and natural gas as well as a manufacturing sector where we may highlight the metallurgical, chemical, textile, printing, publishing, pharmaceutical, beverage, cement and furniture industries.

The main cities are Angra dos Reis, Niteroi, Resende and Volta Redonda. The two first cities offer a growing shipbuilding industry because of a strong resumption of investment, while Resende and Volta Redonda offer significant gains in terms of GDP mainly through a large increase of production of cars and steel products, respectively.

The metropolitan region of Rio de Janeiro, as considered by IBGE, boasts a GDP of R$ 172.5 billion, constituting the second largest cluster of national wealth where is concentrated 70% of the economic power of the state and 8.04% of all goods and services produced in the country.

3.2.4 São Paulo

Located in the South-Eastern region of Brazil, the Estado de São Paulo is the most industrialised and urbanised in the country. The urban rate and industrial development are in accordance with the developed countries of Western Europe such as Spain, Italy, England, France and Germany. However, unlike these countries, the state still lacks systematic and integrated environmental information and operational resources that would enable it to face very serious problems of environmental degradation resulting from a disorganised and expanding urban population.

Currently, São Paulo State has a population of nearly 40 million inhabitants, approximately 22% of the Brazilian population, a population density of 154 inhabitants per km2. Its three large metropolitan areas are São Paulo, Baixada Santista and Campinas, where are concentrated around 21.7 million inhabitants, or 58.6% of the population of the State and 12% of the total population of Brazil (190 million inhabitants). They also have a GDP higher than that of many countries, such as Denmark and Norway, which corresponds to 63.2% of the GDP of São Paulo State and almost one quarter of that of the country.

Some leading conglomerates in the world are installed in São Paulo and responsible for 40.62% of the entire Brazilian GDP, from 30 major Brazilian companies. Seventeen are in the State of São Paulo (Government of the State of São Paulo, 2000).

The State also has about 42% of total participation in Brazilian exports, participating in 11% of exports of basic products and 42% of industrialised products in Brazil. São Paulo State exports approximately 92% of industrialised products made in Brazil (Government of the State of São Paulo, 2000).

3.2.5 Paraná

Curitiba has been elected as the best new business destination of the country in the last few years. The title echoes the view of Latin American executives, who chose the capital of Paraná as the fifth best city to invest in the continent. In the survey conducted by the magazine America Economia, Curitiba was surpassed only by São Paulo, Santiago (Chile), Monterrey (Mexico) and Miami (USA) (America Economia, 2006). Strategically located on the axis of countries in the Mercosul and near major ports, such as Paranaguá, Curitiba retains the marks of European colonisation in its cultural diversity, both architectural and gastronomic, but in recent decades has received multinationals such as Volvo and Renault, which help the city to be considered as a major car manufacturing centre of the country.

With a vast industrial park of about 43 million m2, the metropolitan region of Curitiba has attracted large companies such as ExxonMobil, Sadia, Kraft Foods, Siemens and HSBC, responsible for providing services in information technology to 77 countries. Also, the city has received over 822 foreign missions basically formed by town planners, engineers and managers interested in their urban planning. Moreover, the flow of tourists has exceeded the number of inhabitants with 2 million visitors, at least half of whom arrive in the city on business (VEJA, 2006).

3.2.6 Santa Catarina

The economy of Santa Catarina is very diverse with each region showing growth potential. The GDP of the state is R$ 62.2 billion, the seventh largest in Brazil, accounting for about 4.0% of the national total. The main economic activities are agriculture, livestock, fisheries, tourism, and extractive industries. Moreover, Santa Catarina, being the seventh richest state in Brazil, and the State of Paraná (fifth) and Rio Grande do Sul (fourth) represent about18.2% of the country's economy (IBGE, 2007b).

The economy is based on industry, primarily agribusiness, textiles, ceramics and metal-product, ore extraction, and livestock. The state of Santa Catarina is the largest exporter of chicken and pork, where Sadia and Perdigão are the two largest Brazilian food companies located there. Among the industries are WEG and EMBRACO, the first being one of the largest manufacturers of electric motors in the world and the latter one of the largest manufacturers of compressors for refrigerators.

3.2.7 Rio Grande do Sul

The most southerly state of Brazil, Rio Grande do Sul, shares a border with Uruguay and Argentina that allows the State a prime location between the countries that make up the Mercosul[2] economic group.

The GDP of Rio Grande do Sul is Brazil's fourth largest. In 2006, it grew 2.7%, reaching R$ 156 billion. The GDP per capita grew 1.6% in the same year, to R$ 14.2 thousand. One of the biggest producers and exporters of grain in Brazil, the State also has much of its economy based on the industrial sector (40.6%) (IBGE, 2007b).

The good condition of its roads, telecommunications and energy resources, and programmes offered by the State government has made Rio Grande do Sul champion in the attraction of national and international investments. In 2003 and 2004, the installation of 145 new ventures was confirmed, such as John Deere, Pirelli, AGCO, Bunge and GKN. Private investment reached about US$ 14 billion and the vacancies offered to workers totaled about 29,200.

[2] **Mercosur** or **Mercosul** (Spanish: *Mercado Común del Sur*, Portuguese: *Mercado Comum do Sul*, English: *Southern Common Market*) is a Regional Trade Agreement (RTA) among Argentina, Brazil, Paraguay and Uruguay founded in 1991 by the Treaty of Asunción, which was later amended and updated by the 1994 Treaty of Ouro Preto. Its purpose is to promote free trade and the fluid movement of goods, people, and currency.

4 Belo Horizonte – Porto Alegre Corridor

4.1 Background

In Brazil, the transport of passengers by road is responsible for driving more than 140 million users per year where the leader mode is bus transport in the collective movement of commuters travelling cross-border states (ANTT, 2008). The interstate service, in particular, is responsible for almost 95% of total travelling made in the country. As a result, road transport has expressive participation in the Brazilian economy, assuming an annual turnover greater than about R$ 2.5 billion in the terms of regular services provided by private companies where about 13,400 buses are used (ANTT, 2008).

These figures can be considered as a consequence of several years of massive investment of government on highway infrastructure where through the current network is clearly seen the disparity between the amount of roads (over 1M km) and railroads (23,116 km) built in the country (ANTT, 2008). When compared the Brazilian railroad with other countries such as USA and Australia where they have similar dimension, the Brazilian network is completely obsolete and covers only small part of the country. The services of passengers virtually ended and remain only freight transport mostly for the transportation of minerals, for example. The single line of passengers that still preserving daily service with relative comfort is the Belo Horizonte-Vitória. However, there are some railroads for tourist operation, such as Curitiba-Paranaguá (Paraná State) and Campinas-Jaguariúna (São Paulo State).

The development of high-speed line between Belo Horizonte and Porto Alegre, illustrated by Figure 4.1, will link the capital states of south and southeast region and strategic cities along the corridor. Both regions are the richest and most populated of Brazil and there also be the largest metropolitan regions of the country, whose population comprises roughly 100 million inhabitants (IBGE, 2007a). In addition, the states that compose both aforementioned regions bring together more than 70% of the Brazilian GDP, where are also located the highest developed region and installed more than 75% of the industries of the country (IBGE, 2007b). Therefore, the proposed route operated by passenger railway transport may facilitate cross-boundary travel for commuting, leisure and business.

Considering all scenarios pointed out together with the federal law 11.297/2006 that allows using of private investment in the VHSR project and put forward the feasible studies of São Paulo – Rio de Janeiro link under coordination of VALEC, the author describes underpinning details about the connexion between Belo Horizonte and Porto Alegre where a rail link should provide new capacity for travelling between the capital states and improve north-south journey times, together with relieving expected congestion on road and air network on the aforecited regions.

Figure 4.1: Alignment between capital cities

Thus, the development of a HSR network can be a revival of rail passenger transport in Brazil. This means not only the development of rail link but the redevelopment of the areas – in particular the creation of a stimulus for urban development in the wider sense (Priemus, 2006).

4.2 Socio Economic

The design specification for a VHSR, as previously pointed out, imposes a set of technical, environmental, geographical and economical constraints. Within them, the VHSR should be developed and managed in order to minimise cost. The building cost of railways system represents more than about 55% of total cost and therefore studies in order to avoid steep gradients, provide the shortest possible route between the destinations, make effective use of current rail infrastructure such as stations and access to city centres, and design to minimise environmental impacts and impacts on habitations must be done where possible.

Furthermore, planning cross-boundary railways should also be analysed aspects of corridor concerning physical and demographic density characteristics; volumes estimated demand distributed on current modes, amount of current trades, and also requires assumptions about socio-economic development in the proposed states and Brazil as a whole.

Table 4.1: Population and Employment in the Metropolitan Area

	Population (1) 2007	*Employment* (2) 2000
São Paulo	19,223,897	9,601,504
Rio de Janeiro	11,571,617	5,394,420
Belo Horizonte	4,939,053	2,718,998
Curitiba	3,172,357	1,508,843
Florianópolis	841,552	399,578
Porto Alegre	3,959,807	2,216,826

(1) IBGE (2007) (2) IBGE (2000)

The Table 4.1 outlines the level of population and employment over the metropolitan areas where the greater São Paulo can be highlighted by its substantial level of employment and demographic density. Furthermore, the population of Brazil in 2050 is estimated by IBGE to have a substantial growth of 37% where the most part may live in greater areas such as São Paulo, Rio de Janeiro, Curitiba, etc. This suggests that development of VHSR can give support to economic growth as has been seen in many countries around the word. Besides of helping to augment effect on the competitiveness of all other sectors of the economy that leads to rise employment rate if mobility is increased.

4.3 Traffic on Corridor

The Table 4.2 demonstrates coach and air trips between all each capitals and São Paulo. As can be seen, the busiest route is São Paulo – Rio de Janeiro where there is greater commuting of 5.8 million of passenger per year by coach and air together. Other routes that can also be highlighted are São Paulo – Belo Horizonte where there are over 2.3 million of passengers per year and São Paulo – Curitiba where greater than 2.2 million of transference annually between both cities. Moreover, the route from São Paulo to Porto Alegre has also had a greater traffic about 1.9 million of passenger per year flight by airplane. The daily private car trips are not mentioned since it was not available from the department of transport and therefore any comments will be estimated figures by the author.

Table 4.2: Existing demand of transportation

	Airplane	*Coach*
São Paulo – Rio de Janeiro – São Paulo		
Average daily trips	182 (1)	210 (2)
Passengers/year	4,584,871 (3)	1,326,243 (4)
São Paulo – Curitiba – São Paulo		
Average daily trips	44 (1)	75 (2)
Passengers/year	1,576,200 (3)	641,225 (4)
São Paulo – Belo Horizonte – São Paulo		
Average daily trips	63 (1)	77 (2)
Passengers/year	1,746,496 (3)	579,710 (4)
Rio de Janeiro – Belo Horizonte – Rio de Janeiro		
Average daily trips	63 (1)	55 (2)
Passengers/year	761,461 (3)	383,153 (4)
São Paulo – Florianópolis – São Paulo		
Average daily trips	29 (1)	20 (2)
Passengers/year	986,489 (3)	67,772 (4)
São Paulo – Porto Alegre – São Paulo		
Average daily trips	62 (1)	9 (2)
Passengers/year	1,923,795 (3)	31,864 (4)
Florianópolis – Porto Alegre – Florianópolis		
Average daily trips	14 (1)	30 (2)
Passengers/year	304,993	172,692 (4)
Curitiba – Porto Alegre – Curitiba		
Average daily trips	14 (1)	20 (2)
Passengers/year	430,697 (3)	49,271 (4)

(1) ANAC website on 28/08/2008, (2) ANTT (2007)

4.4 Journey Time

The time is one of most important component that influences on what kind of mode of transport will be taken. The journey time of some sections in the proposed corridor is presented in Table 4.3 where a comparison is carried out between VHSR and current modes of transport. It clearly demonstrates that the journey performed by VHSR is faster than other modes for trips between cities located between 200 km and 700 km allowing substantial cutting travel times compared with air and car mode. On the other hands, journey over 700 km may not be the attractive mode in a travel time case but a greater fare policy can lead to transfer users from other modes. The coach service is not mentioned since it does not offer the best choice for time journey. Moreover, access and wait time equal to 1.2, 2.5 and 0h were assumed for high-speed rail, air travel and car, respectively.

Table 4.3: Journey time comparison

	VHSR [(1) (2)] *(min)*	*Aircraft* [(1) (4)] *(min)*	*Car* [(1) (3)] *(min)*
Belo Horizonte – São Paulo	189	220	385
Belo Horizonte – Rio de Janeiro	159	240	290
São Paulo – Rio de Janeiro	158	210	300
São Paulo – Curitiba	154	210	270
São Paulo – Florianópolis	213	220	430
São Paulo – Porto Alegre	294	250	660
Curitiba – Florianópolis	132	210	192
Curitiba – Porto Alegre	214	215	455
Florianópolis – Porto Alegre	167	210	295

(1) Single journey considering Access and Waiting time
(2) Single journey assuming average haul speed about 300 km/h
(3) Single journey assuming average haul speed about 90 km/h
(4) TAM Linhas Aéreas S.A.- www.tam.com.br

As previously mentioned, time and cost are factors that significantly influence the choice of mode of transport by user (Papacostas and Prevedouros, 2005). Therefore, the author argues that to ensure the competitiveness of VHSR to other alternatives, it is expected that the journey time between origin and destination on a door-to-door service must be faster considering arrival and departure time in the stations.

The Table 4.4 shows the road distance between the capitals of states, and as can be seen, six combinations of routes are between about 200 km and 600 km and three routes are just over than 700 km that requires a ticket policies to become attractive. This information advocates that VHSR can be a greater mode choice.

Table 4.4: Road distance between capitals

	Distance (km)					
	Belo Horizonte	Rio de Janeiro	São Paulo	Curitiba	Florianópolis	Porto Alegre
Belo Horizonte	x	434	584	1,004	1,301	1,712
Rio de Janeiro	434	x	429	852	1,144	1,553
São Paulo	584	429	X	408	705	1,109
Curitiba	1,004	852	408	x	300	711
Florianópolis	1,301	1,144	705	300	x	476
Porto Alegre	1,712	1,553	1,109	711	476	X

4.5 Station Locations

The worldwide VHSR stations are being developed as an important node of connexion between concentrations of transport, infrastructure and urban functions such as work, facilities, and residential. Priemus (2006) mentioned that VHSR stations offer plenty of potential for the development of high-quality transport nodes with attractive locations for offices, residential housing and service facilities. These facts are called as property-led where development is stimulated primarily by changes in the place and transport-led where development mostly by changes in the node or related infrastructure.

Based on factors above, the author presents a briefly set of appraisal criteria in order to define a suitable choose for station sites. The station location should deliver features in terms of support to current and future demand for transportation; adequate space for operations, accessibility, and station facilities; geometric characteristics in order to accommodate the station layout requirements and design criteria along with minimal constraints such as complex and costly design solutions and inefficient system operations.

Next, the accessing city centres is a critical issue for new railways, as capacity on existing routes is limited or if new tunnelled access is required this can be very costly and therefore VHSR, in the first instance, should be drawn up on small portions of the current rail track mainly in the regions highly populated.

Thus, the author suggests some possible sites along the route in order to build VHSR stations and meet requirements such as the ability of the location to satisfy patronage, increase ridership without threatening the integrity of the environment or existing neighbourhoods, and integrate the station into new and updated plans for surrounding development. However, a deep research on the city may deliver to better places and regions.

A termini station located next to Central station in the city of Belo Horizonte may bring about a greater link with Line 1 of the Brazilian Company of Urban Trains (CBTU) railway. The station is located near to city centre and important business and trends. In addition, the Line 1 also delivers a quick link with the Pampulha Airport through the 1^{o} Maio station. In the case of São Paulo, the author highlights an option to locate and construct a VHSR station surrounding both Julio Prestes and Luz station. The reasons are as following: easier links to existing underground and suburb network, and futuristically the link to international airport of São Paulo that will run from Luz station (Schmid, 2008). Moreover, there is a city council project of revitalization and upgrading of surrounding areas of Luz and Julio Prestes station in order to promote social and economic development of establishments of region.

To the city of Rio de Janeiro, the author suggests two options. The first option represents the Leopoldina station in the Praça da Bandeira neighbour. It is located about 1 km far away of city centre. It is a missed railroad station where there is a greater land available to lay down a HSR station. This option requires public policies in terms of transport and infrastructure for restoration of region because of lack of transport facilities, restaurants, shops and businesses. Moreover, modifications in the track are needed in terms of gauge to meet VHSR requirements. The second option is the Dom Pedro station, in other words, Central do Brasil. It is the busiest station of Rio de Janeiro whole railway lines take place and this option also delivers available land use. Building a HSR station next to Central do Brasil must be deeply studied since its current conditions such as where there are too many transport facilities and other functions present at station location may lead to conflict or chaos.

In Curitiba, the city council is building up a corridor between Pinheirinho and Atuba neighbour, namely, Avenida Linha Verde. The project will link the two sides of the city in shorter travel time and connect the centre of city to BR-116 through segregated bus lanes (PMC, 2008). Thus, the author suggests the option where a terminus could be located next to Capanema stadium and intercity coach station. It would be in line with the new infrastructure made by city council. Moreover, there are freight lines operated by America Latina Logística (ALL) where can deliver more opportunities for accessing into the city.

To Santa Catarina State, the author suggests two possibilities to construct the VHSR station in São José or Florianópolis. The São José has a greater number of enterprises in the city, about greater than 19 thousand among three neighbours (Barreiros, Campinas, and Kobrasol), as well as it is located nearest commercial and industrial areas, shopping centre Itaguaçú, city council building and the express highway where goes to the Florianópolis island. The Florianópolis option, the termini could be laid down next to the old and new coach station where there is a plenty available land for the development of VHSR and links with the current infrastructure of Florianópolis council. However, this option delivers the needs of building a new bridge between the continent and island in order to run the VHSR.

In the case of Porto Alegre, the termini station might be built next to Airport station of the Trensurb Railway Company. This station provides access to Salgado Filho airport and a link with the railway system of metropolitan area.

4.6 Alignment

The search for an optimal alignment for the proposed route takes a long and complex process where there are many issues that conflict with one another. The characteristics that the planner must be taken account are geographic features (hills, valleys, mountains, rivers, sort of grounds, railways inability to climb steep gradients), passenger considerations (limited vertical, lateral accelerations, and jerk), community severance (cut communities and may block the expansion of built up areas), political considerations (politicians may lobby for a particular route, and NIMBY considerations), land contamination (contamination by chemicals or previous traffic on old alignments are expensive to clear up), archaeological constraints, existing utilities (existing sewers, water, and gas pipes etc), environmental issues (animal routes, visual intrusion, noise and vibration), and technical aspects.

The route from Belo Horizonte to Porto Alegre may underlay on many sorts of constraints mainly in terms of environmental and geographical. They are the major constraints that engineering factors and leaders must cope in order to deliver less expenditure in required bridges and tunnels, etc.

In order to illustrate the possible features of VHSR line a proposal made by an Italian company, namely, Italplan Engineering, Environment & Transports estimated that the route between São Paulo and Rio de Janeiro would have nearly 403km long split into roughly 105 km (26.1%), 132 km (32.7%) and 166 km (41.2%) where are bridge, tunnelling and trackbed, respectively. Those figures demonstrate similarities to VHSR previously built in Korea. The Korean high-speed line is composed by 133 km long in an open route (28%), 163 km in tunnels (34%), and 181 km in viaducts (38%) and its cost was over € 42 million per kilometre presented by Steer, Davies & Gleave (2004).

Regarding some of the international costs are adopted for mainly reference but it might not be totally comparable with the future Brazilian costs since must be taken into account the many variations in cost that is highly dependent on whether the route is on viaduct, in tunnel or on flat or hilly land, environmental and safety regulations. For example, the construction of routes through tunnels or over viaducts is shown to be 4-6 times more expensive per kilometre than construction over flat land (Steer et al., 2004).

The São Paulo – Rio de Janeiro route will pass through Serra do Mar and next strategic cities to economy of states as São Jose dos Campos, Taubaté, Resende and Volta Redonda. Where some intermediate stops can aggregate value for the system; however, it must be analysed in order to not affect compromise of the competitiveness and bring greater operational performance of the system.

At the same way, São Paulo – Curitiba route was stated by Prof Cavichiolo (IEP) on the 6th World Congress on High Speed Rail where the line could be composed about 356 km long where tunnelling will take about 80 km long (22,5%), bridges and viaducts nearly 70 km long (19,7%), and trackbed 206 km long (57,8%). These features are similar to the Japanese high-speed railway.

In order to link São Paulo to Belo Horizonte and Belo Horizonte to Rio de Janeiro, the author mentions that there is a case for a creation of branch of roughly 300 km from Resende or Volta Redonda to Belo Horizonte. Resende hosts car industries such as Volkswagen and Volta Redonda is involved in steel industries. However, the author advocates that Resende has greater potential than Volta Redonda for hosting the diversion to Belo Horizonte. It is based on available plenty land and its localization is in the middle of São Paulo – Rio de Janeiro corridor. This option is similar to the Mokpo route in South Korea that can be seen in Section 6.5.

Through the Curitiba – Florianópolis route, the alignment will be run across regions such as Vale and Foz do Itajaí where Blumenau Joinville have great conurbations and industries (IBGE, 2005). One of the major issues that must be pointed out is the difference of elevation between both cities about 935 m. It may lead to increase of the line length and more expenditure in building. On the other hand, the next section from Florianópolis to Porto Alegre will be laid over regions such as Tubarão and Carbonífera that represent where Tubarão and Criciúma also have high rate of industrialisation.

Tabela 4.1: Socio-Economical data of strategic cities along the corridor

	Population(1)
São Jose dos Campos (SP)	594,948
Taubaté (SP)	265,514
Resende (RJ)	118,547
Volta Redonda (RJ)	255,653
Joinville (SC)	487,003
Criciúma (SC)	185,506
Blumenau (SC)	292,972

IBGE(1)

5 Technical Aspects of Very High-speed Rail Systems

5.1 Background

High-speed railways need constant updating to new systems if they are to be winners in competing transportation modes. The author outlines international experience on technical aspects of high-speed systems in this chapter, giving an overview regarding particular characteristics of rolling stock, infrastructure, and power traction that must be taken into account in the project in order to bring superior results in ongoing savings and savings on capital costs.

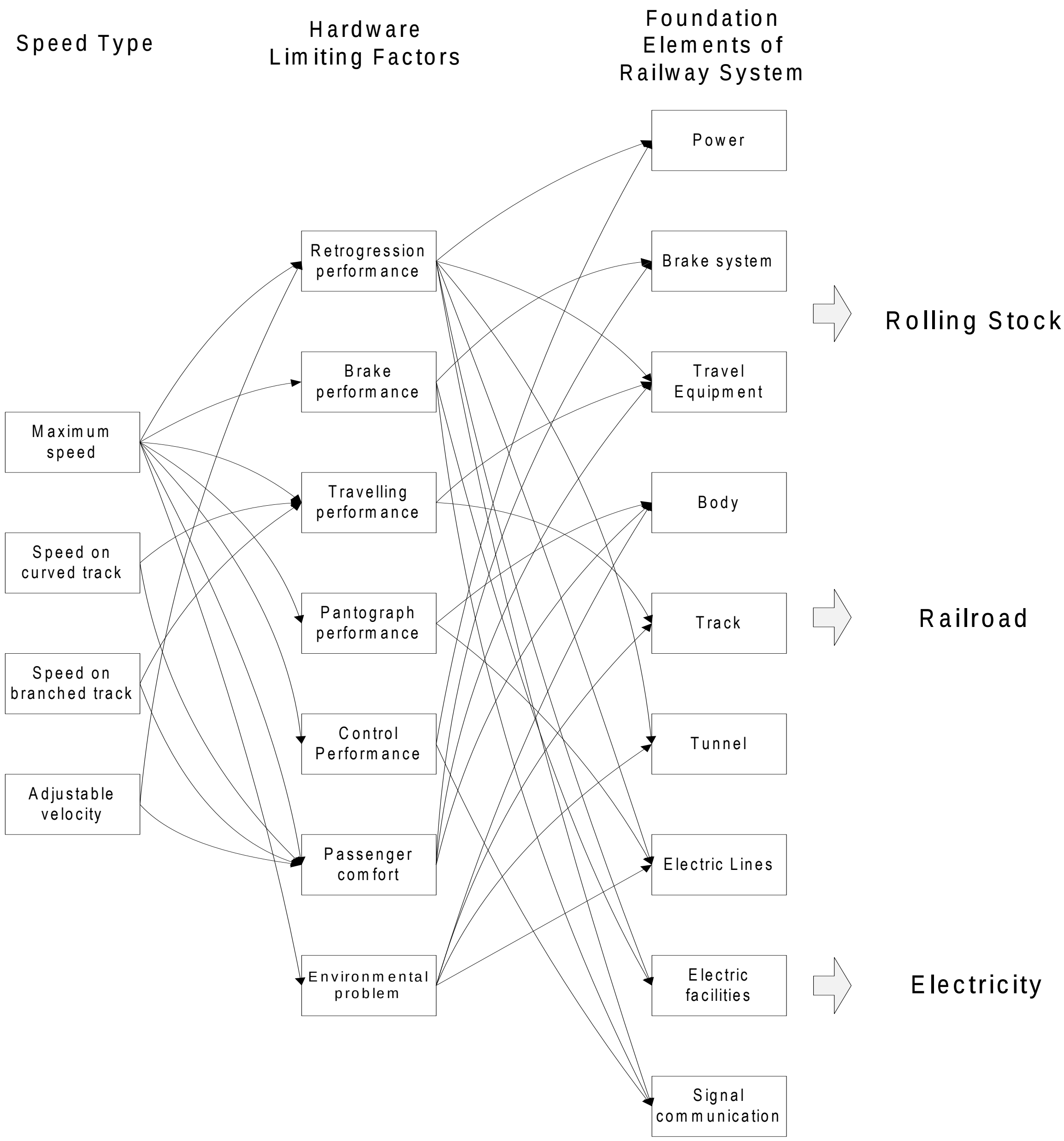


Figure 5.1: Limiting factors for the speed goes up (Raghunathan et al., 2002)

The Figure 5.1 demonstrates the technical limiting factor to the speed of trains and associated factors. These factors are mainly associated with the train body, the track line, the electric devices around the track, etc. For instance, the train's speed along a curved track is limited by the travelling performance and passenger comfort and safety, which are again associated with the train body and track line. Thus, to be able to increase the maximum speed of trains, it is necessary to take account of these limiting factors.

5.2 Rolling Stock

5.2.1 Weight-to-Passenger Ratio

One important characteristic of high-speed rolling stock is reduced passenger car weight. Studies carried out in High-speed Trains by Rochard & Schmid (2004) demonstrate some aspects of the influence of weight in energy consumption, infrastructure maintenance cost, and lower life-cycle costs.

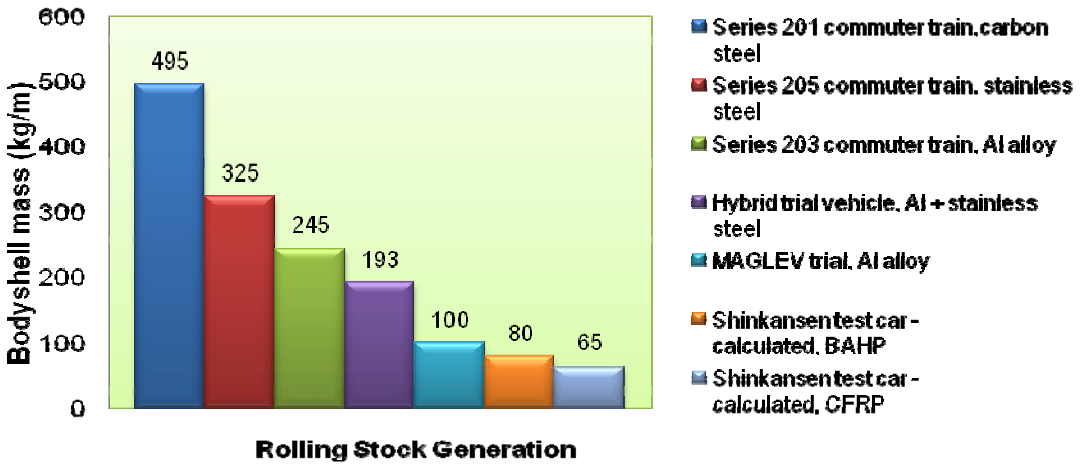


Figure 5.2: Bodyshell mass relative to construction material (Suzuki and Satoh, 1995)

Cost saving is the major driver of new developments in the railways system. The Korean Railway Research Centre has been developing its new type of TGV train, namely, VHSR350x, where modifications such as the use of aluminium alloy in their body-shell leads to reduced weight that can be of benefit by bringing down the capital cost of infrastructure and the ongoing maintenance cost, as pointed out by Rochard & Schmid (2004).

Currently in Japan, carbon fibre reinforced plastic (CFRP) and brazed aluminium honeycomb panels (BAHP) have been applied to build the bodyshells of future generations of Shinkansen (Rochard & Schmid, 2004). A comparison of bodyshell masses, in kg/m, is given in Figure 5.2 for various vehicle types relative to the materials used in their construction.

Energy consumption of rolling stock is highly related with their kinetic energy. Lighter trains require less use of energy to be in movement allowing the use of lower traction and braking systems. Moreover, this provides savings in the size or spacing of substations and power supply facilities, with an effect on cost as well as on direct and indirect pollution. Thus, lower train mass can be expected to reduce dynamic track forces such as vertical and stiffness forces and, consequently, there is less ground-borne vibration.

5.2.2 Air Effects

The aerodynamic and aeroacoustic are air effects linked with the speed-up of transportation vehicles. Factors associated with the flows or turbulence occurring around railway trains are transformed into aerodynamic drag, noise and vibration resulting in considerable energy losses and reduced performance of the train.

The train’s aerodynamics are related to diverse factors such as aerodynamic drag, pressure variations inside the train, and pressure waves when it goes in and out of tunnels. Vibration can cause reduction of performance and loss of energy as mentioned above. On the other hand, competent design brings positive results: for example, the design of the VHSR350x in Korea has led to travel at 350 km/h in commercial service with 15% less drag than the KTX by designing an aerodynamic train nose (Chul, 2007).

Table 5.1: Aerodynamic versus Related Matters (Rochard and Schmid, 2004)

Aerodynamic Problems	*Related Matters*
Aerodynamic drag of train	Maximum speed, energy consumption
Aerodynamic characteristics of train due to cross-winds	Safety in strong cross-winds
Aerodynamic force due to passing by of two trains	Running stability, Quality of comfort for passengers
Winds induced by train	Safety for passengers on platforms, Safety for maintenance workers
Pressure variations in tunnels	Quality of comfort for passengers, Ear discomfort, Air tightness of vehicle, Stress upon vehicle, Ventilating system of vehicle
Micro-pressure waves radiating from tunnel exit	Environmental problems near tunnel exit
Ventilation and heat transfer in underground station and tunnel	Quality of comfort for passengers, Prevention of disaster (fire)
Aerodynamic noise	Environmental problems

Table 5.1 lists the major aerodynamic problems of the VHSR and associated factors closely related to the train shape, which is required to produce aerodynamically good characteristics.

Thus, high-speed railway train system connecting these cities in Brazil must be built with a high level of aerodynamic and aero-acoustic performance, smooth surfaces, and the middle part of train should be a sleek design in order to deliver safe and comfortable transport with less air pollution and noise, and reliable transportation with low cost and maintenance.

5.2.3 Alternating Current

For high performance of the High-speed Train, quality and reliability of the power supplied must be available. The current technology used to feed high-speed trains is AC high voltage. The systems commonly used for high-speed lines are the 15kV, 16 ½ Hz and 25 kVac, 50/60 Hz. The AC systems require special transmission features in order to reduce ground current leakage. However, the last is the world standard for mainlines and high-speed lines.

The 25 kV, 50/60 Hz can be supplied in two configurations. The first is where the voltage generated and transmitted to the trains is 25kV and the second is 50 kV, an auto-transformer scheme' where the transmission is done at 50 kV, but the rolling stock will receive 25 kV.

5.2.4 Traction Motors

The motors fitted in high-speed trains use modem power electronics and the associated microprocessor-based control electronics in order to make it feasible to control AC or DC traction motors from AC supplies.

The first generation of controllers for a variable-voltage and variable-frequency supply were of low reliability and made the power electronic converter more complicated, especially when working from a AC supply, and arguably less reliable and more expensive. However, the latest generation of power electronic inverters (i.e. providing a vvvf' supply) based on Gate-Commutated Thyristors (IGCT) are suited for high power applications such as high-speed railways, being more compact and reliable than the previous generation based on Gate-Turn-off Thyristors (GTO) and are now able to control all sorts of motors.

5.2.5 Contact Systems

The pantograph is the most current collection device used by high-speed lines. It collects electric current from overhead lines for electric trains. The most common type of pantograph today is the so-called half-pantograph or 'Z'-shaped pantograph, which has evolved to provide a more compact and responsive single-arm design at high-speeds as trains get faster. The half-pantograph can be seen in use on everything from the very fastest trains such as the TGV to low-speed urban tram systems. Moreover, the Japanese Shinkansen has tested a multi-split slider pantograph and using only one pantograph per trainset with pantograph noise insulation panel for reduction of noise in the high-speed test train Fastech 360 (Endo, 2005).

Thus, pantographs must be specially designed in order to assure high-speed collection performance from the catenary when the train is running at high-speeds and be eco-friendly and low-noise.

5.3 Infrastructure

5.3.1 Track

Most of the conventional railways are still running on traditional ballasted track type; however, an increasing applications of ballastless track can be seen on high-speed railways worldwide (Esveld, 2003). For instance, Chinese high-speed railways have planned to use more than 4000 km of ballastless on their tracks for the near future (Steenbergen et al., 2007).

Actually, life cycle costing, construction time, availability and durability have played an increasingly important role on designing of new high-speed track. That results on new attitudes in favour of ballastless system than ballasted track concepts. This preference is due to the fact that ballastless has several advantages over ballasted track. For example, structural advantages (higher longitudinal and lateral permanent stability), operational advantages such as reduction of maintenance with 70 – 90% (Esveld, 2001); In spite of open line great care must be taken to ensure that the sub-grade layers are homogenous and capable of bearing the loads imposed, prevention of churning up of ballast particles at high speed, and an increase of passenger comfort as well as safety, due to the higher track stability and better alignment). In contrast, the high initial investment costs and a lower vibration and noise absorption, which may also lead to structural damage at an early stage.

Table 5.2: Comparison of VHSR infrastructure characteristics (Lindahl, 2001)

	TSI CEN	JR Tokaido	JR Sanyo	JR Tokyo Joetsu	DB Hannover Würzburg	DB Köln-Rhein Mann	SNCF TGV Paris-Sud Est	SNCF TGV Atlantic	BV Botniabanan (partly)
Max. design speed (km/h)					280	300	300	350	250
Max. service speed (km/h)		270	300	275	250		270	300	200[a]/250[b]
Cant (mm)	180	200	180	180	65	160	180	180	150
Cant deficiency (mm)	100	100	100	100	80	150	85	60	100/220
Cant excess (mm)	110				50				100
Min. curve radius (m)		2500	4000	4000	7000	3350	4000	6250	3200
Min. radius of design speed (m)					5100	3425	4000	6020	2950/2000
Track distance (m)	4.5	1.24	4.3	4.3			4.2	4.2	4.2
Min. vertical curve radius (m)		10000	15000	15000	22000		12000/14000		11000
Max gradient (%o)	35	20	15	15	12.5	40	35	25	10

a. Category A trains
b. Category S trains (tilt technology)

The Table 5.2 illustrates a comparison between different parameters for high-speed construction on different railways companies through world. It brings some geometry parameters applied of high-speed railway for the comfort of passengers and great ride.

Next, the wide spacing between the lines is important for high-speed track because when two trains pass each other, the speed difference can be as much as 600 km/h and creates a burst of air pressure. Repeated stress on the windows may cause fatigue, which result in breakage of window glasses. The minimum distance between track centres adopted by some of the high-speed networks using standard gauge is given in Table 5.3 below.

Table 5.3: Minimum distance between tracks

Country	*Minimum distance between tracks (m)*		
	250 km/h	300 km/h	350 km/h
France	4.2	4.2	4.5
Germany	4.5	4.5	4.5
Italy	4.5	5.0	5.0
Spain	4.3	4.3	4.7

Most of the high-speed networks have used UIC 60 rails of 900 A grade steel. It is suggested that attention should be paid to the aspects; acceptance, assembly, welding, surface defects, etc.

5.3.2 Tunnel

The cost of tunnelling construction is much higher as compared to other modes such as cutting and embankment construction. As a result, there has been tendency to avoid tunnels in order to reduce the cost of construction, but if the curvature and gradient used to avoid tunnels is not suitable for permitting the desired speed, its construction becomes unavoidable.

Furthermore, airwaves at high speeds are generated inside the tunnels, which can be detrimental to the health of passenger. However, this health hazard can be mitigated whether alternatives such as increased cross-sectional area of the tunnel, avoiding double line tunnels, operating only air sealed coaches, and provision of pressure release shafts may be applied.

5.3.3 Level crossing / grade separation

Normally level crossing is not suitable for higher speed train operation and hence for road transport either road over bridges or road under bridges need to be planned. However, in unavoidable circumstances, level crossings must be interlocked with the signals. Sophisticated arrangement of interlocking the signals of train with that of road transport with help of video camera is used on JR.

5.3.4 Fencing

On very high-speed lines, trespassing is very risky. Even the train may suffer accident and consequences of accidents can be alarming. Thus, the entire high-speed track is generally provided with fencing. In any case, areas prone to trespassing have to be provided with fencing on high-speed routes.

5.3.5 Environment

The aspect of the environment most affected by the increase in speed is the subject of noise. In fact, the nature of the noise changes with the speed, such that as the speed increases, the predominant noise, which is that of motor up to 120 km/h, becomes the track noise 160 km/h, then the pantograph and aerodynamic noises above 250/300 km/h.

In principle it is reasonable to suppose that the more the speed increases the more noise problems will be created. As a result measures should be taken to protect against noise (screens, mounds of earth, etc.), as well as possible modifications of the route or the creation of artificial tunnels or covered sections, modifications of the maintenance (grinding) and, modifications to the rolling stock.

5.4 Traction Power System

In order to push forward the very high-speed train at speeds of up to 350 km/h, power traction must be available and of high quality. Modern traction power systems (TPS) for VHSR have become more and more comparable to grid capacity because of the high energy consumption when trains are running at high-speeds. Very high-speed lines are dependent on the availability of power supplies and overhead contact lines and the technology used in designing these catenaries is an essential feature.

The most common system used to feed the high-speed trains is alternating current (AC) voltage obtained from either public or private power networks. Goodman (2006) points out that reasons for adopting AC voltage come from economic arguments: that AC is easy to step up and step down in voltage by using transformers, and transmission at high voltage delivers power with the smallest possible current, resulting in savings in the cost of cable and in the size of substations, and greater performance when compared to direct current (DC) systems.

As mentioned previously some vehicles are fed by 15kV, 16 2/3 Hz and 25 kV, 50/60 Hz depending on the country. Therefore, the systems commonly used in high-speed line are the 15kV, 16 ½ Hz and 25 kV, 50/60 Hz. However, the last is the world standard for high-speed lines and mainlines. Profillidis (2006) illustrates the different types of VHSR electrification systems in Europe as can be seen in Table 5.4. In addition, the International Standard (IEC 60580) also mentions the different sorts of distribution systems and different traction voltage parameters standardised by the International Electrotechnical Committee 9 on Electric Railway Equipment.

Table 5.4: European Characteristics of electrification of some VHSR (Profillidis, 2006)

	Paris – Lyon	*Paris – Marseille*	*Madrid – Barcelona*	*Berlin – Hannover*	*Cologne – Frankfurt*
Lengh of line (km)	394	206	450	189	135
Maximum gradient (%o)	35	20	25	12.5	40
Maximum total power per train (kW)	14	18 (Duplex Train)	12	19	19
Traction System	25 kV 50 Hz	25 kV 50 Hz	25 kV 50 Hz	15 kV 16 $^{2}/_{3}$ Hz	15 kV 16 $^{2}/_{3}$ Hz
Medium distance between substations (km)	52	51	50	38	19,6
Medium power of substations (MW)	40	60	30	30	30
Power per km of line (MW/km)	0.8	1.2	0.6	0.8	1.5
Maximum intensity per track (A)	~1,000	1,000	1,000	1,000~1,500	1,500

The 25 kV, 50/60 Hz system can be supplied by two sorts of configurations. The first, where the voltage generated and transmitted to the trains is 25kV is called the 'booster scheme' and the 50 kV 'auto-transformer scheme' where the transmission is done at 50 kV, but the rolling stock will receive 25 kV.

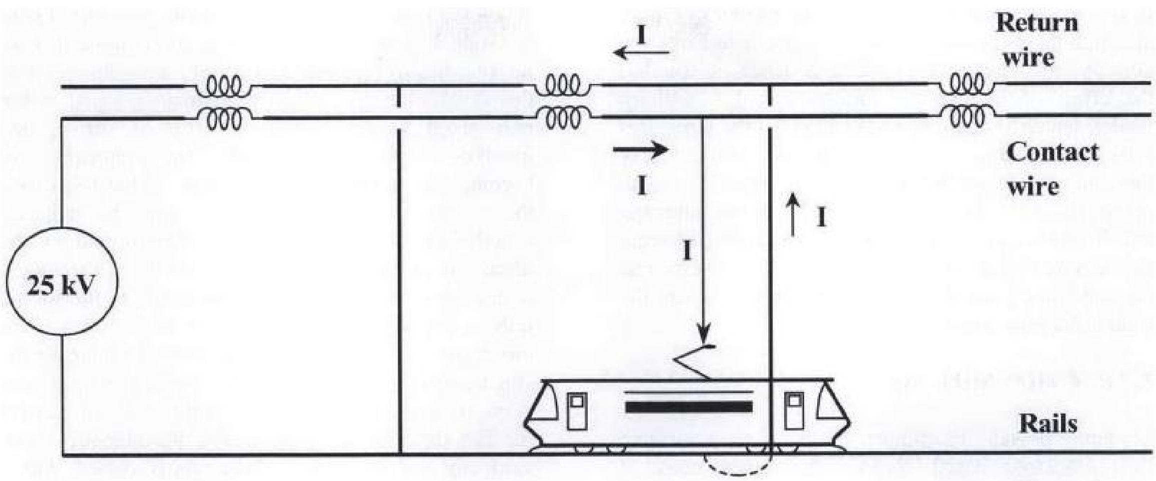


Figure 5.3: Booster Scheme (Goodman, 2006)

One of the major advantages of this system is the balance of ampere-turn. The ampere-turn balance is imposed by the 'current-sucking transformers' that force the current to flow up through the closest mid-point connection into the return conductor where, being fairly close to the overhead, it tends to cancel the field due to the catenary current (Goodman, 2006).

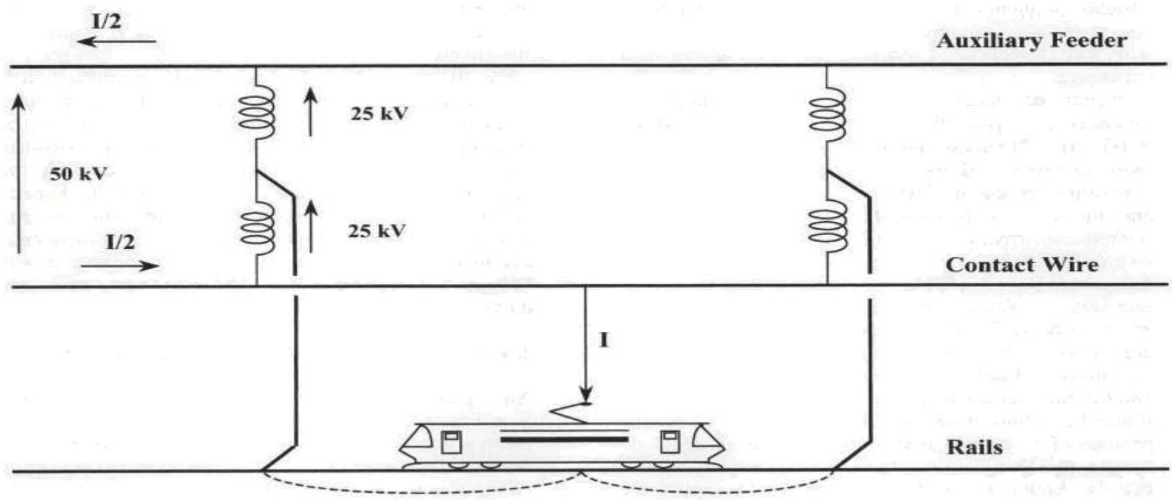


Figure 5.4 Auto-transformer Scheme (Goodman, 2006)

In the 50 kV autotransformer scheme, shown in Figure 5.4, although the principal reason for its use is to halve the current and increase the feeding distance, it also has the effect of forcing the current into the auxiliary feeder, which is again mounted high on the structures (this time needing 25 kV insulators, of course, unlike the return conductor in the BT scheme which is at earth potential). AT's are fitted at roughly 10 km intervals, which lessens their effectiveness in reducing external fields as neither the BT scheme nor the AT scheme can prevent some ground current in the section where the train is drawing current (Goodman, 2006).

Thus, the AC traction power system must be specially designed to avoid an unbalanced impact on the grid that can cause power system instabilities. This concern is raised since the large and single-phase loads by using of VVHSR. For instance, the Taiwanese high-speed railway engineers, during the early planning stages of their VHSR, started to evaluate the possible dynamic behaviour of VHSR (45 units of 14MW trainsets moving at 300 k/h) on the power grid (Hsi and Chen, 2001).

6 Case Studies

6.1 Background

The rationale for adopting Very High-speed Rail between major cities is driven by a number of reasons previously mentioned. They are as follows: (i) the need to relieve congestion in all modes of transport or on an existing railway network, (ii) the desire to transfer traffic from other modes to rail to achieve better overall journey times, (iii) the need to link a remote region to a national centre for socio-economic reasons, (iv) the decision to shorten a circuitous route, (v) the requirement to allow sustained higher-speed running and (vi) national pride and politics, in some cases (Harris, 2004). The author outlines some case studies in Japan, France, Britain, and Korea as follows.

6.2 Japan

Japan began to reach road and rail capacity limits in the 1960s and the government of the day realised that the space to expand the infrastructure along the existing corridors was not available and that there was a substantial risk to the future of the country's economic development, in the event that transport could not be improved. Nowadays, the Shinkansen technology runs in line with changes in the Japanese social situation and economy, delivering low environmental impact, greater cost saving, and rising speeds in a safe way.

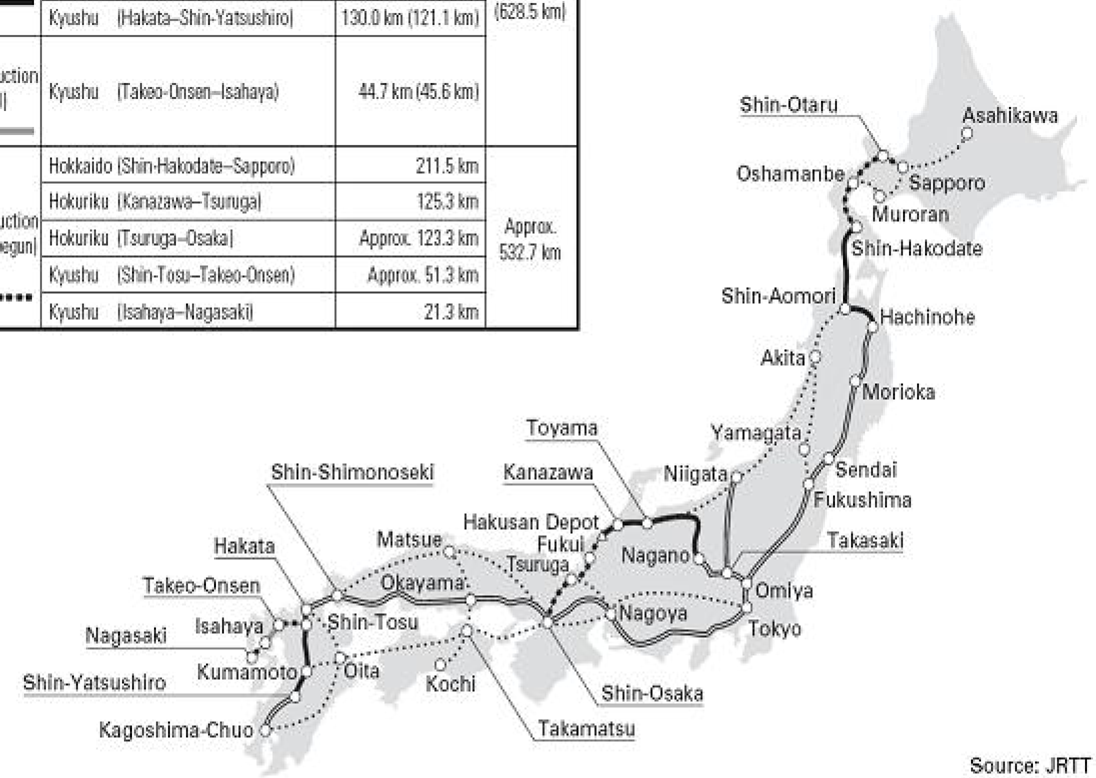
Japan is a long thin archipelago in the Pacific Ocean. It is formed by the four main islands of Honshu, Hokkaido, Kyushu and Shikoku, plus more than 3,000 smaller islands. About 73% of the total land area is mountainous and the main centres of population for the 127 million Japanese are on the coastal plain or bordering rivers. As a result, the cities along the coastal plain have high population densities, generating a large and concentrated demand for travel by railway. The geography, geology and climatic conditions of Japan have pushed the drive to build a major part of railway lines along long tunnels and bridges designed to withstand earthquakes, floods, and deep snow. Furthermore, since Shinkansen tracks pass through densely populated cities, stringent noise and vibration environmental standards are required as well.

The current service operates the fastest scheduled station-to-station service in the world, from Hiroshima to Kokura: 192 km in 44 minutes (average speed 261.8 km/h). The frequency of service is extremely high, with 2-minute headways on some routes during the peak periods. Three levels of train service are provided: Super Express (Nozomi), Express (Hikari) and 'all stations' (Kodama).

The Japanese Railway narrow gauge (1067 mm) is still used for the conventional trains but the VHSR lines have been built to standard gauge (1465 mm) since the first Tokaido Shinkansen in 1964 and together with San'yo, Joetsu, Tohoku, Hokuriku, and Kyushu constitute 2,175.9 km of the current network allowing maximum speeds of from 260 up to 300 km/h. Furthermore, an average of 920,000 passengers per day used Shinkansen in 2005 (Takatsu, 2007). The Figure 6.1 Illustrates the current and planned railway lines over the archipelago.

Total		Line extension (Construction extension)	6,852 km
Lines in operation	Tokaido (Tokyo–Shin-Osaka)	515.4 km	2,175.9 km New shinkansen lines 340.8 km
	San'yo (Shin-Osaka–Hakata)	553.7 km	
	Tohoku (Tokyo–Morioka)	496.5 km	
	Tohoku (Morioka–Hachinohe)	96.6 km	
	Joetsu (Omiya–Niigata)	269.5 km	
	Hokuriku (Takasaki–Nagano)	117.4 km	
	Kyushu (Shin-Yatsushiro–Kagoshima-Chuo)	126.8 km	
New lines planned (construction already begun)	Hokkaido (Shin-Aomori–Shin-Hakodate)	148.8 km (148.7 km)	634.1 km (628.5 km)
	Tohoku (Hachinohe–Shin-Aomori)	81.8 km (81.2 km)	
	Hokuriku (Nagano–Kanazawa)	228.0 km (231.1 km)	
	Hokuriku (Fukui Station)	0.8 km (0.8 km)	
	Kyushu (Hakata–Shin-Yatsushiro)	130.0 km (121.1 km)	
(Construction planned)	Kyushu (Takeo-Onsen–Isahaya)	44.7 km (45.6 km)	
(Construction not yet begun)	Hokkaido (Shin-Hakodate–Sapporo)	211.5 km	Approx. 532.7 km
	Hokuriku (Kanazawa–Tsuruga)	125.3 km	
	Hokuriku (Tsuruga–Osaka)	Approx. 123.3 km	
	Kyushu (Shin-Tosu–Takeo-Onsen)	Approx. 51.3 km	
	Kyushu (Isahaya–Nagasaki)	21.3 km	

Lines in basic plan	Hokkaido (Sapporo–Asahikawa)	Approx. 3,510 km
	Hokkaido south route (Oshamanbe–Muroran–Sapporo)	
	Uetsu (Toyama–Niigata–Akita–Aomori)	
	Ouu (Fukushima–Yamagata–Akita)	
	Chuo (Tokyo–Osaka)	
	Hokuriku/Chukyo (Tsuruga–Nagoya)	
	San'in (Osaka–Matsue–Shimonoseki)	
	Chugoku crossing (Okayama–Matsue)	
	Shikoku (Osaka–Takamatsu–Oita)	
	Shikoku crossing (Okayama–Takamatsu–Kochi)	
	East Kyushu (Fukuoka–Oita–Kagoshima)	
	Kyushu crossing (Oita–Kumamoto)	



Source: JRTT

Figure 6.1: Map of Japanese high-speed rail network (Takatsu, 2007)

Table 6.1: Shinkansen construction specification (Takatsu, 2007)

	Tokaido	*San'yo*	*Tohoku/Joetsu*	*Hokuriku Takasaki – Nagano*	*Tohoku Morioka – Hachinohe*	*Kyushu Yatsushiro – Kagoshima-Chuo*
Minimum radius of curvature (m)	2,500	4,000	4,000	4,000	4,000	4,000
Maximum grade (%o)	20	15	15	30	20	35
Basic track Structure	Ballast	Ballast, Slab	Slab	Slab	Slab	Slab
Rail weight (kg/m)	53 → 60	60	60	60	60	60
Overhead catenary voltage (V)	25,000	25,000	25,000	25,000	25,000	25,000
Frequency (Hz)	60	60	60	60	60	60
Feeding System	BT → AT	AT	AT	AT	AT	AT
Overhead catenary system	Composite element ↓ Heavy compound	Heavy compound	Heavy compound	High-speed overhead catenary	High-speed overhead catenary	High-speed overhead catenary
ATC System	Single Frequency → Dual frequency → Digital	Single Frequency → Dual Frequency	Dual-frequency	Dual-frequency	Digital	Digital
Train radio system	Radio waves → LCX	Radio waves → LCX	LCX	LCX	LCX	LCX
Core transmission line	Multiple small-diameter coaxial cables	Multiple small-diameter coaxial cables	Multiple small-diameter coaxial cables → Optical fibre cable	Optical fibre cable	Optical fibre cable	Optical fibre cable

Notes:
1. Standard specifications have been given. The specifications on some sections of track may differ.
2. The arrow sign shows the initial specification and subsequent improvements made.
3. Source: JRTT

The technologies used in the infrastructure of Shinkansen have been constantly developed in order to save on building costs and enhance the performance of the system in a safe manner, for example, using new boring technologies for tunnelling in shifting ground in the Shirasu plateau, slab track along the corridors, building with hybrid civil engineering. An overview of construction specifications is presented in Table 6.1 and Figure 6.2 gives a breakdown of Shinkansen structures by percentage.

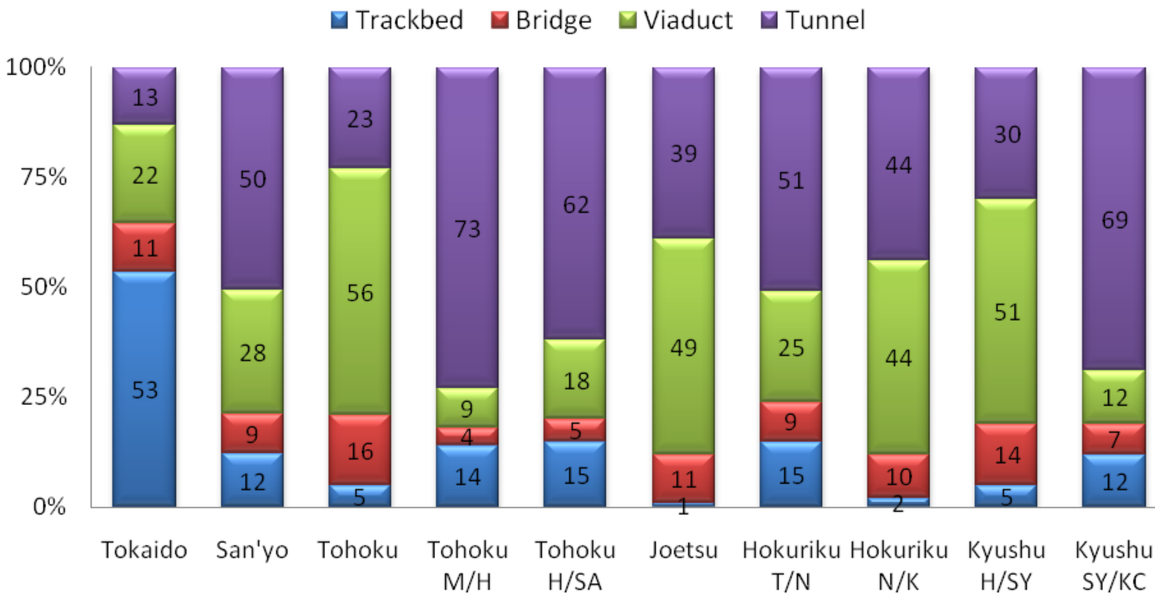


Figure 6.2: Breakdown of Shinkansen structures

It is generally accepted that the Tokaido and Sanyo Shinkansen lines are commercially viable, producing surpluses for Central Japan Railway and West Japan. The Joetsu Shinkansen line makes a marginal contribution, as far as Sendai. The other lines have been or are being built for socio-economic reasons and will be operated largely thanks to cross-subsidies from the profitable lines (Connor et al., 2006). Also shown in Figure 6.1, between Tokyo and Osaka, is the alignment of the planned MagLev line with the Yamanashi test track highlighted.

6.3 France

In 1976 the French government funded the first full TGV project and construction of the LGV (Ligne Grande Vitesse) Sud-Est, from the outskirts of Paris towards Lyon, started shortly afterwards. The network is electrified at 25 kV 50 Hz that is the standard high-speed rail type of electrification and featured modern articulated trains, capable of running at 270 km/h. Further lines were built to the South West, the North and around Paris, as well as extensions to Brussels and Marseille. The network has been supplemented by routes to several French regions, Germany and Switzerland, using the existing railway network but with enhanced sections (Perren, 1997).

The average distance between the 20 largest French towns and Paris is 451 km while the average distance of the subset of the 10 largest towns from Paris is even greater, at 553 km. Apart from Lille, most significant cities can be found beyond a 300 km radius from Paris. These distances make the use of high-speed rail services the most effective and efficient solution to the national transport problem. Several important centres beyond the French border are within a 600 km radius from Paris and are therefore also benefiting from high-speed rail services. Marseille, just over 750 km from Paris, has only recently joined the high-speed club and has become a very successful destination. Lille is a special case since the city is located on the TGV Nord line which leads to the Channel Tunnel (Connor et al., 2006).

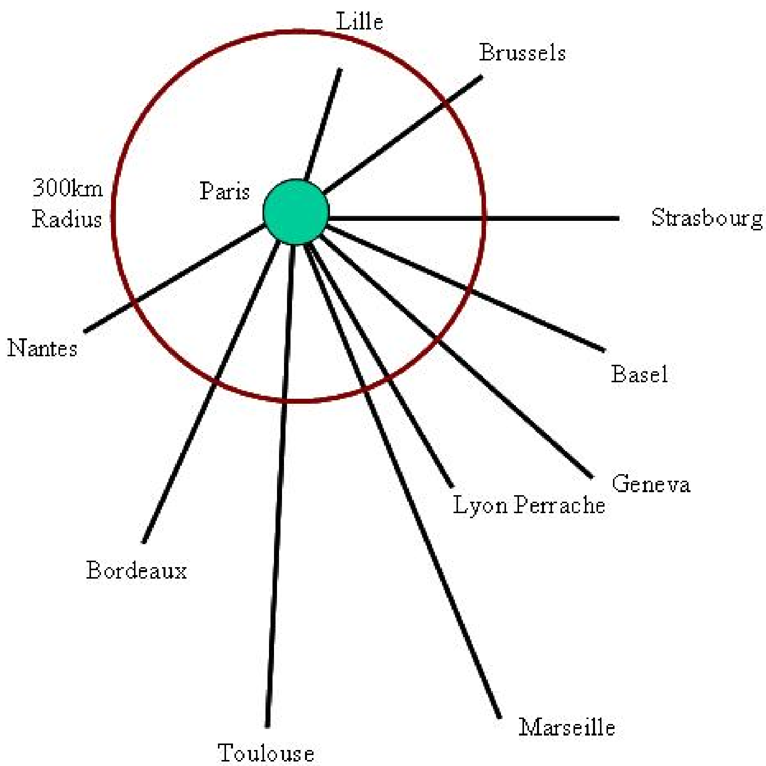


Figure 6.3: Urban centres a 300 km radius around Paris (Connor et al., 2006)

6.4 Great Britain

High-Speed Train (HST) services started in Britain in 1976, on the Great Western main line between London and Bristol/Swansea. The HST had been designed and built in Britain and was to become the most successful diesel high-speed train ever built. The HSTs are still in main line high-speed service today and are currently undergoing major refurbishment, including the fitting of new engines.

The Eurostar high-speed train service to France began operation in 1994, connecting continental Europe with London via the Channel Tunnel, using Inter-capitals trains derived from the TGV. In 2007 the CTRL link was completed and this is currently the only built high-speed line in Britain using SNCF high-speed systems design standards, allowing journey times of only 2 h from London to Brussels and of only 2 h 15 m from London to Paris [Dyson and Kirk, 2006].

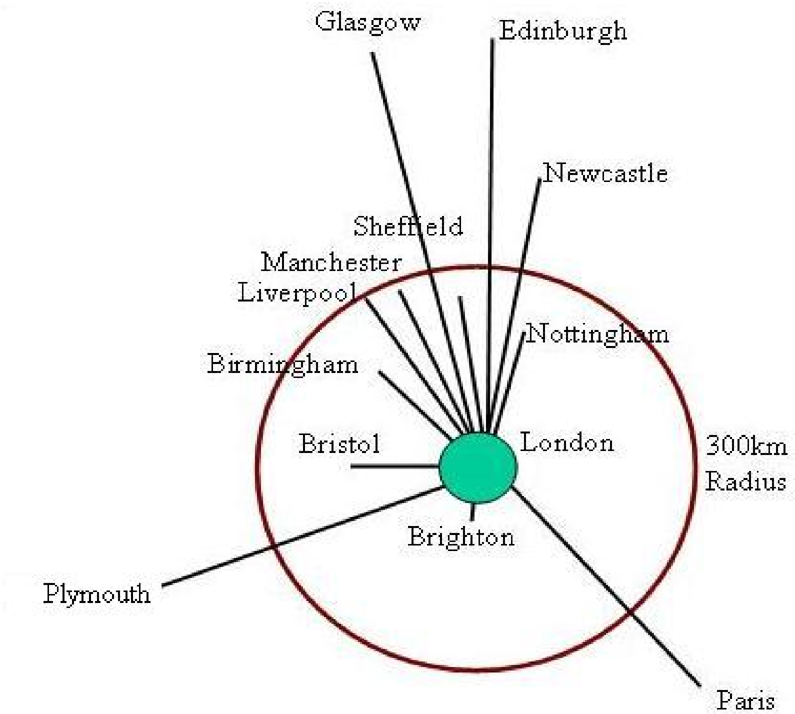


Figure 6.4: Major urban centres a 300 km radius around London (Connor et al., 2006)

London and the immediate south-east have the biggest country's economy with a growing population of around eight million for the capital and a further five million in its vicinity. Most major conurbations are situated in the south of the M62 which links Liverpool, Leeds and Hull, nearly 300 km from London. Only Newcastle and Scotland's central belt, combining Edinburgh and Glasgow, are north of this line. The major traffic generators and destinations are within a 300 km radius from London and less than 150 km from each where journey times below 2 h can be achieved easily between these centres and London by railway, without having to build a high-speed line which would also be expected to serve intermediate destinations (Connor et al., 2006).

6.5 Korea

Korean's High-speed railway (Korean Train Express or KTX) was designed and funded by the Korean government to link the capital Seoul to Busan. Seoul–Busan is Korea's key economic zone where 75% of the Korean GDP is produced. The region of Seoul is home to 19 million inhabitants and 70% of people are settled along the corridor. The geography of South Korea demonstrates a largely mountainous terrain which has led to many building constraints for cities.

Korail opened the first section of the line on 31 March 2004, with a delay of several years on the original programme, because of overambitious schedules and poor workmanship on some bridges and viaducts. The second phase is to be completed in 2010, linking Seoul to Busan by entirely new tracks. Following the opening of the first phase, the very high-speed rail link will be over 683 km long between Seoul and Busan, comprised of the 232 km Seoul–Daejeon–DongDaegu high-speed line section, and 451 km of existing lines composed of a branch to Gwangju (1.4 million inhabitants), 353 km from Seoul, and Mokpo (0.5 million inhabitants), 408 km from Seoul, which will be known as the Honam Line. See Figure 6.5.

Figure 6.5: The Korean Corridors

The high-speed line is 133 km long in the open (28%), 163 km in tunnels (34%), and 181 km over viaducts (38%). The line is fed by 25 kV, 60 Hz overhead lines and the track gauge of 1465 mm was designed for speeds of up to 350 km/h.

The French TGV technology was adopted by Korail but Korea's Railway Research Centre is currently developing a new type of TGV-derived train with the capability of travelling at 350 km/h in commercial service with 15% less drag than the KTX by designing an aerodynamic train nose. The Table 6.2 Table below outlines the differences between types of Korean high-speed trains.

Table 6.2: Technical comparison of VHSR350 versus KTX (Chul, 2007)

Item	***VHSR350x***	***KTX***
Maximum speed (km/h)	350	300
Number of Seats	366 (2 motor cars, B passenger carriages)	935
Body Shell	Aluminium	Steel
Motor	Induction	Synchronous
Power control	IGCT	Thyristor
Brakes	+ Eddy current	Friction/Electrical

To date, the KTX has transported over 103,000 daily passengers, being split into 85,000 on the Seoul–Busan branch and 18,000 on the Seoul–Mokpo section. During the weekday 140-149 services are delivered to users and 169 services at weekends with 3.5 hourly services in each direction (Chul, 2007).

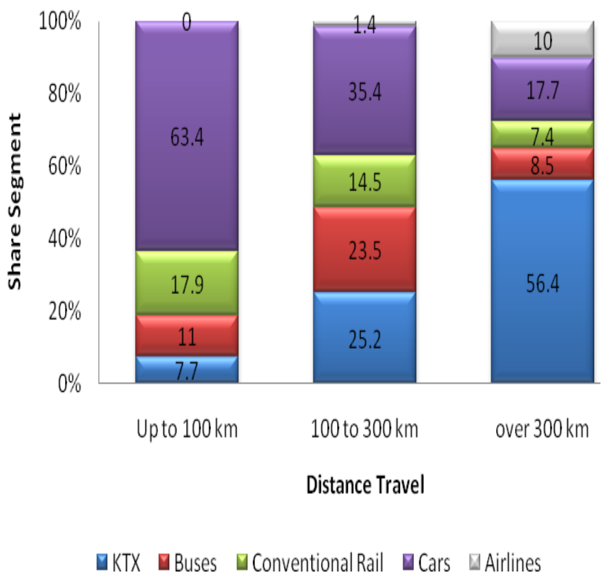


Figure 6.6: Market Segment of Korean Transportation (Chul, 2007)

The Figure 6.6 illustrates the current market segmentation of Korean transportation. The current situation demonstrates that VHSR increases its participation in the market segment when the distance of travel also increases, whereas travel by car shows a dramatic drop when the travel distance increases. Airlines, on the other hand, increase their share of the market with increasing journey distance.

7 Findings: Description, Analysis and Synthesis

The research initially concentrated on surveying theories regarding planning transportation, technical and operational aspects in order to define drivers to be allocated to VHSR development in the Southeast and South regions of Brazil. The findings were as follows:

- the choice of transportation mode addressed that there are advantages for very high-speed railways over other modes where travelling must be taken between 200 km and 600 km long and therefore the most capital cities aforementioned are located between in this distance from São Paulo city. On the other hand, railway may compete with longer distance journey or longer journey time since there is no direct service, or frequencies are poor. In addition, time and price are main drivers of railway market where business travellers are usually willing to pay highly for speed comfort and convenience.

- the use of system engineering and project management in the development of long-term and costly project demonstrated toward better cost performance results, as well as schedule performance and increased the suitability to stakeholders' need. In contrast, overruns nearly 50% on average has been detected on projects without application of SE and PM (INCOSE). The Docklands Light Rail (Hayward, 1997) and Victoria Line Upgrade are examples that demonstrate that passenger railways can take advantages from SE and PM whether they are correctly applied to system.

- the definition of travelling as a derived demand, models for forecasting demand leaded to an important role in the feasibility studies for building new passenger railway.

- the VHSR is a very complex systems comprising many different elements that cannot be neglected and it is essential to consider all these items simultaneously and ensure that each ties in correctly with others.. They are as follows: infrastructure (including civil engineering works, track, catenary, etc.), stations (location, functional design, equipment, etc.), rolling stock (from technical point of view, comfort, design, etc.), operations (design and planning, control, rules), signalling systems, maintenance policy and systems, financing, marketing procedures, and management.

- the studies of geography and economy of Brazil indicated how Brazil is subdivided into its diverse natural characteristics; cities, population, and infrastructure of transportation over the country. Those geographical figures provided what must be taken into account in order to minimise the environmental concerns along Belo Horizonte – Porto Alegre route. The economical figures also provided to the reader the idea how the richness's Brazil are spread into regions and cities in terms of industries and trades; as well as demonstrated the possibilities of building a passenger railway link between the aforementioned cities. In addition, São Paulo, Rio de Janeiro, Belo Horizonte, Curitiba, Florianópolis, and Porto Alegre have high level of GDP per capita (IBGE, 2007b) and conurbations of Brazil (IBGE, 2007a).

- the literature review highlighted a number of forces driving VHSR, with the main drivers reflecting a desire to have an integrated planning and transport at the national, regional, strategic and local level to promote more sustainable transport choices for people, accessibility to businesses, jobs, shopping, leisure facilities and services, and reduce the journey time and the need to travel, especially by car and air. In contrast, concerns in the capacity on existing routes, needs for new tunnelled access, refurbishment of infrastructure and tracks for accessing city centres was detected as one of the most critical issue for VHSR. Those concerns over VHSR networks when linking large urban centres, access to alternative modes, together with the influence of regional geography on the design, the size of the network and the frequency of stops were related to studies of Vickerman (1997). In addition, VHSR has also delivered some benefits as following revenue, more mobility and capacity, time savings, relief of congestion, accidents and less environmental effects, and local and regional development. However, in context of long term effects, VHSR were favourable to environmental concerns and safe mobility instead of funding problems for the development of VHSR.

- the location of high speed stations has an important and strategic aspect for the success of the system as a whole. Since them are well located, some results such as benefits from the advantages of the reduced journey times, great links to airports, city centre, mass transit systems and private transport have been delivered to users of VHSR the world over.

- the arguments on environmental grounds advocated a favour of very high-speed railway link from Belo Horizonte to Porto Alegre could attract modal shift from air and road. However, rail's energy consumption and carbon emissions increase with speed and this would erode rail's environmental advantage and so it is important to consider the costs involved in reducing carbon emissions in this way.

- the operating of VHSR requires such as: ‘train sets’ instead of conventional trains (locomotive and cars), because of the power weight/ratio and also for other technical reasons, such as aerodynamic conditions, reliability, safety, etc.; dedicated lines where layout parameters, transverse sections, track quality, catenary and power supply, special environmental conditions, etc., must be able to sustain high operational speeds; line side signals are no longer useable at more than 200 km/h since there is no guarantee that they will be observed in time and therefore In-cab signalling is absolutely necessary to operate at high speed.

- the typical infrastructure parameters for VHSR can be mentioned as follows: Power systems, two kinds of power systems can be used to increase the train speed up to 350 km/h, they are 25 kV (booster) or 2 x 25 kV (Auto-transformer), single phase at 60 Hz. Signalling, a full onboard signalling system is necessary. Track, track centre distance about 4 m and 5m, roughly 200 km/h and 350 km/h respectively; Maximum cant: 150/170 mm; Track superstructure components (typical ballasted or ballastless track), Rail type: Usually, 60 kg/m, welded; Turnouts, they can have movable or fixed crossings. Layout specifications: Maximum gradient depending on geographical characteristics and operating conditions for passenger traffic only: up to 35/40 mm/m (suitable rolling stock).

Horizontal curve radius	*Minimum (m)*	*Ideal (m)*
200 km/h	2,500 m	3,500 m
300 km/h	5,500 m	7,000 m

- the case studies demonstrated that high speed line successfully integrated the regional economies with the mainstream economy and reduced the disparity amongst regions within the country.

- the accessing city centres is a critical issue for new railways where capacity on existing routes is limited, inappropriate infrastructure for VHSR, available land are the major factors that must be taken in account.

- the VHSR development the world over demonstrated that through varying design concepts for services can also achieve high levels of performance in terms of commercial aspects. For instance, activities such as marketing procedures (trademarks, advertising), reservation and ticketing systems, ticket control (controlling access), on-board customer facilities (wireless, computer aids), and post-travel services can underpin the highest performance.

- the pricing system in VHSR companies has undertaken increasingly use variable prices for different types of services (business and private journey), where the prices offered can vary considerably as result of travelling periods or other circumstances that influencing demand. In addition, some companies have adopted various procedures imported from the airlines like “yield management”; on the other words, maximisation of the income per train.

- the VHSR requires substantial investment that can be provided from different ways, as private and public bodies. For example, the costs of high speed lines are generally paid for out of public funds (Japan, Europe, and Korea). The French TGV applies share funding and responsibilities between different public bodies. In some cases, private funding can be attracted for part of the investment PPP (Public-Private Partnership, i.e. Spain - France link) or BOT (Build - Operate - Transfer, i.e. China-Taiwan) are two possible ways of combining public and private resources.

- the cost of building a new VHSR line in Europe are as follows: building of 1 km takes about €12-30 million, maintenance of 1 km costs €70,000 per year, train cost about 350 places takes about €20-25 million each, maintenance of a train costs about €1 million per year or about €2 per km (500,000 km / train & year) (UIC, 2008).

8 Conclusions and Recommendations

The overall aim of this thesis was to analyse the need to construct an express railway link from Belo Horizonte to Porto Alegre, particularly in relation to bring together all aspects of railway systems engineering and to integrate all the elements into the route. The author objectives were to: Identify the forces driving VHSR transport and the barriers to the successful development of passenger rail transport through the capital cities of Brazilian South-Eastern and South region. Evaluate critically some of the models and frameworks relevant to supporting a ‘Transport Board’ in coping with VHSR technology. Explore the Brazilian transport and socio-economic database and outline the practices related to design, operation and management of VHSR, including inducement and barriers, and Formulate recommendations on "Transport Board" design issues.

8.1 Conclusion

Based on objectives and the review of the available literature, the author has concluded the following points:

The current scenarios of transportation in the southeast and south region demonstrate that there are considerable reasons for building VHSR in Brazil. For example, the overcrowding in airports, high traffic on road networks and forecasting demands provide support to it.

The implementation of VHSR will provide savings in travel time, enhancing mobility and relieving environmental pressure of traffic along currently congested routes, making journeys for travellers more affordable and comfortable manner, and promoting accessibility to employment opportunities on both sides of the boundary and throughout the regions.

The very high-speed railway can provide a solution to Brazilian’s passenger transport needs in the South and Southeast regions. However, the prioritisation of a flow of investment for such section of the corridor must be taken;

VHSR may cause substantial environmental impacts in accessing the centres of major conurbations and along the route. However, the author suggests that through government policies and proper supervision by the authority is possible to develop a scheme that avoids the most critical environmental designations and mitigates the worst impacts.

MagLev technology is incompatible with some parts of existing systems and its long-term reliability is still not proven. It is thus not the preferred option for a future Brazilian very high-speed railway system.

Energy cost and availability of energy are factors that militate against the saving operational costs realisation of very high-speed railway worldwide. Regardless of technology adopted, energy use increases in proportion to square of the speed and very high-speed operation can be costly and unsustainable. Therefore, it will force the designer and manufacturers to reduce weight of the vehicle improve design and aerodynamics, which will improve the energy profile of VHSR and environmental imprints.

VHSR termini fully connected with local networks of transport will provide to user easier access to urban centres of capital connected. It also delivers greater efficiency and promotes interconnectivity between both a concentration of transport and infrastructure and a concentration of urban functions (work, facilities, and residential function).

Working with the topography to minimise gradients and hence the need for tunnels, additional stations to serve intermediate destinations add value, phased development improves the economics;

The question of ballast or no ballast is not limited to the assessment of the total life cycle costs of the track. Some aspects, such as the track equipment, the availability of the line, the costs and the conditions of maintenance and repair, the forces in the case of derailment, etc. need to be assessed in detail. Although, the ballast track is still used on conventional railways but ballastless track has become preferable since presents such advantages as low maintenance, high availability, low structure height, and low weight.

The high-speed line must include the major urban centres in the South and Southeast region of Brazil with greater focus on Belo Horizonte, São Paulo, Rio de Janeiro, Curitiba, Florianópolis, Belo Horizonte, and Porto Alegre.

The case of VHSR in Brazil can be deferred but not ruled out altogether as suggested by the opponents. Sooner or later, the policy maker won't be able to solve the transport problems without going for passenger railway transport. So the approach should not be to 'find and fix' but to 'predict and prevent'.

8.2 Recommendations

Regarding the complexity of design and operating VHSR the author based on the findings and analysis recommends the following further actions:

It should make more effective use of an expensive infrastructure;

It should use of modern civil engineering techniques to widen railway routes without requiring substantial additional land take;

It should initiate of research into railway extension requirements and construction strategies;

It should be adequately addressed by improvement in design and technology and policies the arguments of environment and climate change against VHSR;

It should enhance professional expertise and organisational capacity in order to successful integration and development of system through training and exchange technology;

It should strengthen organisations internally through the adoption of coherent and consistent policies and commitment of sufficient resources to achieve strategic and operational integration

It should encourage tertiary educators to incorporate opportunities to facilitate interdisciplinary activity in professionally accredited programmes (eg, engineering and planning).

It should consider the 'reserve of speed' that all new lines have from the point of view of the route of the infrastructure because of the different life of all the parts involved in the operation of a high speed system.

It should adopt gentle curves in view of restriction on maximum values of cant deficiency and cant excess along with maximum speed of operation.

It should recall the proposals of the European Railways in the Interoperability Technical Specifications (STI) for the infrastructure for ruling gradients, for example, considering a maximum gradient of 35 ‰ over a length of 6 km maximum and 25 ‰ over 10 km.

It should be considered the aspects which concern the noise when a new line is designed for speeds which exceed 300 km/h.

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