Strategic Planning for Rail System Design

An Application for Portuguese High Speed Rail

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"If a man will begin with certainties, he shall end in doubts: but if he will be content to begin with doubts, he shall end in certainties."

-Sir Francis Bacon (1561-1626)

"The only certainty is that everything is uncertain."

-Pliny the Elder (23-79 AD)

A riddle about decisions under uncertainty

A minister of transport had to choose between two major railway designs, both of which had a very uncertain and yet unknown price-performance. Before making a decision, there was only time to do one simulation study to estimate the price-performance of one of the alternatives. The chief system engineer had a clever idea to guarantee that the minister would choose the better alternative with a probability of more than 50%. He advised to flip a coin and to do the simulation study for one of the alternatives to find PP1. He let the minister make a wild guess WG for a reasonable price-performance and advised to decide as follows:
If PP1 > WG then choose alternative 1.
If PP1<=WG then choose alternative 2.
He convinced the minister that his chance was indeed >50%. How? There are three possibilities:
(a) WG >= Max[PP1,PP2]
(b) WG< Min[PP1,PP2]
(c) Min<=WG<Max
Under (a) and (b) his chance is 50%, while under (c) his chance is 100%. So his overall chance to choose the better alternative is P(a)/2+P(b)+P(c)/2=1/2+P(b)/2>1/2 and this holds for every wild guess and all possible probabilities P(a), P(b) and P(c). Is this true?

Prefix and acknowledgements

From September 2006 to January 2007, I have been writing part of my Master thesis in Industrial Engineering and Management at the Massachusetts Institute of Technology (MIT). Under the supervision of Professor Richard de Neufville and Professor Joseph Sussman, I worked on Real Options in railway design as a part of the Portugal project, a collaboration between MIT and the Portuguese government that had just been started. While I worked on rail, PhD-student Joshua McConnell and MSc-student Richard Duane Chambers covered road and air. I enjoyed our weekly group meetings and was inspired by the comments from the Professors and fellow students. Professor De Neufville's course ESD71 (Real Options Analysis for Engineering Systems) helped me get a clearer view about Real Options. I also want to thank MIT PhD-student Maya Abu Zeid for sharing the material she had collected on the Portugal project.

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Mostly, I want to thank my parents and grandparents for their love, support and guidance throughout my life. Thank you for your faith and pride in me. I love you very much!

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Abstract

In Europe there is an increased political support for building High Speed Rail connections. Spain for example will invest over 100 billion euro in the next decade in new lines. While there are plans to build new expensive HSR connections, all throughout Europe railways are struggling financially. Financial performance of railways deviates a lot from the prognoses. In most cases, costs exceed prognoses by far and demand is less than what is forecasted.

The choice whether to invest in rail or not is not within the scope of this thesis. If the political decision is made to upgrade transportation systems by investing in railways, a plea can be made for a flexible design of the railway system which depends on developments of the key variables in the system and other modes. The logic behind this is that the financial performance of the system can be improved if there is a pre-specified plan for every possible future scenario. We have shown through reasoning in other fields and a case example for the railways that having a flexible plan for building and operating railway systems can have major financial benefits over the fixed system design. The theory applied in this thesis is known as Dynamic Strategic Planning (DSP), of which Real Options Analysis is a large part.

Although there are great theoretical benefits to flexible planning on a strategic level, there are some pitfalls that might dampen the expected system performance. The success is bound by the ability of the organization to act economically rational which might be difficult in a political environment. Furthermore, acting agile to new unforeseen developments can be a challenge for organizations if they don’t have expertise in the field. Another factor of concern remains the capacity to approximate the variables that are needed as input for the flexible strategy evaluation well.

Based on DSP theory, applications thereof, and an analysis of the European and Portuguese situation in the railways, advice is given if flexible planning can help improve the financial performance of the current high speed rail plans in Portugal.

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Chapter 1 Introduction

The European Union aims to strengthen its transportation network by building Trans-European Networks (TENs) on road, air and rail. A lot of effort and funding goes towards building High Speed Rail connections in the next couple of decades. This thesis will focus on the upgrading of the Portuguese rail transportation system by building new High Speed Rail lines on the Lisbon-Porto and Lisbon-Madrid track for an expected 9 billion Euro.

While there are plans to build new expensive HSR connections, in Portugal and all throughout Europe the railways are struggling financially. Financial performance of railways deviates greatly from the prognoses as pointed out by Flyvbjerg (2003). In most cases, costs exceed the forecasts by far and demand is less than what is predicted. There is a lot of uncertainty in railway design yet the current strategies for building and operating railway systems is based on single-number design scenarios that will occur with 100% accuracy.

Traditional capital discounting techniques like the Net Present Value (NPV), Internal Rate of Return (IRR), or Payback Ratio are applied to determine if constructing a railway line is worthwhile. There are two big problems with the conventional valuation approaches.

First, reducing the financial outcome distribution to the average value does not always get the same results as using the entire distribution. This phenomenon is called the flaw of averages and will be discussed in later chapters.

Second, and most important, the traditional approach is very rigid and does not allow for maximizing the project value as uncertainties develop, it only states if the project is (not) worthwhile for the chosen single values. One fixed strategy, a master plan, is developed and stuck to for all future scenarios without taking into account how uncertainties turn out. There is no risk limitation (by abandoning the project) and exploiting unexpected gains (by expansion). These sources of gaining value are not covered by the traditional methods.

The choice whether to invest in rail or not is not within the scope of this thesis. If the decision is made to expand a countries transportation system with HSR technology, we want to show that a flexible building and operating strategy of the railway system can increase the value. This flexible design is achieved through Dynamic Strategic Planning (DSP). It is dynamic because it recognizes the fact that the future is uncertain and needs to be managed flexibly instead of fixed. Strategic means the system performance is optimized on a long-term. Planning indicates that a set of steps is designed on what should be done under what circumstance.

One of the methodologies in Dynamic Strategic Planning is Real Options Analysis (ROA). Real Options give opportunities to manipulate the distribution of the Value-At-Risk (VAR) and Value-At-Gain (VAG) to our benefit. Decision Analysis (DA) is used to calculate the value of executing flexibilities at certain points in time.

In this thesis we will compare a fixed strategy that uses traditional valuation approaches with a flexible strategy that recognizes uncertainty and uses DSP tools to react to it. The theoretical advantages and disadvantages will be illustrated by case examples from other fields and then they will be applied to a railway case to demonstrate how they can be of aid for Portuguese railways design.

Most European countries are facing the same issues as Portugal for building High Speed Rail Lines. The major investments and economical development opportunities that are inherent to HSR, make the technology highly relevant for Europe. In the Netherlands, for instance, the political battle on whether to build a high speed line that connects the North to Randstad is concerning many Dutch people.

Exploring ways in which to maximize financial rail performance is thus highly significant for many countries. The need for better and faster transportation is correlated with the economic development of a country (Zahivi, 1981). Train technology has improved immensely over the past few decades and new political developments have led to the desire for building a High Speed Rail network throughout Europe. The aim of this thesis is to show that the limitations of the traditional evaluation techniques also apply to rail system design. In addition, the possibilities of using a flexible approach are explored for the railways. High Speed Rail lines are very controversial. The many opponents of HSR lines emphasize the huge cost and commercial failure rates while proponents see the potential benefits that HSR could bring to a region. A flexible strategy could bring both sides together as it limits the risks and preserves and expands the benefits.

Results that differ from the forecasts are very common in rail design (Flyvbjerg, 2003) but it is possible to improve railway performance by recognizing the uncertainty in railways. This was not done in Portugal in the 1990s, when the decision was made to upgrade the rail transportation network by buying high speed tilting trains called Alfa Pendular (AP) and upgrading the existing track for several billion euros. The APs were definitely not the success that many hoped they would be causing trains to be initially slower and nowadays barely faster than the old rail system.

We will not try to give a precise advice on how exactly Portugal should design its new railway system. The emphasis is on the value of thinking flexibly and responding to uncertainties as they develop. The amount of real data on rail that is publicly available is very limited. Also, we do not pretend to give a full list of Real Options in rail design as the Portuguese railway experts have much more insight in their situation and could think of some more flexibility options. Two of the most important Real Options, namely

Waiting-to-Invest and Exit-Operations are worked out for a case example. Other options like gaining more information by tests (e.g. a test track) are mentioned and shown for other fields.

Although this thesis only focuses on railways, it is crucial to think about rail as being a part of the total transportation network. Air, road and waterway are the other means of transportation that could either influence the benefits of rail positively or negatively. All modes in the transportation network should complete each other. Balance in transportation is crucial for the success of the entire system.

Finally, the plausibility of applying a flexible strategy in Portugal will be discussed. The dynamics between politics and economical/technological decisions will be reviewed.

The structure of the thesis is as follows.

In chapter 2, a description of the real world problem will be provided. Uncertainties in system design will be identified as major sources of system underperformance. The central thesis question will be derived from these factors.

Chapter 3 will describe High Speed transportation technologies and High Speed Rail in particular. Traditional system evaluation techniques like Net Present Value will be listed and HSR performance models will outlined.

In chapters 4 and 5 we will highlight policy issues of the past and present as well as the future plans for Portuguese rail transport. Reasons why there is a need for upgrading the rail network will be listed from both a Portuguese and a European perspective. An impression of the decision making process in the railways in Portugal will be provided.

Chapter 6 consists of explaining the deficiencies in traditional design approaches. Real Options Analysis, Decision Analysis, and Sensitivity Analysis are proposed as the main tools in Dynamic Strategic Planning (DSP) to develop flexible investment strategies.

After identifying the major uncertainties for rail in chapter 7, two Real Options will be listed for the railways. In this chapter, these Real Options will be explored for an example application in a HSR case. The results from this case will be added to findings from previous chapters to find the fit of DSP and the Portuguese HSR plans.

Finally, we will provide conclusions and recommendations to the Portuguese government in chapter 8.

Chapter 2: Description of the real world problem

2.1 Introduction

This chapter will describe why opportunities exist to improve the design of transportation systems. This is done in two ways. First, the theoretical need for expansion of the transportation network and speed is examined. Thereafter, uncertainty in systems is reviewed with case examples in transportation and railways.

It is standard practice to design transportation systems according to forecasts for their entire lifetime. The problem with this is that the forecasts are highly inaccurate and system performance is ultimately less than what is expected. Traditionally, the role of management is to stick to the master-plan that is designed based on the initial forecasts. This does not allow for risks to be limited and opportunities to be exploited as uncertainties develop. Especially in the capital intensive railroad systems this may lead to a significant financial loss. This is one of the reasons why high speed rail is such a heavily debated topic.

High Speed Rail is one of the technologies that can be used to meet the transportation demand of a country or region. After describing high speed rail technology, we will look at methods for the design and valuation of railway systems. The major flaws in the methods will be pointed out and a different approach to system design that can handle uncertainty better will be proposed.

2.2 Theoretical need for speed: rising demand for faster transportation

The need for faster transportation means is related to a rise in transportation demand in pkm/year. For modeling the transportation demand in a region, two factors are important according to Zahavi (1981): the travel time budget (TTB) and the travel money budget (TMB).

Zahavi found that in each country on average humans spend a fixed amount of time per day traveling. According to Schafer and Victor (1999) this travel time budget (TTB) is approximately 1.1 hours per person per day (Figure 1). There are local differences in TTB due to factors such as societal wealth and the level of urban development. Lower income groups in a society have a higher TTB due to their restricted housing opportunities and the tendency to opt for slower, less expensive means of transportation. In large cities, Schafer and Victor suggest that congestion slows travel speed and TTB is above the national average.

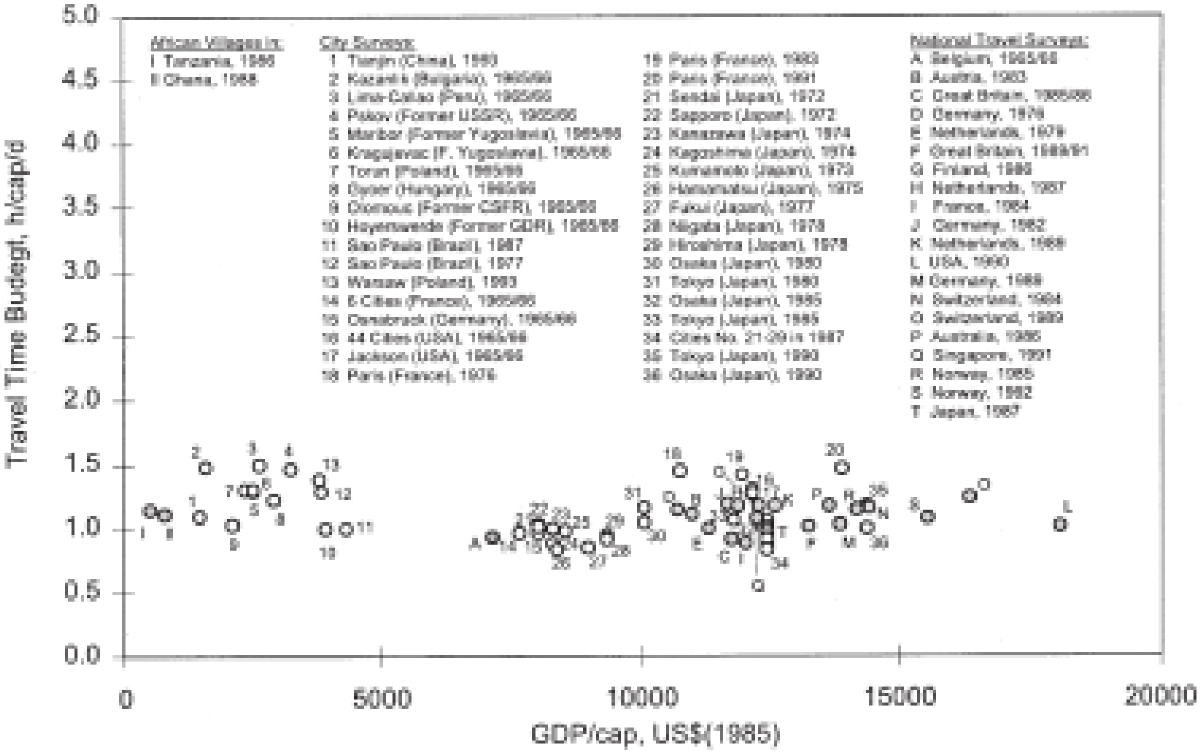


Figure 1: Travel time budget vs GDP; Schafer and Victor (1999)

Zahavi further defines the travel money budget (TMB) as the fixed proportion of time income that people spend on traveling. For most industrialized countries, Schafer and Victor found that the TMB is 10-15% of total expenditure. Countries with a higher degree of motorization usually spend relatively more money on traveling.

Schafer and Victor proved the existence of a linear relationship between the growth in GDP/cap (US$) and growth in the capital traffic volume (pkm). For every US$ GDP/cap extra, people travel on average one pkm more. In diverse regions, this number might be different because of variation in infrastructures, population densities, cultures, and unit costs of transport.

With increasing GDPs per capita all over the world and in Western-Europe specifically 1,9% per year, the demand for traveling will increase. As the TTB is historically constant, travel speed must thus increase in order to meet this demand. Figure 2 shows the long run theoretical target point for per capita traffic volume in pkm for different regions in the world.

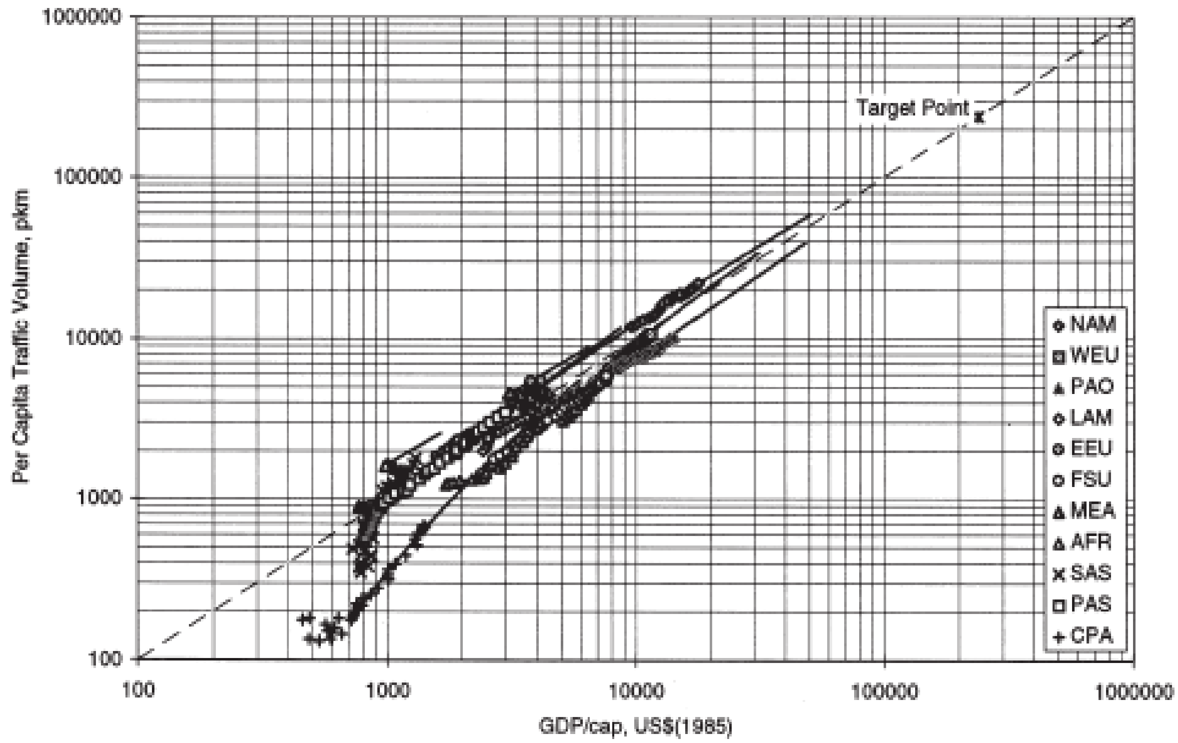


Figure 2: Traffic volume versus GDP; WEU=Western-Europe

This theoretical relationship between GDP and transportation demand would help us design transportation systems better if we knew how the GDP would develop in time. While it is known that the average GDP growth is 1.9% for European countries, this does not help the design of the Portuguese transportation system. The GDP of the individual countries fluctuates a lot each year. A growth of 1.9% on average during 10 years does not specify how the augmentation is distributed over the years. It could be a constant 1.9% over all ten years. But it is also possible that there is no or negative growth during the first years and a big growth during the last years. The design of the transportation system in both scenarios could be very different. If for example the existing transportation system can handle the current demand, there is no need for upgrading with the second scenario and capital costs are saved.

GDP predictions all over the world are being revised several times a year, with large deviations in forecasts within short periods. In 2003, for instance, the Malaysian Institute of Economic Research (MIER) slashed its GDP growth forecast from 5.7% to 3.7% due to the consequences of SARS in the region. Shortly after, it was raised again to 4.3% because the war in Iraq had a positive influence on the country.

That predictions are even unreliable on a short term is shown by Isiklar and Lahiri (2006). They have conducted research on the ability of forecasting the GDP growth in 18 industrialized countries. The time span they have taken for their research is 24 months in advance. Their results show that forecasts are not useful at all 18 months or more before the end date. For a timespan of 24-18 months, the forecasts remain stable which might imply that there is not enough information to revise the forecasts. How dependable the initial forecasts then are, is very questionable. In some countries, among which The Netherlands and Portugal, the forecast did not outperform the naïve forecast (GDP growth remains stable) as late as 10-13 months before the end date. In Figure 3, the data for GDP growth in the USA is given for the years 1991-2002. Note how inaccurate forecasts tend to be. The expected GDP growth fluctuates considerably for the years 1991-1994 and 1999-2002. In 2000, the forecast was initially a bit over 2% but the true value turned out to be about 5%. In 1995, even a month before the end date the forecasts were off by one percent.

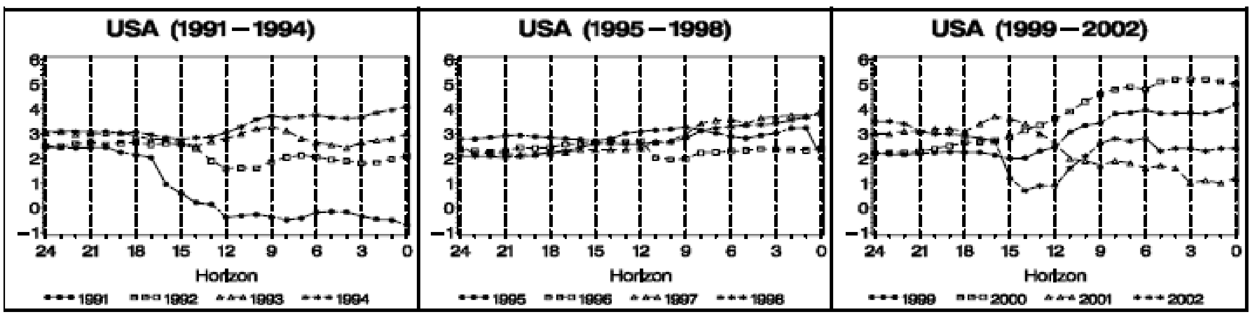


Figure 3: GDP growth forecasts for the USA and actual values 1991-2002, Isiklar and Lahiri (2006)

Fluctuations in the GDP growth of Portugal can be found in Figure 4. The graph shows that GDP growth was very unstable until 2003. Since the 1990s, the overall trend was downward for Portugal and in 2003 it became the first EU country to be considered in a recession. The IMF prediction was that the economy would grow by only 0.4% in 2004 which was the lowest growth in the EU. Neither Portugal nor the EU had expected this to happen a few years earlier. Fortunately, the Portuguese economy is in an upswing again with GDP growth of 1.1% in 2006. The forecasts made by The Bank of Portugal for the country's GDP in 2007 are being adjusted upwards. The initial expectation was 1.2% in the 2006 winter bulletin, which was increased to 1.5% in early January and which was further upgraded to 1.8% at the end of January. The increase of 50% from the initial forecast within a bit over a month does again show the accuracy of forecasts.

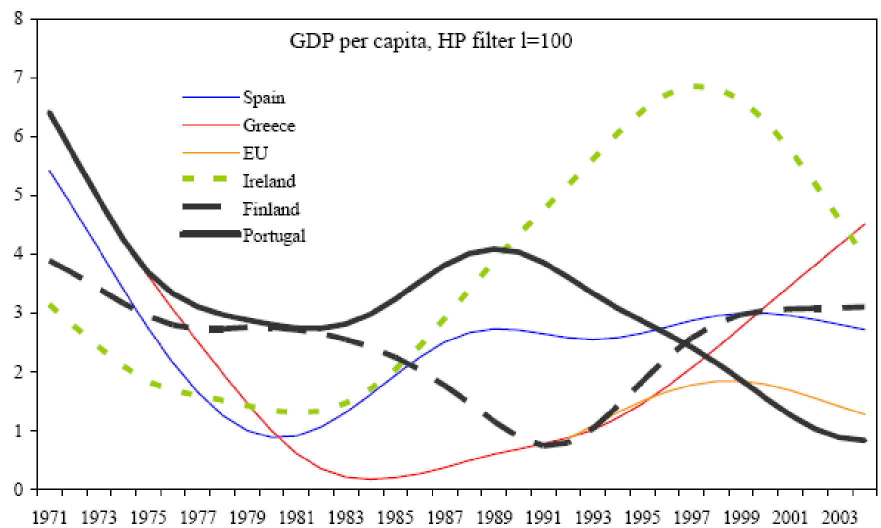


Figure 4: GDP growth in Portugal, IMF (2005)

That the GDP expectations for Portugal have the same inaccuracy as the forecasts for the USA (and other countries) is outlaid in figure 5.

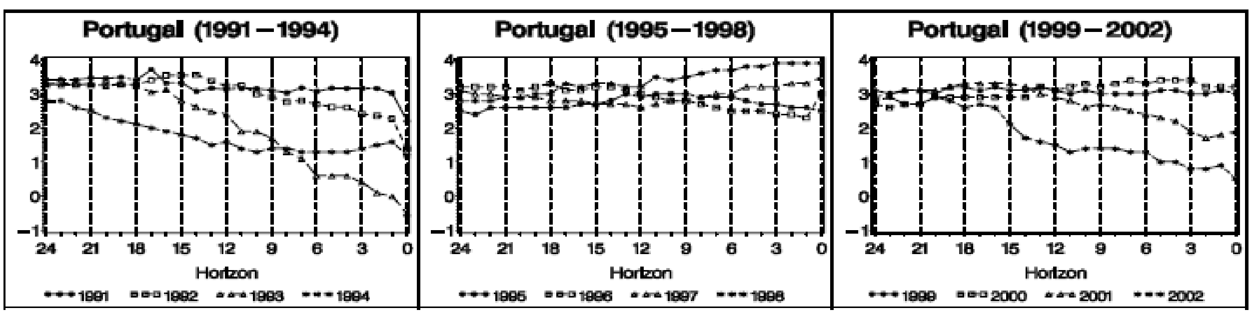


Figure 5: GDP growth forecasts for Portugal and actual values 1991-2002, Isiklar and Lahiri (2006)

Imagine what designing transportation systems to GDP predictions would mean. Transportation systems are usually designed for a system life of 20-30 years. Making forecasts of GDP on that time horizon is very close to a wild guess. As transportation demand is directly linked to GDP growth, this means that designing a fixed system and sticking to a master plan based on the forecasts is just about as likely to lead to the desired results as playing the lottery.

The relation of the GDP and transportation demand is not immediately intuitive. That the performance of transportation systems is related to energy prices is quite apparent. As energy prices increase, the cost of traveling increases and the demand drops. The GDP is a complex macroeconomic measure and it is very difficult to impossible to predict. Are the seemingly simple energy price levels any different when it comes to forecasting? The answer is no as the next section will show.

Energy cost: Oil and gas prices

Oil prices play an important part in our economy as they influence our energy consumption, price and income growth levels. Oil still is the most important source for fuel in transportation. Lynch (2002) has shown that the forecasting of oil prices is very inaccurate. Both the world's most noted academic scholars and the very well funded Department of Energy (DOE) of the United States have not been able to give correct predictions for the future as demonstrated in Figures 6 and 7.

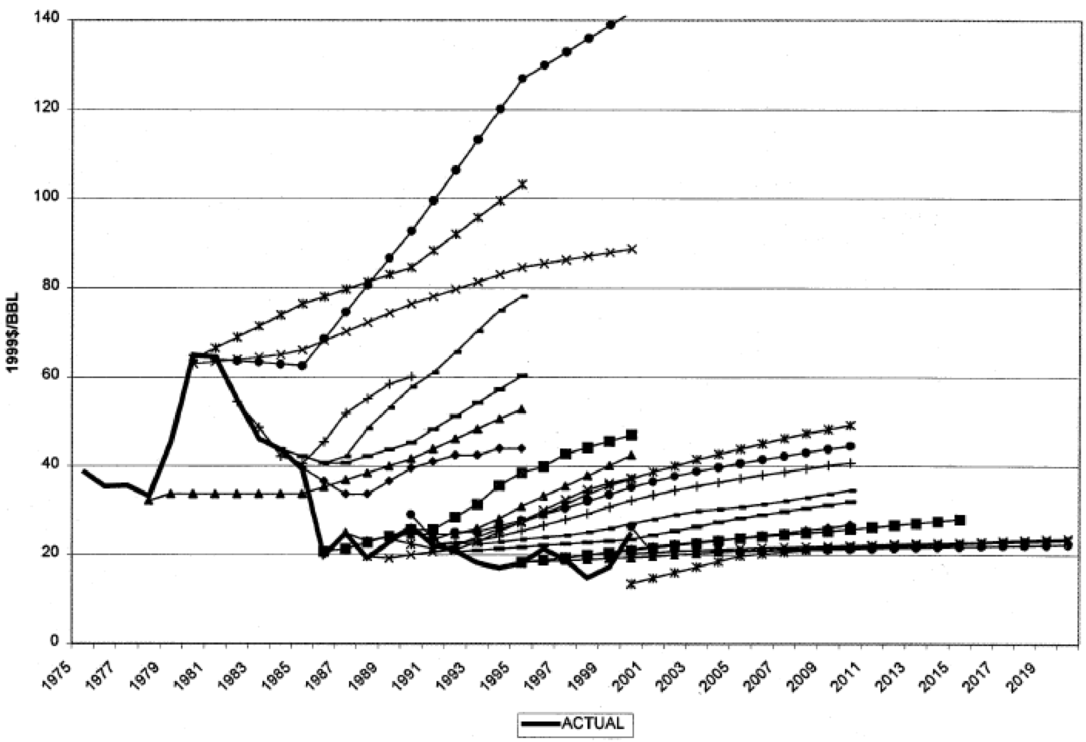


Figure 6: DOE predictions for oil prices versus actual price (Lynch 2002)

Prices in this commodity market are determined by supply and demand. One would think that supply can be easily predicted as most oilfields are known and there is a certain expectation on how much oil will be discovered. This is not the case as shown in figure 7. Estimates about resource availability are highly unreliable and speculative in the energy sector. So even for variables that are more graspable than the GDP, the forecasts are perfectly wrong.

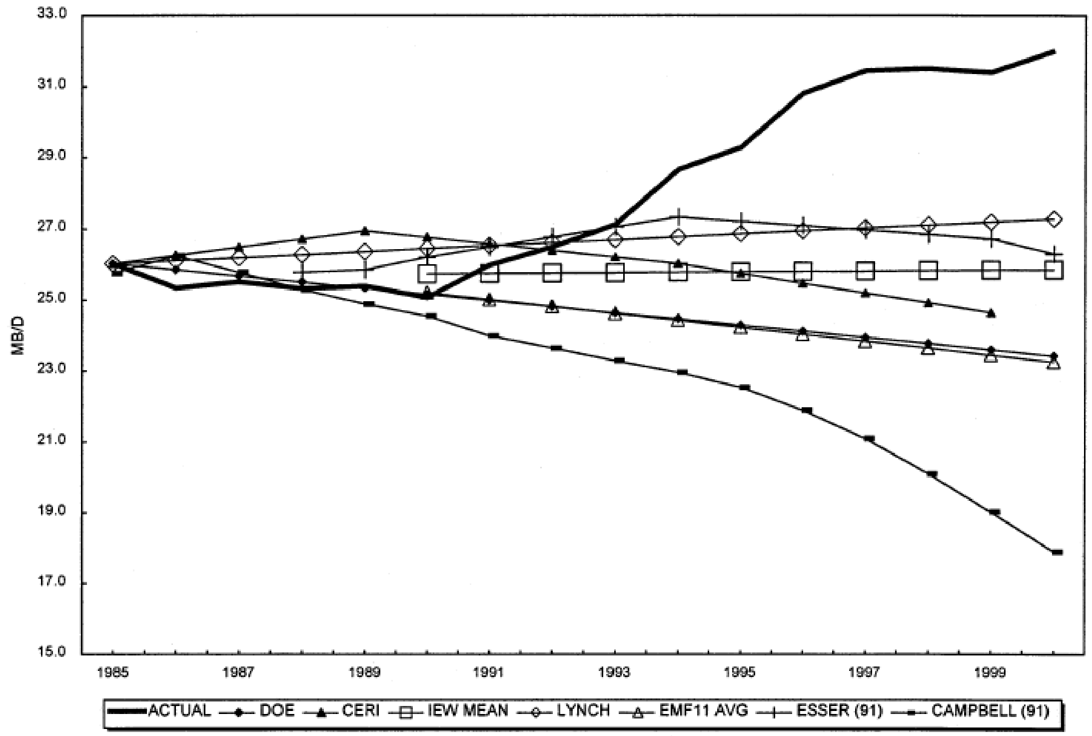


Figure 7: Major non-OPEC supply forecasts (take from Lynch 2002)

The forecasts for oil prices mentioned above are predictions for several years. However on a short term of one month it is difficult to forecast energy prices as well. For instance gas prices depend highly on weather conditions and can go up by more than 10% as demand increases if the weather is cold. As we all know, the weather cannot be predicted much in advance and on top of that predictions are not always accurate even on a short term. Experts state that gas is more difficult to forecast than petroleum because the data is much less complete and reliable.

The performance of transportation systems that are designed on forecasts is not the performance that was initially expected. Not only GDP and energy prices can be used to forecast transportation demand. In transportation, there is indeed a great amount of uncertainty about the factors that determine system performance as will be outlaid in the next case example about the Montreal Airport.[i]

Case example: Montreal Airport

Mirabel International Airport located 45 miles north of Montreal (Canada) was an ambitious project built to accommodate 6.8 million passengers annually. The Canadian government expected a passenger increase that the existing airport Dorval could not be able to handle (traffic growth at Dorval was 15-20% in the 1960s). When the decision was made to build Mirabel airport in the 1960s, air travel was indeed commercially booming. Montreal was economically the most important city in Canada. Flights to the

West-Coast of the United States refueled in Montreal because of the limited range of aircraft engines. This caused an increasing amount of noise and air pollution at Dorval airport, which was located close to the city centre. A new site outside the city was selected to build Mirabel airport and construction was finished in 1975. The new airport which is the second largest airport in the world in terms of area ($393km^2$) was built for 500 million Canadian dollars and opened in 1975.

The estimated number of passengers was never reached. In 2002 only 800,000 people used the airport. In 2003 the long criticized Canadian 'white elephant' was closed for passengers and now only serves cargo flights. A couple of un-anticipated factors changed the future drastically[ii]. In 1976 a separatist government was elected in Quebec and business started to move away from Montreal and transfer to Toronto. Airlines were discontent as they had to split their services between Dorval and Mirabel. This was very inconvenient for passengers as the connection between the airports was by bus and took up to two hours due to heavy traffic. When aircraft engines were developed that could fly directly to the West-Coast without stopping to refuel, airlines withdrew from the Canadian airports. Both political and technological factors influenced the performance of Mirabel airport. The forecast for demand was definitely wrong leading to huge losses for the Canadian people and an embarrassment for the government.

The Montreal airport is an excellent example of misplanning in transportation systems. Similar underperformance is also inherent to rail systems. This is explained in the next paragraph

2.5 Railway performance

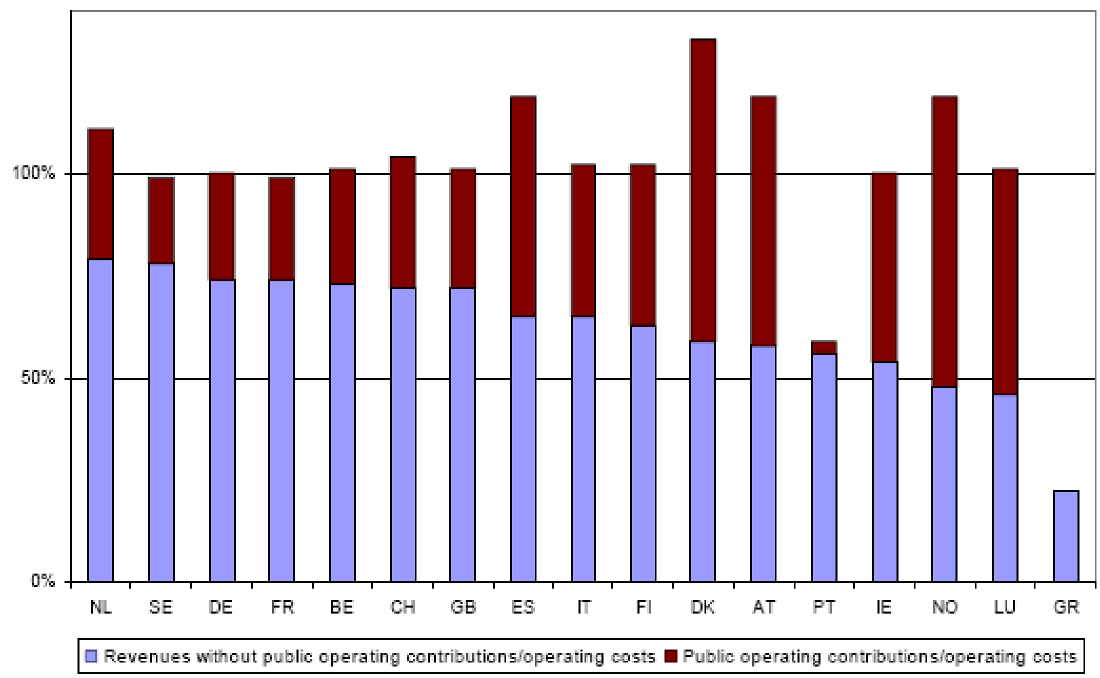
Railways are mega-projects with very high costs. Especially the investments for HSR are immense: the new HSR lines in Portugal will cost almost 9 billion Euro.

In the past 50 years, railways all over the world have been struggling to break even and most of them have built up high debts (Figure 8). Most European railways cannot even cover their operational costs with their revenues. Some can break even or make a small profit if one adds the public contributions to the railway sector. Note that the debt of several national railway companies is a significant percentage of the GDP. For example, in Italy and France the relative debt is 4.9% and 2.6% of GDP. Still, in most European countries, new lines are being planned which usually don't meet the (financial) expectations and increase railway debt even further. The less than expected performance is due to two factors: costs turn out to be much higher and demand is lower than forecasted.

	1994 Railway debts (million ECU)	1994 Rail debt in % GDP
Austria	2892	1.7
Belgium	3539	1.8
Denmark	2782	2.3
Finland	166	0.2
France	28731	2.6
Germany*	5795	0.3
Greece	937	1.1
Ireland	323	0.7
Italy	42067	4.9
Luxembourg	168	1.4
Netherlands	2807	1.0
Portugal	1529	2.1
Spain	8140	2.0
Sweden	1958	1.2
UK	10709	1.2
TOTAL	**112543**	
Approximate 2005 prices	€ 150 billion	

Notes : * After recapitalisation; Debt in 1993 was 33 788 MECU.
Source: Mercer Management Consulting reported in ECMT 1998.

Figure 8: European railway debt



Source: NERA.

Figure 9: Revenues and operating costs of European rail

In railways, large deviations from the forecasted costs are very common. In most cases costs turn out to be much higher than expected. Actual railway costs are on average 45% higher than estimated costs (the standard deviation is 38) as documented by Flyvbjerg (2003). The Shinkansen Joetsu rail line for instance had a 100% cost overrun compared with forecasted costs. Other mega-projects with spectacular cost overruns include the Suez Canal (1900% cost overrun) and the Sydney Opera House (1500% cost overrun).

Demand in railway transportation is extremely difficult to foretell as well although many elaborate forecasting models (e.g. Mandel et al. 1997, Hensher 1997, Lopez-Pita 2005) exist. Good examples of forecasts being far off actual values are Calcutta metro where actual traffic was 5% of estimated traffic, the Channel Tunnel where demand was 18% of forecasted demand and the TGV Nord with actual travel being 25% of forecasted travel. Flyvbjerg's study showed that average inaccuracy of rail passenger forecasts is -39% (with a standard deviation of 52) and for two-thirds of rail projects, forecasts are overestimated by more than two-thirds.

The problems in forecasting of railways are not only an international problem. In Portugal, similar examples of imprecise demand and cost forecasting can be found (described in chapter 4). Recent examples are the Fertagus line (operating since 1999) and the Alfa Pendular trains (operating since 1999 with problems). On the Fertagus line, actual demand was 50% lower than forecasted demand in the first year. On average it is now 35% lower than forecasted. Late delivery and technological problems have raised costs of the AP high speed rail system. The track between Lisbon-Porto has still not been upgraded fully and is planned to be replaced in order to achieve interoperability with European networks.

Flyvbjerg criticizes that although many multibillion dollar mega infrastructure projects are an economic, environmental and public disaster, more and more are started. He calls for both increased accountability by involving the private sector and increased risk analysis and management to improve their performance. The first point is already being addressed by the European Union and Portugal with the increasing privatization of railways (described in chapter 5). A flexible design strategy is an issue that has not been explored yet for the railways. In the following chapters we will take a look at what the major flaws are of the current design methods, how a flexible strategy works theoretically and how it can be applied to the Portuguese railway system.

As stated before, the inability to make precise predictions about variables that are essential to system design is not only limited to the field of transportation. The GDP and energy prices for instance have an impact on many other industries. The forecasting of the variables that are critical for system performance is very inaccurate in general. Next to these two examples related to transportation, cases can be found in engineering applications such as airport design (De Neufville, 2007), satellite fleet design (De Weck et al., 2003 and 2004), off-shore oil platform design (Babajide, 2007), Rental Car Pricing (Marcus et al. 2005) and many other areas. Forecasts are wrong for multiple reasons which will be analyzed in the next paragraph.

2.6 Why predictions are inaccurate

There are several reasons why predictions do not reflect the future as pointed out by Engerman (2005) and De Neufville (2003).

The first type of error is conceptual, because it assumes that the future is an extension of the past. It is wrong to suppose that the future will be the same as the past. For

example, the technological progress that has been made in the last 30 years is incredible. Cellular phones were invented in 1979, nowadays almost everyone has (at least) one. Many inventions contributed to the popularity of computers like microprocessors (1976), ink-jet printers (1976), Windows (1985), World Wide Web protocol and language (1990), and Pentium processors (1993). The commercialization of the internet has completely changed our world.
Other factors besides technological development like major political changes (e.g. 9/11), economic booms and recessions (e.g. The Great Depression in 1929), new industrial alliances or cartels can influence system behavior. It is impossible to anticipate these surprises, but it is important to realize that they will occur.

The second type of error is based on the fact that the past can be interpreted in various ways causing ambiguity. Many extrapolations are possible for the past data set. For instance, a wrong or incomplete model might be used for the forecasting. Or the data that are used as input for the model might be wrong, incomplete or misinterpreted. Furthermore, the debate about the future might be clouded by political opinions which influence the course of the extrapolations. The number of periods examined is another factor that can change the recommendations for the best design of a system. Finally, there is a lot of attention about the equilibrium the system will take over time, but not the speed at which it will reach this equilibrium.

The result of assuming one single future based on predictions is that the wrong decisions are made for the design of engineering systems. This can concern scale (demand sizing) of the system or perhaps the type of system (scope) is not suited at all for deviating futures. Greden et al. (2005) identify the following risk classes, uncertainties and quantification means:

Risk class	**Uncertainties**	**Data source or means of quantification**
Market	-Demand for product/service provided by system -Demand as a function of environmental features -Energy prices (e.g. electricity, gas)	-Historical data (if available) -Expert opinion -Simulation models of system performance
Technological	-Success/failure of new technology -Introduction of new, superior technology	-Expert opinion -Simulation models of system performance -Stochastic models
Climate (for systems whose performance depends on climate)	-Future ambient climate temperature and solar radiation -Global climate change and warming trends	-Stochastic climate models based on historical data and global climate change inputs -Simulation model of system subject to stochastic climate

Future use		-Expert opinion -Historical data
Regulatory	-Introduction of new standards for existing facilities	-Expert information and opinion

Figure 10: Risks, uncertainties and data sources for innovative technologies, Greden et al. (2005)

There is a difference between uncertainty and risk. Uncertainty deals with the spread of possible future scenarios, while risk is a measure of the effect that the relevant uncertainties have on our projects.
The following conditions must exist for risk to be evident (Mun, 2006):

- Uncertainties and risks have a time horizon.
- Uncertainties exist in the future and will evolve over time.
- Uncertainties become risks if they affect the outcomes and scenarios of the system.
- These changing scenarios' effect on the system can be measured.
- The measurement has to be set against a benchmark.

Risk can be measured in many ways (Mun, 2006):

- Probability of occurrence
- Standard deviation or occurrence
- Semi-standard deviation
- Volatility
- Beta
- Coefficient of variation
- Value at risk (VaR)
- Worst-case scenario or regret
- Risk-adjusted return on capital (RAROC)

Still, with the traditional valuation methods (like Net Present Value, see next chapter) the performance calculations of systems are based on single, average numbers. Thus a linear relationship is assumed between using average input variables (instead of a distribution of input variables) and getting an expected performance value that is a weighted solution for all output scenarios. A simple example showing that linearity cannot be assumed is when for different demand levels, an average capacity is planned in a plant. The higher demand scenarios cannot be exploited as capacity is restricted to the average and there is no protection against the lower demand scenarios. The actual value will thus be less than the expected value calculated with the average. This nonlinear behavior of system performance is known as the Flaw of Averages. It will be described more thoroughly with the traditional valuation techniques in chapter 6.

2.7 Chapter conclusion and thesis research question

When systems are designed in order to achieve the maximum benefit for the purpose which they are designed for, a lot of forecasts are made about the essential variables

that influence system behavior.
We have shown that the projected values on which system design is based are obviously very inaccurate.

Both internationally and in Portugal, rail systems have not performed as forecasted. The lesson to be learnt is that the future cannot be accurately predicted in (railway) system design. Planning a system with average forecasts that apply to one possible future outcome is highly unlikely to describe real system behavior. Nowadays, rail systems are still designed on predictions to match just one future scenario.

This leads to suboptimal system performance as risks cannot be avoided and opportunities cannot be exploited. Instead of the fixed master-plan approach, in the next chapters we will propose working with a variety of possible scenarios and designing a flexible strategy that is able to adapt to these scenarios.

There are two possible approaches to researching the impact of a flexible design strategy.
One way is to view the Portuguese government as the primary stakeholder for which the thesis is written. The problem with this approach is that a preliminary screening for the availability of data for costs and benefits of the Portuguese railways has shown that these are not readily obtainable. Also, it takes a lot of expertise in railway technology to analyze the data and give a feasible advice for a specific situation. This would make an analysis within the scope of a Master thesis impossible.

Another opportunity is to look at the scientific applicability of a flexible strategy to the railways and to use the HSR network in Portugal as a case study. In this approach, the emphasis is more on the usefulness of the methodology that is proposed in a real life situation. It is not necessary to obtain as much detailed data as in the first approach. Yet both the policy and the technology aspect have a place in the thesis. The policy facet is represented in the regulatory, historic and political background of Portugal and the railways. The methodology for engineering systems in a flexible way, Dynamic Strategic Planning (DSP), is applicable to technology strategy. It is quantitative in nature as it is closely related to the financial field of options. Simulation techniques are also a part of applying DSP to cases.
This approach to improving system performance is interesting to the academic community but it provides useful results to governments and large companies as well. Although no actual advice is given about how the HSR line in Portugal should be designed, it gives a sound recommendation in whether it is useful to explore the embedding of flexible design strategies in large transportation projects like HSR.

The central question in this thesis will be:

Can the performance of (high speed) rail transportation systems be improved with flexible planning techniques for the case of Portugal?

In order to answer this question, we will answer the following sub-questions in the next chapters:

Chapter 3: Characteristics of high-speed train transportation

- What are high-speed transportation means?
- What are high speed train technologies?
- What are valuation methods for high speed rail system design?
- How can the impact of HSR on a country be captured?
- Who are the stakeholders in high speed rail systems?

Chapter 4: A historical and policy view on railways in Europe and Portugal

- How did high speed trains develop in Europe?
- What are criteria for success in high speed rail?
- What is the history of Portuguese railways?
- What is the current situation in Portuguese railways (lines, operators, etc)?

Chapter 5: Close-up on Portuguese rail system performance

- What is the current system performance of the Portuguese railways?
- What are uncertainties in rail system design? (sources of risk and opportunity)
- What are the plans for Portuguese railways?
- What is the policy and future issues influencing Portuguese transportation policy?

Chapter 6: Traditional valuation methods and flexible valuation methods

- What are the consequences of uncertainty in system design?
- How do the traditional design valuation methods take uncertainty into account?
- What alternative approaches are there to react to uncertainty?
- How do they provide value under uncertainty?

Chapter 7: Application of a flexible plan to High Speed Rail Design

- How is uncertainty in HSR projects handled by governments?
- Which uncertainty in HSR projects needs to be examined more closely?
- What are possible consequences of average benefit planning in transportation projects?
- How can DSP be applied to HSR benefit management?
- Which Real Options could be used for benefit management of HSR?
- How can these Real Options be translated into models that fit the DSP approach?
- How can the success of DSP in HSR benefit management be evaluated?
- How does the case of HSR perform in this evaluation framework?

In chapter 8, we will finish with conclusions and recommendations in which the central thesis question is answered based on the previous chapters.

Chapter 3 High Speed Train characteristics

3.1 Introduction

In this chapter, more insight in the choices that need to be made in high speed train design is provided. This is done by looking at the high speed transportation means in general, high speed train technologies in specific, and analyzing what the drivers are to opt for high speed train technology. Other choices that need to be made are the evaluation method, the evaluation model and its parameters. This decision is influenced by stakeholder interests, which we will finally address.

3.2 Transportation means

With the current level of technology there are several feasible ways to transport passengers and/or freight:

- Road
- Air
- Railway
- Inland waterway
- Maritime
- Pipeline

The fast transportation modes are defined as having an average operational speed of minimum 200-250km/h. This means that Air or High Speed Train are the only fast transportation modes. The costs and benefits of implementing HSR from a country perspective are according to De Rus and Inglada (1997):

– Costs and revenues of the construction and operation of the project.

– Variation in costs and revenues of other transport operators.

– Time savings for HST users.

– Time savings for road users due to the reduction of traffic congestion.

– Changes in quality of service.

– Reduction of traffic accidents.

– Regional economic development.

– Environmental impact

The average operating speed is thus not the only thing that matters. When customers decide on which travel mode to choose, also waiting times, transfer times, and quality (e.g. availability and comfort) are factors that consumers take into account. Social responsibility (e.g. benefiting the environment or reducing the number of accidents) is increasingly important in public and private decisions.

3.3 High Speed Train (HST) technology

High Speed Trains (HST) are usually trains with operating speeds above 200 km/h. Currently, there are two types of HST technology operating. The most popular one is High Speed Rail (HSR). These trains travel on a stronger version of the conventional rail track. HSR technology has been operating in several countries like Japan (Shinkansen since 1964), France (TGV since 1981) or Germany (ICE since 1991). High speed rail has three train types:

- Locomotive/special power car propulsion
- Electric multiple unit
- Diesel multiple unit

Jet Propelled Trains (Excel 2006) are being developed and might become a fourth HSR technology that is faster and environmental friendlier. Other possible technology improvements in HSR are a lower weight and better passenger space utilization by redesign of the propulsion system, bogie and car body (Najafi et al. 1996) The major components of the HSR system are the infrastructure (special track, bridges and grade separations), trains, energy systems which supply power to the trains, and signaling systems which guard the safety on the tracks and signal the maximum speed to the trains. The infrastructure is by far the most expensive part of the HSR lines, accounting for more than 90% of the total expenditures.

Maglev (magnetic levitation) technology is rather new and special infrastructure needs to be built for it. It is based on the repelling force of magnets for propulsion which is applied in two technologies (Holmer, 2003):

- Electro-magnetic suspension (EMS) is a German Transrapid technology; China has been operating it in Shanghai. Although the EMS Shanghai line was not a huge success (on average 73 out of 440 seats filled; price cuts of 33%-80% and children free), in October 2006 China placed a massive new order to connect Shanghai and Beijing. These plans are highly criticized by authors like Wen et al. who plead for HSR as a means of intercity transportation in China.

- Electro-dynamic suspension (EDS); developed and implemented by Japan.

Vuchic and Castello (2002) have compared HSR and Maglev system features and advise against the use of Maglev technology because it is costly and has not matured yet.

SYSTEM FEATURES	MAGLEV	HSR
a. Travel time factors		
• Maximum speeds	420 – 450 km/h (261 - 280 mph)	300 – 350 km/h (186 - 217 mph)
• Acceleration rates	Higher at upper speed range	
b. Intermodal compatibility		
• Network connectivity	None / single lines	Excellent / extensive networks
• Use of existing infrastructure	New and elevated guideways, tunnels and stations needed	New lines combined with existing lines and stations can be used
c. Costs		
• Investment costs[16]	$12 - 55 M / km ($19 - 88 M / mile)	$6 - 25 M / km ($10 - 40 M / mile)
• Operating and maintenance costs	Uncertain	Known
• Energy consumption[17]	Higher than HSR	
d. Additional factors		
• Riding comfort		Superior
• System image / passenger attraction	Excellent, plus initial innovation interest	Excellent / superior network accessibility
• Impacts on surroundings	Lower noise and vibration	Tracks mostly at grade

Figure 11: Maglev and HSR comparison, Vuchic and Castello (2002)

In Europe, HSR is preferred over Maglev as infrastructure costs are about four times lower and it is compatible with the existing rail networks (Janic, 2003). Regional circumstances and conditions are very important in the profitability of the Maglev system (Elhorst et al. 2006). In Japan however, Maglev is popular because it has a larger air gap between the trains and the track which is safer during earthquakes. One of the costly components of Maglev is the power supply to the trains. Each train needs its own power facility now but research is being done to be able to share power facilities with several trains.

Maglev is not promoted for its better safety record but for its hypothetically higher speeds. The gains are much lower for a bit higher speed though. As the maximum speed is raised, more resources are needed to achieve the same increase in speed. But the time gain that is achieved by raising the maximum operating speed, decreases as is shown by Vuchic and Castello (2002). This is a typical example of decreasing returns to scale and decreasing economies to scale.

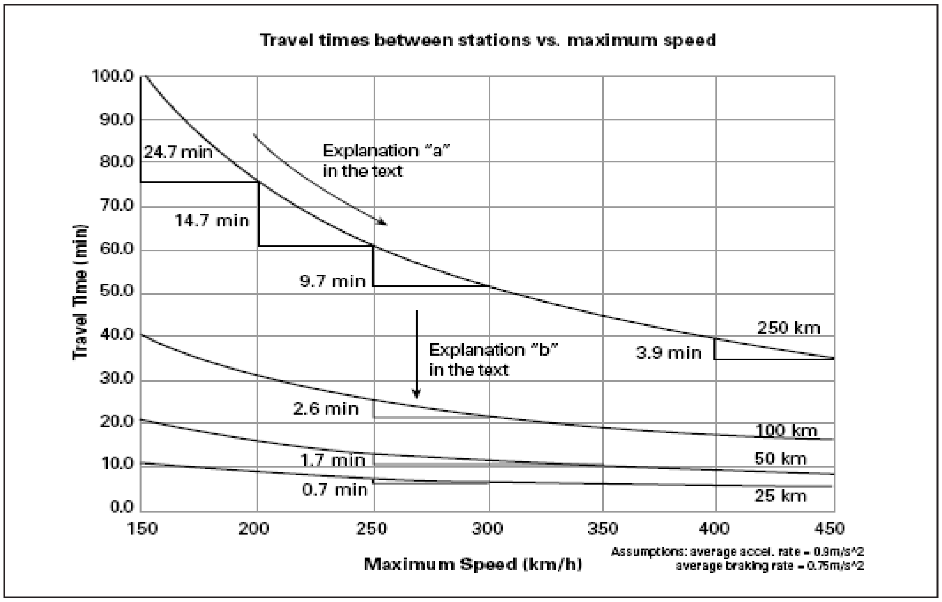


Figure 12: Travel time, speed, and station density from Vuchic and Castello (2002)

Next to this, in 2007 the maximum speed of a Maglev train is 481 km/h while the French TGV set a new speed record for regular HSR technology at 475 km/h. This difference is of no consequence. Concluding, for the European situation the choice for High Speed Rail instead of Maglev technology seems the wisest and there are very few reasons for developing Maglev technology (simultaneously to regular HSR).

3.4 Evaluation methods

The models that are used to measure the impact of HSR are derived from the advantages and benefits that are mentioned above. Both researchers and designers of the railroads assign a monetary value to the factors mentioned above and use traditional valuation tools (like Net Present Value, Internal Rate of Return and Payback Ratio). We will discuss these valuation methods briefly before discussing their application in railroads.

3.4.1 Net Present Value (NPV)

The Net Present Value is a measure of profitability that discounts all cashflows (benefits and costs) to the current point in time. Usually it is defined as the sum of present values of the periodic cashflows (revenues less costs) minus the initial investment:

$$NPV = I_0 + \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Where

I_0=initial investment

B_i= benefits at time i

C_i=costs at time i

R= discount rate

N=number of periods

The advantages of the NPV are that it depends on both the time value of money, which is represented by the periods 0..n and the discount rate which is a measure for risk. When the Net Present Value equals zero, it means that the minimum profitability standard is met. If the NPV is positive, extra profit above the minimum is realized.

The major disadvantage is that the meaning of the NPV is not intuitive to most people. Also, it does not provide a measure of scale of the profitability versus the investment. Finally, NPV is reliant on the chosen discount rate which can be manipulated as we have seen before.

3.4.2 Benefit-cost ratio

The benefit –cost ratio is the ratio of the discounted value of benefits and costs:

$$BC-ratio = \frac{discounted\ benefits}{discounted\ costs}$$

An advantage over the NPV is that the BC-ratio is a scaled measure of profitability. If the BC-ratio is larger than one, the project is profitable. Just like NPV, it is sensitive to the discount rate used. A large disadvantage of BC-ratio is that capital intensive projects are favored over projects with large reoccurring costs. This is the main reason to use NPV over BC-ratio.

3.4.3 Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) avoids the political discussion about which discount rate to use. It is the discount rate at which the net present value of the project equals zero. Projects are ranked in desirability according to the highest IRR. It is more difficult to calculate than NPV and BC-ratio. IRR could also be ambiguous (having several solutions) if there are (closure) costs in a project which exceed the total undiscounted benefits minus the investment costs.

3.4.4 Cost Effectiveness Ratio

When it is difficult to express the benefits of a project in money, the cost-effectiveness ratio could be used as an alternative measure of impact. It is used in cases where there is no market for the services/products provided (government services) or if moral/ethical issues are concerned (f.e. how much is a live worth?). The largest disadvantage of the cost effectiveness ratio is that there are no guidelines on how much the ratio should be. This makes the discussion again highly political.

3.4.5 Payback Period

The payback period is the easiest of the economic valuation techniques and is defined as:

$$Payback\ period = \frac{I_0}{Annual\ net\ undiscounted\ benefits}$$

The payback period does not consider time value of money and is difficult to apply to projects whose number of periods differs. It is best suited for comparing similar projects with constant streams of cash flows, a situation which is very rare in business practice.

3.5 Modeling in Rail

Net Present Value (NPV) is the most popular financial valuation tool. It is applied by 96% of the CFOs of large companies (Teach, 2003) and it is also used by railroads and scholars to calculate the benefit of HSR. The other tools are also mentioned in financial reports of the railroad companies but decisions seem to be made purely based on NPV. This is affirmed by the two approaches for modeling the impact of HSR: social welfare on one side and profit on the other side.

3.5.1 Social welfare as a measure for HSR impact

The first one is the concept of social welfare (for instance described by De Rus and Inglada (1997) and De Rus and Nombela (2005) and applied to the high speed AVE trains in Spain). De Rus et al. define social welfare as the unweighed sum of consumer and producer surpluses. Assuming a continuous flow of benefits and costs, social welfare in the base case can be expressed as the sum of the surplus of passengers using the rail with the new technology, the producer surplus of the firm operating the new technology, and the surplus of the alternative modes (road, air, conventional rail) users and producers, during the life of the system properly discounted at the social discount rate. All non-monetary benefits and costs are given a monetary value for the calculation of the NPV. For instance, the value of the time people spend in a transportation mode is derived from customer surveys and economic models of the transportation system per country/region. Economists measure the value of this travel time by examining situations in which people can trade time for money, such as by choosing different means for travel (Small, 2006).The average cost of a fatal accident, noise pollution, CO_2 emissions, etc. are also measurable in monetary units.

Although other benefits than travel time savings have been mentioned for HST (Time savings for road users due to the reduction of traffic congestion, Changes in quality of service, Reduction of traffic accidents, Regional economic development, and Environmental impact), studies (f.e. Haynes 1997, Sasaki et al. 1997) have shown that the impact of these benefits is marginal. Travel time savings for HST users is the (by far) largest non-monetary benefit of the rail system.

The initial model of De Rus et al. shows the trade-off effects of HSR versus the other transportation modes very well. It is a simplified version that does not take all benefits and costs mentioned above into account. Also the linear connection of the trade-off curves is debated. Still, it provides significant insight in the complexity and impact of HSR on the entire country.

3.5.1.1 Social welfare modeling by De Rus et al. (1997)

The model of De Rus et al. (1997) builds on separate scenarios for the transportation modes:

- One benefit-cost scenario for bus/train including HSR
- A second benefit-cost scenario for car
- A third benefit-cost scenario for air

The total impact of High Speed Rail is the addition of the contributions of these three points.

Bus/train

The impacts of bus or train are modeled as shown in figure 13.

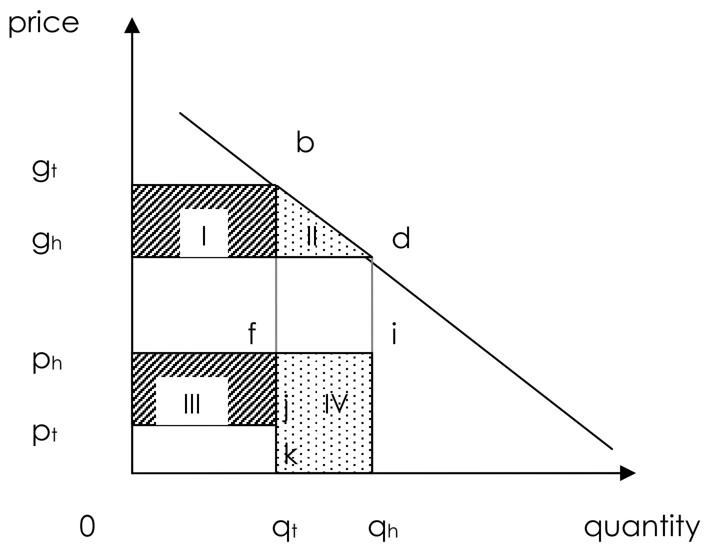


Figure 13: Train/Bus substitution by High Speed Rail

Assuming that the net benefit of HSR exceeds that of conventional paid transportation (bus/train), this benefit can be modeled as:

$(g_t\text{-}g_h)q_t+1/2(g_t\text{-}g_h)(q_h\text{-}q_t)+p_hq_h\ p_tq_t$ {surface I + surface II + surface III+ surface IV}

where:

g_t= initial generalized cost of regular traveling= $p_t+(g_t\text{-}p_t)$ where

p_t= travel fare for train

$g_t\text{-}p_t$= value of total journey time regular transportation

q_t= number of travelers in regular transportation that would switch to HST

g_h= generalized travel cost of HSR

p_h= travel fare HSR

$g_h\text{-}p_h$= value of total journey time HSR

q_h= number of travelers of HSR (diverted from regular traffic and extra new travelers)

In order to achieve these benefits, the following costs and savings are made:

C_h=costs for the introduction of HSR

C_t=savings from closure of conventional transportation services

The net benefit for HSR becomes:

$(g_t\text{-}g_h)q_t+1/2(g_t\text{-}g_h)(q_h\text{-}q_t)+p_hq_h\ p_tq_t+C_t\text{-}C_h$

This can be simplified considering:

- The gross benefits of the diverted traffic q_t are the time savings due to the introduction of a faster transport mode= value of total journey time in regular transportation – value of total journey time in HST = $((g_t\text{-}p_t)\text{-}(g_h\text{-}p_h))q_t=(g_t\text{-}g_n)q_t+(p_n\text{-}p_t)q_t$=surface I + surface III
- The social benefit of generated traffic $(q_h\text{-}q_t)$ equals the area under the demand function from q_t to q_h excluding the travel time spent $(g_h\text{-}p_h)(q_t\text{-}q_h)$ = ½($g_h\text{-}p_h)(q_t\text{-}q_h)$+ $(p_n\text{-}p_t)(q_h\text{-}q_t)$= surface II + surface IV

Car

The lower demand for car transportation due to the introduction of HSR is modeled in figure 14.

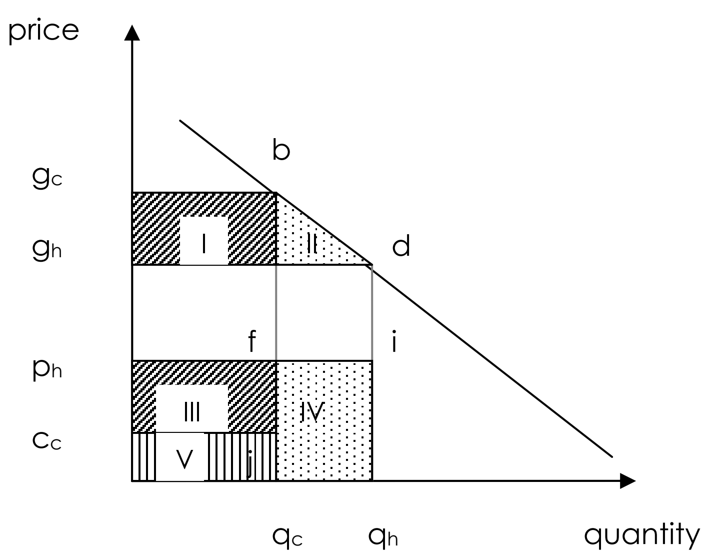


Figure 14: Car transportation substitution by High Speed Rail

The savings of real resources from deviated car traffic are:

$(g_c\text{-}g_h)q_c$+ ½$(g_c\text{-}g_h)(q_h\text{-}q_c)+p_hq_h$ = surface I + surface II + surface III, IV, V where

c_c=maintenance costs, fuel, lubricant consumption, wearing out of tires, half of car depreciation

g_c= initial generalized cost of traveling by car

q_t= number of travelers in regular transportation that would switch to HST

g_h= generalized travel cost of HSR

p_h= travel fare HSR

g_h-p_h= value of total journey time HSR

q_h= number of travelers of HSR (diverted from regular traffic and extra new travelers)

The savings from real resources from deviated traffic equal the sum of surface I and surface III. The savings in operating costs of car journeys equal surface V. Other (reasonably tangible) factors that are not added in this model but could be are:

- Less accidents
- Less road congestion

The difference between cars and the other modes basically is that trains/buses/airplanes always travel, no matter the number of passengers. If there are no passengers in a car, this car will not travel.

Air transport

It is assumed that there is no time saving from shifting from air transport to HST:

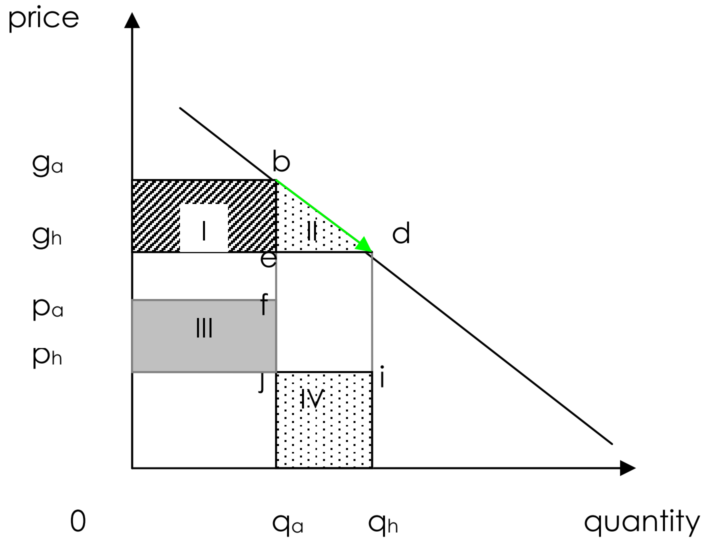


Figure 15: Air transportation substitution by High Speed Rail

where

g_a= generalized cost of air transport passengers

g_h= generalized cost of air transport passengers after introduction of HST

p_a= travel fare air

p_h= travel fare HST

g_h-p_h= value of total journey time HST

q_h= number of travelers of HST (diverted from regular traffic and extra new travelers)

In this figure, users change to slower mode of transport because they are compensated by lower prices ($p_h<p_a$) for the increase in total journey time per passenger $(g_h-p_h)>(g_a-p_a)$.

For deviated journeys (q_a), society looses the difference between surfaces I and II: an increase of the resources employed (total value of time) in doing the same journeys.

- The impact due to change in value of time equals the value of time before HST minus the value of time after HST: $(g_a-p_a)q_a - (g_h-p_h)q_a=(g_a-g_h)q_a+(p_h-p_a)q_a$
- The benefit of generated traffic equals surface II + surface IV + savings derived from flight service closures= $\frac{1}{2}(q_h-q_a)(g_a-g_h)$

The model of De Rus et al. (1997) does not model all the impact of HSR. Newer and very complex models have been developed to try to capture the interactions between the different transportation modes. It is very important to realize that HSR cannot be seen as an independent mode. It is part of the bigger transportation system and its impact on the country can be far reaching. Therefore it is crucial to analyze HSR in a bigger picture when the transportation network is designed.

3.5.2 Profit as a measure for HSR impact

The second approach to calculating the impact of HSR is directly related to the profitability of the HSR itself (used for instance in Taiwan, Chang and Chen 2001). As transportation systems are privatized all over Europe, indeed only the monetary profits that HRS would generate could seem important. It would be advisable though that governments also keep in mind the possibility of failure of commercial rail systems. If a country still wants to have rail as a transportations means while it is not profitable, the value of operating it themselves might be relevant. For instance in the USA which is economically one of the most liberal countries in the world, it has proven very difficult to run competitive passenger rail connections. High speed rail is almost non-existent because the private sector thinks the rewards barely cover operating costs and too insecure to take a chance (Thompson, 1994). Furthermore, the total impact on the country, as described by the social welfare concept, is not captured fully by looking only at the profit.

Because the debate about the railways is very political and non-profit related arguments are used for and against the rail line, it is important to approach the matter from a social impact perspective. In later chapters of this report, we will use a limited model of social welfare (without explicifying the interactions between modes) as a measure of HSR performance. That interactions between modes exist is a known fact, but it is not doable within the scope of the thesis to model them precisely. The simple model does not disregard these interactions and could be extended to the degree of detail mentioned above.

3.6 Stakeholders determine model and model parameter choices

The complexity of the models and the large number of estimates is not the only problem when it comes to evaluating the system performance. The approaches mentioned above implicitly define the different stakeholders in the development of high speed rail but do not emphasize the political factors of HSR very much. As we will see in the next chapter these motives weigh heavily. Depending on the desired result, the choice of model and model parameters would be different per stakeholder. A stakeholder analysis for the impact of HSR could be:

Stakeholder	***Advantage***	***Disadvantage***
Individual consumers	+diversified transportation: better quantity and quality makes traveling easier and more comfortable +faster transportation by HSR makes travel faster	-possibly less/more expensive transportation by other modes
(investors in) HSR-company	+revenues	-costs
Companies operating in other modes	+network synergies	-replacement of own services by HSR
National government	+revenues from HSR +cost reduction for other government owned modes +economic growth +cleaner environment +less accidents +less clogging on other modes +meeting European standards of environment and economic growth better	-costs from HSR -loss of revenue for other government owned modes
European government	+uniting Europe by creating large mutual structures +uniting Europe by reducing travel time between countries	-HSR is subsidized heavily

Figure 16: Stakeholder analysis for HSR

As already explained, it would be very difficult to capture the factors in this stakeholder analysis in a way that is satisfying for all. Discussion points for scenarios based on which HSR plans should be evaluated are possible on several levels which will all influence the desirability of the HSR:

- Global/country level: the demand for transportation follows the GDP trend as we have seen earlier. Fluctuations of the GDP are difficult to project and many scenarios are possible. Unexpected political and economical developments will affect the GDP in the future, leaving a lot of room for political interpretation of the future.
- Transportation mode level: what will the distribution of the transportation demand be between air, road and air? New technologies might either positively (extra taxes on cars, new energy supply systems for Maglev making it cheaper) or negatively (e.g. bio-cells for cheaper and cleaner road travel) affect the

demand for rail. Depending on the attitude for or against HSR, the future scenarios on this level can be determined to suit the stakeholder.

- HST technology level: F.e. Maglev technology is more expensive now but if some technology issues (with the energy supply) are resolved, it might become more attractive than HSR. By those who want to delay the decision to build HSR or companies who produce competing technologies a convincing argument against HSR can be made.
- HSR technology application: there are uncertainties about how a technology will perform when it is actually applied in reality. Operating conditions will not be the same as those on the test track of the manufacturer. One could think about different climate/weather conditions, staff with a different level of skills, etc. This can again be positively or negatively be estimated.

The first two levels affect the demand for HSR, the third one affects the cost structure and the forth level affects both cost and demand.

Although strategic political motives cannot be assigned a monetary value very well, they are one of the biggest drivers of the motivation for implementing HSR networks as shown in chapter 4. In that chapter, the background and future policy issues for the Portuguese rail transportation network will be addressed.

3.7 Chapter conclusion

Several choices need to be made in high speed train design and evaluation. First, we have looked at the technological possibilities in which high speed train transportation can be realized. High Speed Rail (HSR) is shown to be much better suited than Maglev trains to be applied in European countries.

Second, the evaluation techniques that are used for the evaluation of a high speed train technology have been explored. Net Present Value technique is the most popular of the traditional techniques. It is conceptually superior to other techniques that do not account for the value of time and immediate gives an indication if a project is worthwhile.

Third, the goal function for railway evaluation must be determined. The choices are ‘profit only’ versus the broader ‘social welfare’ concept. Social welfare evaluation is better suited under the current regulatory and economical conditions of European countries. It is advised to use this approach as massive public funds go into this transportation mode.

Forth, there are many, many ways in which social welfare can be modeled. To give some insight in them and show their complexity, we have provided a model by De Rus et al. (1997). By modeling the impact of HSR and deciding on the input variables to be used, implicitly the weight of the stakeholder interests is determined. This stakeholder analysis is usually omitted. There are a lot differing interests when HSR lines are built and the modeling is certainly not as objective as most studies that design and use models for HSR want to convince the reader. We have given a stakeholder overview to show the different forces that might influence the modeling and decision process.

4 History and policy of Portuguese railways

In this chapter, developments that have influenced Portuguese rail from the beginning period to the current age will be looked upon. Three main periods can be distinguished in Portuguese rail:

- Profitable period 1850s-1920s
- Profitability declines and Portuguese railways face serious trouble 1920s-1975
- New impulse in European rail which also affects Portugal 1975-now

4.1 Profitable rail period 1850s-1920s

The 19th century brought technological developments that established rail as the dominant transportation means in Europe. Major technological breakthroughs were achieved in the United Kingdom, stimulated by the need for better freight transportation in the mining industry during the Industrial Revolution. In 1812 a commercially successful locomotive was constructed by John Blenkinsop and Matthew Murray replacing the horse powered vehicles.[iii] In 1825 the first train ran on wrought iron rails designed by John Birkenshaw which allowed for longer distances to be covered faster than on conventional wooden or cast iron rails.

The Portuguese railroads were established with British involvement.[iv] In 1844, the Portuguese state decided that a railroad should be created near Lisbon and a competition was issued. The contest was won by a company founded in London on May 14, 1852, by the Englishman Hardy Hislop. The Companhia Central Peninsular dos Caminhos de Ferro de Portugal opened its first passenger line covering the Lisbon-Carregado track in 1856. The inauguration trip by King D. Pedro V did not go as planned. One of the two locomotives that pulled the train was not functioning properly, causing considerable delay to the passengers. The remaining locomotive first pulled one half of the train wagons and then came back for the other half. The company was dissolved within a year and operations were taken over by Portuguese state and another English investor, Sir Morton Petto. This company also failed and in 1865 the Paris headquartered Royal Company of the Portuguese Railways was established. After Portugal became a Republic it was renamed to Caminhos de Ferro Portugueses (CP).

Technological uncertainty was already a problem in the early days of the railroads. From Barreiro to Beja, the line was built by two companies who each bet on different dominant designs for the gauge size. One company built track of Iberian gauge size (1668 mm) from Beja to Vendas Novas, while the other used narrow gauge (1440mm) for the connection Vendas Novas to Barreiro. This caused operating problems and as Iberian gauge seemed to become the dominant national track, the narrow track was replaced with Iberian track.

An example of another costly uncertainty in railroads was delay in the construction of the Sado line. Bridge construction problems kept the initial track design from being realized until 1925. The tracks to the small village near the bridge were already opened in 1920 (Setúbal to Alcácer do Sal) and 1918 (Garvão to Alcácer do Sal).[v]

Over the years, CP became the most influential railway company in Portugal. It set the national technological standard for rail transportation. In 1927, shortly after Salazar taking over power, several lines were transferred to be operated by CP. The remaining lines were swallowed up by CP 20 years later.[vi]

4.2 Decline of railways 1920s-1975

The railroads remained profitable until the 1920s. The first quarter of the 20th century was politically very turbulent. After years of monarchy, in 1910 the first Republic of Portugal was established. The young democracy was struggling and between 1910 and 1925 the country had forty-five governments.[vii] WWI, civil wars and labor union activity had a negative influence on the railways with violent riots and derailing of trains. Political instability ended with the military coup on May 28th 1925 which established an authoritarian regime of fascist inspiration under the dictatorship of Salazar that would govern Portugal for 50 years.

In 1931, CP reported a severe loss of 12 million Escudos (2.1 million euros) due to competition of the roads. Still trust in the railways was big and CP continued to build new lines.[viii] The second quarter of the 20th century was increasingly challenging on the railways in Europe. Alternative modes of transportation reduced demand for railroad travel. The automobile (especially the Ford model A, T and V8) was getting very popular for shorter distances[ix]. Airships for commercial passenger travel were introduced in 1935 with the arrival of fixed wing, propeller driven Douglas DC3 planes[x]. Other companies like Boeing (707) and Fokker (F27) followed with commercially successful planes in the early 1950s.

Furthermore, railways faced financial problems after the wars and the Great Depression in 1929. The heavy burden of repairing infrastructure after the wars, forced many local railways to withdraw and let the state take over its operation. The ruin of global economy in the late 1920s reduced rail travel demand further. Increased costs made governments step in and nationalize many of the European railways (Perkins, 2005). Portuguese railroads were not nationalized but received heavy government subsidizing. Political unrest on the Iberian Peninsula (the Spanish civil war in 1936) led to the temporary closing of international rail lines from Portugal. The 1940s were characterized by the closing of many connections because of fuel shortage and switching train technology to adapt to whatever fuel source was available.[xi]

Since WWII, large financial contributions have been made to European railways to cover losses and give rail a chance to recover from the political and economical turbulence.[xii] Investments to increase demand in Portugal like the electrification of railway track in the 1960s, have not proven to be sufficient. Economic growth made air and plane travel explode while demand for railroads continued to diminish. After WWII, airplane technology had advanced so much that this became the favored mode for longer distance transportation. Cars also became progressively cheaper and gained a larger travel market share.

On April 25th 1974 the peaceful Carnation Revolution ended the Salazar dictatorship and established a new democracy.[xiii] There was a massive call to nationalize all major industries. In 1975 CP was nationalized and its severe financial problems resulted in the closure of lesser used lines. Plans to put the railways on a healthier financial foundation in 1982 turned into riots and strikes and the outlook for rail was bad.

4.3 Developments in the last 20 years; Europe's influence increases

Portugal's plans for upgrading the rail system were triggered by developments in Europe. European countries started improving their transportation systems with new technologies since the 1960s. During the same time, the European Union became an increasingly powerful political player.

4.3.1 Developments in European countries

Prior to the centralized European efforts, the large European countries had started to upgrade their national railway systems. This encouraged Portugal to do the same.

Investments in national European rail networks were inspired by Japanese progress. Japan was the first country to build dedicated rail lines for high speed travel. Plans to construct the first Shinkansen high speed rail line from Tokyo to Osaka were made in the 1940s. Conventional Japanese railways were much less suited to be upgraded to higher speeds because they were 1,068 mm narrow gauge. As the position of Japan in WWII weakened, the country abandoned high speed plans until the 1960s when World Bank funding was obtained. On October 1st, 1964, Japan Railways started operating the Shinkansen, just in time for the Tokyo Olympics. Within three years, the Shinkansen had carried 100 million passengers. Benefiting from the EXPO'70, in the first 12 years over one billion passengers were transported.

The incredible safety record (zero casualties even after the derailing of trains due to earthquakes) and higher speeds of the Shinkansen (initial maximum speeds of 210 km/h) appealed very much to the most powerful European countries.

France started designing the world's second commercial high speed rail service. The Train à Grande Vitesse (TGV) was first proposed in the 1970s when government policy strongly favored new technologies. The TGV first operated on September 27th, 1981, between Paris and Lyon and the primary target group was business travelers. The TGV provided a noteworthy faster connection between the two cities and leisure travelers started using the service on large scale. By 1985 15M people were using the TGV annually. Total rail passengers increased from 12.5 M in 1980 to 22.9 M in 1992 of which 18.9M TGV. It has almost fully replaced air travel on this route and car traffic growth was 1/3 of the growth on other routes. The French Railways SNCF reported that the expected minimal financial rate of return (12%) was surpassed and the actual rate of return was 15%. The TGV on the Paris-Lyon route was reportedly fully amortized after 12 years (1993). The TGV Atlantique had a net return 22% of gross revenue and the TGV Sud's net return was a staggering 38%. The numbers are provided by the railways themselves and some say that not all costs are take fully into account, making the official numbers inaccurate.

Inspired by the perceived success of the TGV, the neighboring countries Belgium, Italy and Switzerland built their own high-speed lines.[xiv] The Eurostar further expanded TGV operations in 1994 and ever since connects Belgium, the Netherlands and the United Kingdom to France. Eurostar has notably substituted air travel on the London-Paris and London-Brussels routes.

The United Kingdom developed its own high speed rail technology InterCity 125 and British Rail introduced it between 1976 and 1982. These trains reached over 150 km/h by 1985. The tilting train technology AdvancedPassengerTrain (APT) was researched simultaneously but was never implemented in the United Kingdom due to technological problems. Rather, it was sold to Fiat in Italy which further developed tilting trains and sold them to Italy, Portugal, Slovenia, Finland, the Czech Republic, United Kingdom and Switzerland. The tilting trains have not reached technological maturity and cannot be classified as a technological or commercial success. On the London-Glasgow track, for example, the trains are nowadays still 15 minutes slower than the scheduled times in 1981. All five operating trains in the Czech Republic suffer from software and functional problems spanning from failing air-conditioning and heating to failures of the tilting control (January 2006).[xv] The Portuguese tilting trains (Alfa Pendular) have also encountered similar difficulties which will be discussed later.

Germany has experimented with high speed intercity trains since the 1970s to match up to the plans of its historic rivals France and the United Kingdom. In 1988 the prototype for the InterCity Express (ICE) set the German speed record of 407 km/h on the test track

Hanover-Würzburg. In 1991, the ICE started operating commercially between Hanover-Fulda-Würzburg (maximum speed 280km/h) and Mannheim-Stuttgart (maximum speed 250km/h). ICE trains run on lower speeds to The Netherlands and Belgium. ICE technology is also employed in China, Russia and Spain.[xvi]

When the Franco regime fell in 1975 in Spain, the country started modernizing its ancient rail system to catch up with the rest of Europe. The high speed rail Alta Velocidad Española (AVE) first entered service on April 21sd, 1992, between Madrid and Seville. Travel times have been cut to only 2.5 hours on the 471 km long line. After replacing its national ASFA signaling system with European standardized ETCS level 1 signaling technology, AVE reached operating speeds of 280 km/h. RENFE is upgrading ETCS to level 2 in order to reach operating speeds of 350 km/h in 2007. Because of the huge reduction in travel time between Madrid and Sevilla, currently more than 80% of travelers use the AVE, and less than 20% travel by air.[xvii] Not everything is positive about the Spanish high speed train. On the Madrid-Sevilla corridor demand decreased after the EXPO in 1992. RENFE had to apply a low-pricing policy, cutting prices by half to stimulate demand. This latest AVE project has been plagued by major failures regarding signaling equipment, train speeds, and tunnel design. Due to geological problems the full speed of the train cannot be reached.

It is very difficult to determine which of these projects are commercial successes. All countries report positively about the railways and the public sees the benefits in service and time gains. Information about the actual revenues and costs are not made public and the net impact on countries is uncertain. According to Vickerman (1996), from the performance of the existing European rail networks, a few 'criteria for success' for High Speed Rail can be derived which should at least be met for rail lines to be feasible:

1. Link large urban centers (at least 0.75 M) at distances of 400-750 km capable of generating flows of around 12-15 M passengers per year by rail at a minimum

2. Connectedness from the HSR to the end destination of passengers is important. There should be good transfer possibilities to complementary transportation modes on both:

    - lower level: local and regional networks

    - higher level: international and inter-continental networks

    At the same time if the access to competing transportation modes is disadvantaged by poor connections to the major cities like for instance at Lyon due to the position of Satolas Airport (27 km from the city without rapid transit connection) or Paris (Orly and Riossy-Charle de Gaulle Airports have poor direct links) this has a positive influence on HSR.

3. The ability to serve a wider area than just the major urban centers helps utilize the infrastructure and increases the financial return on investment
4. Socio-economic returns due to reduction of congestion and accident costs on roads in areas where there are substantial problems might attribute to the desirability of HSR.

These criteria match the Portuguese plans for HSR as will be shown in the next sections.

4.3.2 Portuguese rail policy

When Portugal joined the European Union in 1986, increased political support established new hopes for the railways as a major player in Portuguese transportation. The European Union was becoming more politically powerful and there were ambitions to implement transnational transportation networks (TENs). About 60% of European investments in the TEN-program would be on rail network development. This was not only stimulated by hopes to speed up European unification but also by technological developments in high speed rail. There was (and still is) a lot of EU-funding available for the upgrading of the transportation networks of poorer EU countries like Portugal and Spain.

Portugal has made significant changes to keep up with the European countries and comply with European regulations. In order to join the first wave in the European Economic and Monetary Union, Portugal had to conform to European regulations. Privatization in Portugal started in the mid-1990s, and has also affected the railway sector. According to European Union directives[xviii], transport activities on one hand and infrastructure management on the other need to be provided by different organizations. To coordinate a correct infrastructure charging and fair rail infrastructure access, a supervisory body needs to be responsible. This supervisory body also mediates in conflicts between the infrastructure company and the transportation agents.

Rail liberalization in Portugal began in 1997. The old railway company Comboios de Portugal (CP) was split into the infrastructure company REFER and the new CP, which is the rail operator. Supervising the relationship between these companies, the rail regulator INFT (Instituto Nacional do Transporte Ferroviário) was founded simultaneously. Private operators were stimulated compete with CP but until now only Fertagus has entered the railway market.

4.4 CP

In this paragraph the current situation in the railways will be explored. The rail connections offered by CP can be divided in two types: national and international.

National rail connections are:

- **AP**-Alfa Pendular
- **IC**-Intercidades
- **R**-Regional
- **IR**-Inter-Regional

The national rail connections are roughly shown in Figure 17. For a more detailed view, please see Appendix 1. The AP trains will be discussed in the next section.

Figure 17: National rail connections in Portugal[xix]

The international rail connections are the Sud-Expresso to Hendaye at the French border (marked red in Figure 2) and Lusitânia Comboio Hotel to Madrid (marked yellow).

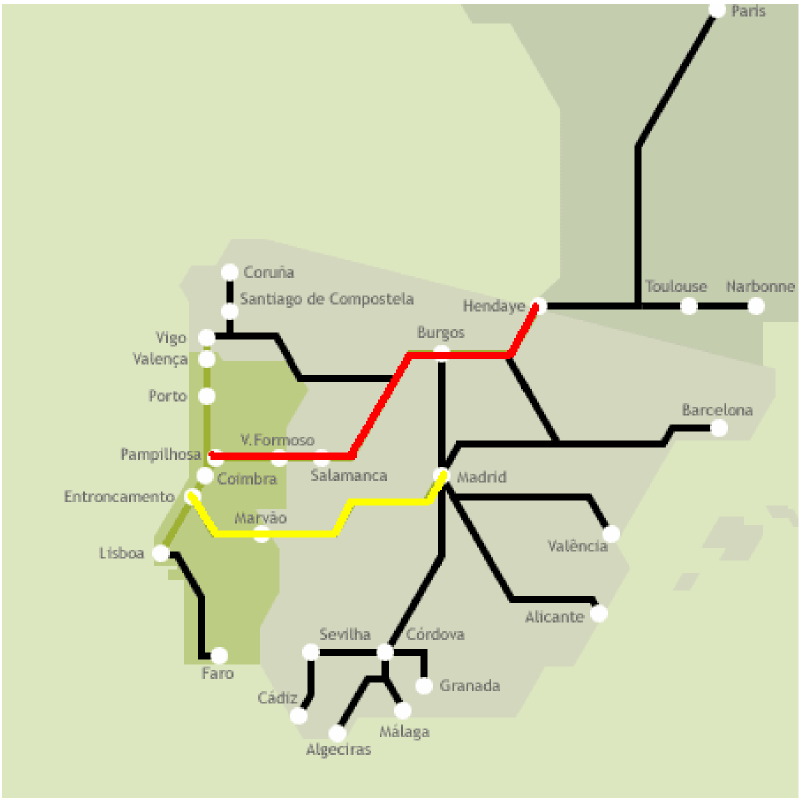


Figure 18: International rail connections in Portugal[xx]

Travel times on international rail connections are very high. To the French border at Hendaye, travel time is over 14h. To reach Paris, one would have to transfer to the TGV and travel for another couple of hours. The connection with Madrid takes 10h20, almost nine times longer than the journey by air which is 1h10. If booked in advance, prices for rail are more expensive then air travel. Air fares start at 80 euro for a roundtrip (which increases to over 300 euro if the time horizon to the flight is short). A reasonable quality rail seat to Madrid is 160 euro and up.

Not only is the service level low but CP is making huge losses. Costs outweighed revenues for years, with revenues covering barely 55% of operating costs. Before the reorganization in 1997, the debt of CP was 1.529 billion ecu in 1994, equaling 2.1% of GDP. For 2003 CP has estimated a net loss of 230 million euro, and expects a net loss of about 214 million euro for 2004. In 2004, 133 million passengers and 9.5 million tons of freight were carried by CP. Modernizations have been implemented to try to put the railways back on solid financial founding. Except the reorganization of the railway sector, new investments have been made in existing conventional rail and a new high speed rail line has been realized: the Alfa Pendular (AP).

First investments in high speed rail were made in 1995 when the Alfa Pendular (AP) tilting trains were ordered from Fiat for a faster Lisbon-Porto connection. This would later be extended to cities Braga in the North and Faro in the South. The tilting train technology was supposed to enable a faster speed in the curvy Portuguese landscape with maximum speeds up to 220 km/h without building an entirely new rail network. The trains would operate on existing track that had to be upgraded for the APs. Between 1998 and 2001 the following investments were made for the APs:[xxi]

- Renewal of existing rails with UIC60 and 54 on mono-bloc and bi-bloc concrete sleepers
- New alignments have been constructed to ease curves
- 161 new bridges built to replace level crossings
- Relay-based automatic fixed block signaling is replaced by 31 electronic and three central traffic control installations
- Rolling stock: Bogies on Pendolinos had to be redesigned for operation on Portugal's 1,668mm (5ft 6in) gauge track, and traction motors are mounted under floor

The 336km (209 miles) route between Lisbon and Porto was divided into three sections, covering Braco de Prata-Entroncamento, Entroncamento-Pampilhosa, and Pampilhosa-Vila Nova de Gaia. Between 35% and 40% of the line had been completely modernized by 2004, while work was continuing on a further 30%. Expectations are that the track will be completely upgraded by 2007. The trains run on 1688 mm Iberian gauge track.

Since 1999 the APs have carried about 5 million passengers in total, ridership reaching 1.6 million passengers in 2004. Prices on the Lisbon-Porto track are 36.00 euro for first class and 24.00 euro for tourist class. The Intercity (IC) connection uses the same track in 3h26 and costs 28.50 (first class) or 19.50 euro (tourist class).

In 1993, when the decision was made to buy the APs, the rail travel time between Lisbon and Porto was 3h00. The goal of the APs was to reduce this by 45 minutes to 2h15. The track time between Lisbon and Porto was 3h12 in 2001 and currently it is 3h01 or 3h06, depending on the schedule. This means that the average speed is about 108 km/h.

The Lisbon-Porto track for AP was not officially opened until 2004 because of operating problems. The APs were delivered more than a year late and faced unexpected problems which affected operating reliability (Briginshaw, 2001). Not all trains could be coupled together and there was water ingress in the door mechanism. Operating problems and underperformance in travel time are not only a Portuguese plague as mentioned earlier. Both the UK and the Czech Republic have faced them. The tilting trains don’t seem technology matured enough to operate commercially.

4.5 Fertagus

At this moment, only one other rail operator is active next to CP. Fertagus (Travessia do Tejo Transportes SA) has a thirty year concession to operate the suburban rail service from Lisbon via Pragal to Fogueterio. The service was opened nearly four months later than planned on July 29th 1999. Although Portuguese government expects other private operators to enter and to achieve a full privatization of the passenger rail market by 2010 and of the freight market by 2007, it is questionable how profitable rail is and how many private companies will actually enter. Forecasts for the demand on the Fertagus track have proven wrong, with 35-50% fewer passengers than expected by government calculations (government is now paying the deficits). In addition to this, there have been problems with privatization in general. First, even though infrastructure costs of mega-projects like railways are eligible for European funding between 50-80% from the Cohesion Fund, imposing realistic track charges is difficult. Rail operators in Portugal are bound by fare regulation and they don't generate sufficient revenue to pay all track charges.

4.6 Chapter conclusion

After a booming start in the 19th century, the railways have been loosing ground to road and air transportation since almost 50 years. European countries still have a vision that railways can play a major role in the transportation networks and keep investing large sums in them. Changes in rail technology and a race of the former superpowers to have the most advanced railway system have boosted the popularity of the technology enormously. Since the fall of the Salazar regime and the establishment of a democracy the mid1970s, Portugal has made large efforts to boost the national economy. Progress has in particular been sought in improving the transportation network. Many regulatory changes have been implemented in the Portuguese rail structure to meet European standards which are supposed to increase competition in a liberalized market. Next to regulatory modifications, Portugal followed the European trend to invest in high speed rail. To save funds, first attempts in this direction were made by introducing the relatively cheap tilting train technology (the Alfa Pendular trains) to existing tracks. The country did not take into account that not everything goes as planned, underestimated the risk and did not have a backup plan in case of failure. The Alfa Pendular trains can definitely not be called a success with its higher costs and much lower than expected reduction in travel time. The low demand of the Fertagus track is another example where the Portuguese transportation prospects did not meet the reality.

Rail development in Portugal will be stimulated further in the next decades and the country naturally wants the new plans to be more successful. Throughout the history of Portugal, uncertainty in technological, commercial and political factors has led to lower than predicted performance of the railway system. Deviation from forecasts should not come as a shock and Portugal is definitely no exception in not being able to accurately forecast the future. Many countries like France, Germany, Spain, the UK, etc., are having difficulties predicting railway system outcomes which has resulted in large losses for operators and the state. Before looking at ways in which this uncertainty might be handled, an overview of the European policy and its large influence on the Portuguese rail plans will be considered.

Chapter 5 European HSR policy and Portuguese HSR design

5.1 Introduction

This chapter will describe European policy and its influence on Portuguese transportation strategy. The reasons behind the European pursuit of a better rail transportation network will be explained. Also the impact of European rail regulations and funding on Portugal shall be described. Finally we shall outlay the Portuguese transportation policy, the implications for the railways and the actual HSR plans.

5.2 Transportation policy in Europe

Transport contributes about 10 % of the European Union's GDP. The sector now directly employs 10 million workers. Since 1970 transport activity has more than doubled in the European Union. The traffic of goods has increased by 185 % and passenger transport has risen by 145 %. Whereas European citizens traveled 17 km a day in 1970, in 2000 this was 35 km a day.

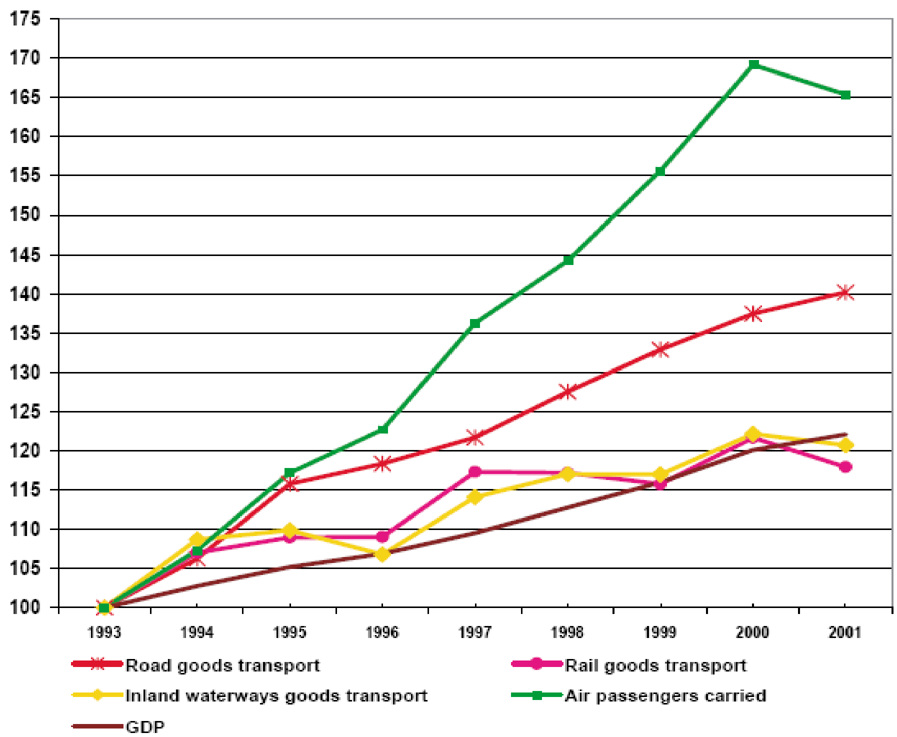


Figure 19: Increase in GDP and travel demand EC (2003)

According to the European Committee (2003), the main factor for increased transportation demand in the last decade has been the geographical dispersion of economic activity. There is a trend towards moving away from urban centers caused by:

- Separation of workplace and residential areas leads to increased commuting
- Increasing number of households with at least two working family members
- Rapid growth of services sector leads to mobility of professionals
- Higher average disposable income leads to a higher level of car ownership
- Increased leisure time leads to more holiday journeys and recreational trips

Transportation and energy are closely related topics that are discussed jointly in European Union policy documents. Current activity in these fields is based on two major European Commission documents:

- The Green Paper entitled *Towards a European strategy for the security of energy supply*, published in November 2000
- The White Paper entitled *European transport policy for 2010: time to decide*, published in September 2001.

In these documents, it is predicted that the volume of goods transported over land will increase by 70 % between 2005 and 2020 in the EU-15 and by up to 95 % in the ten new Member States. National traffic will grow substantially, but traffic between Member States is expected to have the largest expansion. According to the EC, the existing overland infrastructure should be improved in order to accommodate this increase in traffic demand. Daily about 7,500 km of road are affected by road congestion. The EC estimates that traffic jams cost 0.5 point of the joint European GDP, amounting to 40 billion euro annually. About 20% of the rail network is congested and air traffic experiences delays due to take-off and landing capacity limitations of existing airport infrastructure.

Car and air transport have grown exponentially while rail has not been exploited to its fullest potential. The EC reckons that there should be more balance between the transportation modes. An increase in rail services would decongest all transportation modes and lower pollution levels. Road transport generates 84% of greenhouse gas emissions due to transportation. Transportation accounts for 28% of gas emissions so reducing the share of road transport could significantly help limit pollution. As agreed by the European Union in the Kyoto Protocol in 1997, pollution levels need to be reduced by 8% by 2010 compared to the level in 1990. European Union experts expect that if nothing is done, the greenhouse emissions will not decline but rise by 4% by 2010 and as much as 19% by 2030. Portugal (along with Ireland and Spain) is one of the European countries that are not being able to meet Kyoto standards the most. [xxii]

Besides a better balance between the transport modes, the overall transportation opportunities between the Member States need to be improved. This is implemented by the Transnational European Networks (TENs) that provide better road, air and rail.

5.2.1 European TENs

The idea of transnational networks was first officially established in EC Resolution 876 in 1987, which states for rail that:

- "‥ a European high-speed train network would bring peoples closer together and promote European unity, and that the creation of such a network is a *sine qua non* for the establishment of a large integrated market in Europe, especially as intra-European exchanges are developing much more quickly than national traffic"
- "‥ existing routes for high-speed trains are very popular with users, and that the development of a European network would provide a comfortable, rapid, economical and environmentally inoffensive means of transport between the larger European cities, to the extent that it would create no air pollution and would help to reduce the noise pollution caused by traffic, particularly on transalpine routes"
- "‥ direct connections from city centre to city centre (whenever possible) are essential, both to ensure effective liaison between such a European network and other forms of transport, and also for its social, financial and economic success and efficiency"
- "‥ the economic development of Spain and Portugal, and their integration in the European Community, can be speeded up by including some of their railway lines in the European high-speed train network"

In April 2004, the European Commission presented a new strategy for the development of the Trans-European network and declared 30 projects to be of "European interest". Investments for these projects will be 140 billion euro between 2007 and 2013 and add up to 225 billion euro by 2020. Around 60% of the budget is reserved for rail. The gains expected from the completion of the 30 priority projects are substantial:

- a GDP level increase by 0.2 - 0.3 % by 2020;
- the creation of 1 million permanent jobs, in addition to 3 million temporary jobs created during the construction period;
- time-savings on traveling (€ 8 billion per year), congestion delays reduced by 14 %;
- 4 % reduction in greenhouse gases emissions.

5.2.2 Impact on Portugal

Since joining the EU in 1986, one of the main focuses of Portugal has been to improve the infrastructure in order to accelerate economic development. The country has been granted significant financial support from the EU to do this:

- 1989-1993: 18.5 billion euro
- 1994-1999: 14 billion euro (32% of this was allocated to transport infrastructure projects)

- 2000-2006: 23 billion euro has been approved for infrastructure projects

In the next decade, EU will support the construction of two TEN priority projects in Portugal.

The EC is far too optimistic about the expected gains of the TENs according to Vickerman et al. (1997, 1999). The authors evaluated a preliminary version of these plans and cast doubt on the ability of TENs to promote greater convergence in both accessibility and economic development. On top of this, Vickerman et al. argue that the gains that will be achieved through the TENs will largely benefit the core regions of Europe. The impact on the disadvantaged peripheral regions, their convergence towards the average levels of incomes and well-being in the European Union will be negligible. This may widen rather than narrow the differences in accessibility between central and peripheral regions as shown in Figure 20. Vickerman et al. write that the smaller a region, the greater the relative net benefit to non-residents since there will be more non-resident users and a smaller proportion of users will bear the costs, unless the full cost (including any external costs) is charged to users. The great economic benefit of HSR to regions such as Portugal might thus be much lower than anticipated by the EC.

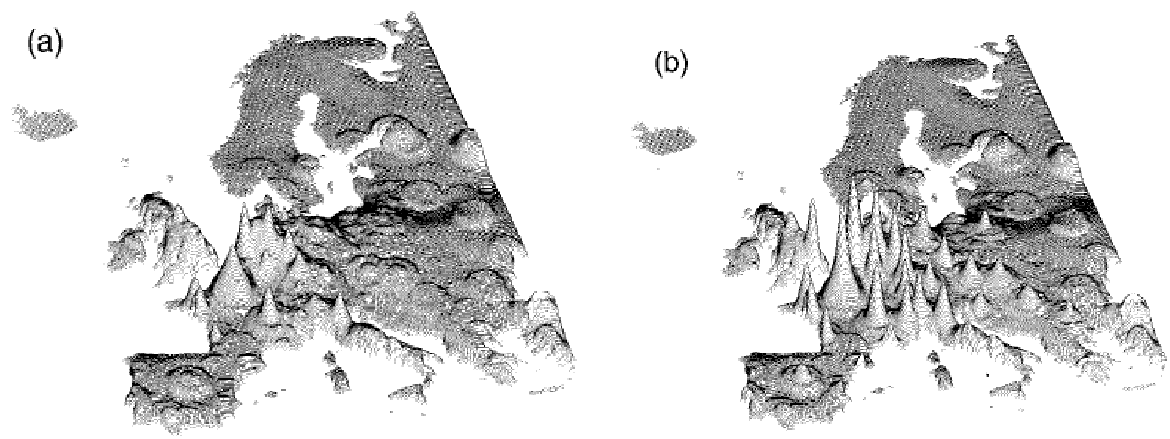


Figure 20: Daily accessibility surface of Europe by rail: (a) 1993 b) 2010; Vickerman et al. (1999)

Next to these economic arguments, the priority projects are also seen as a key element for the creation of an internal market and the reinforcement of economic and social cohesion. Europe pays special attention to the development of poorer regions. Three sources of European funding are available to boost the economies of poorer European countries and to integrate them in Europe: Trans-European Networks (TENs) program budget, EU Cohesion Fund, and European Regional Development Fund (ERDF). Portugal and Spain are the countries with the lowest GDP in the Euro-15 countries with their GDP being about 65-70% of average GDP (and the least developed regions having a GDP between 55-60%). Both Spain and Portugal are using a good portion of these funds.

5.3 European rail regulations

The European Union is becoming a large political and economical force as the Member Countries are transferring more power to it. In the rail sector, regulations have been made that apply for all its Members.

The main organizational directive for rail is 91/440/EEC (Perkins, 2005). It specifies the restructuring of railways and the public budget contributions permitted for reducing the indebtedness of railways (this is extended in 69/1191/EEC and 91/193/EEC which says that railway contribution should be based on a contract rather than break-even budget transfers at the end of the year). The objective of this directive is to reduce deficits, put railway companies on a viable financial footing and maintain financial sustainability. Infrastructure and train operations are organizationally separated. Directive 2001/12/EC further separates freight from passenger accounts. Directives 2001/12/EC and 2004/51/EC introduce track access rights to enable competition in the European freight services. Track access rights for passenger train operators are likely to be launched in the future. Infrastructure funding by national governments is specified in EU regulation 70/1107/EEC. Financial support to rail operators can only be approved by the EC and is not meant to be recurring.

After finishing the organizational regulations, the European Union has started defining technology guidelines and regulations. One of the objectives for the TEN rail network is interoperability and therefore the EU is taking measures for standardization of rail control systems. In 1996 the European Union Council made the first steps towards an interoperable rail network by issuing guidelines in Directive 1996/48 (Interoperability of the Trans-European high speed railway system)[xxiii].

Based on this directive, the European Association for Railway Interoperability (AEIF) was co-founded by the International Union of Railways (UIC)[xxiv], the Union of European Railway Associations (UNIFE)[xxv] and the International Association of Public Transport (UITP)[xxvi] with support of the European Commission. The organization consists of representatives of the infrastructure managers, railway companies and industry.[xxvii] The AEIF drew up the Technical Standards for Interoperability (TSIs) for high-speed rail networks in Europe and is currently working on conventional rail TSIs according to directive 2001/16. TSIs will be further developed by the European Railway Agency which was founded in 2004 and took over the tasks of AEIF.[xxviii]

The EC and the rail industry (manufacturers, infrastructure managers and undertakings) have signed a Memorandum of Understanding[xxix] on the deployment of the European Rail Traffic Management System (ERMTS) on a key part of the European network.[xxx] The goal of ERTMS is to make the European rail interoperable and thus safer and more competitive.

5.3.1 Impact on Portugal

In compliance with the organizational directives, rail reforms in Portugal have been carried out in 1997. The national railways CP were divided in the infrastructure company REFER and a rail operator which kept the name CP. The rail regulator INFT (Instituto Nacional do Transporte Ferroviário) was founded simultaneously and supervises the relationship between infrastructure and operator companies. The first private railway operator Fertagus started operating in 1999.

Until now, Portugal has not done much to comply with the technological regulations, possible due to the fact that so many changes are being implemented at the same time already and that a lot of money was invested in the APs. The country has promised that it will build all new high speed lines according to European specifications. It has not started testing the implementation of those regulations on its existing railway system. This might furthermore have something to do with the fact that the signaling system in Portugal was bought in the early 2000s and people don't want to think about its replacement yet. This makes Portugal the only EU-country that is not taking measures to comply with technological EU-regulations on rail as can be seen in Figure 21.

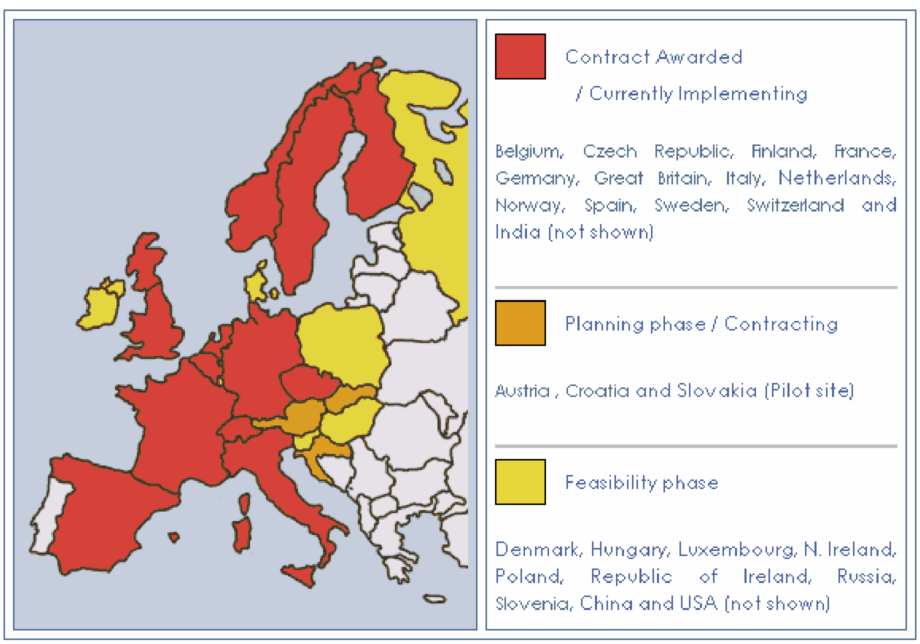


Figure 21: Progress of European standard signaling systems technology (GSM-R) implementation[xxxi]

5.4 Future rail policy in Portugal

Transportation has been one of Portugal's priorities since the 1990s. National factors like increasing automobilization and industrialization played a role in this. In setting the Portuguese railway policy, external reasons like the progress of other European countries and pressure from the EU to modernize the rail network were maybe even more important than the national factors.

Currently, there are plans to build two new Portuguese HSR lines: one national track between Lisbon and Porto and one border-crossing line from Lisbon to Madrid. The HSR plans are mostly motivated by European aspirations towards the development of Trans-European Networks and promises for funding. Europe also inspired the general transportation strategy of Portugal for the next decade which is described in the Accessibility and Transport Operational Program (POAT).

5.4.1 General transportation strategy: POAT and government program

On December 12th 2004, the Accessibility and Transport Operational Program (POAT or OPAT) was agreed on by Portuguese government and the EU. This program costs 3.369 billion euro of which the EU will contribute 1.388 billion. Its goal is to enhance the quality and efficiency of the transport system and lessen the disparities between the coastal and inner regions". POAT consists of the following priority areas and measures:[xxxii]

- **Priority 1: Integrating the country's infrastructure into the European Transport Network**
  The principal objective is to link Portugal's economic corridors with its neighbor Spain and the rest of Europe. This will include measures for investments in the construction, renovation, and modernization of national roads, rail links, and airports.
  - **Measure 1.1: Multimodal linkages between Portugal, Spain and the rest of Europe**
  - **Measure 1.2: Speeding up the construction of structural transversal and diagonal routes**
- **Priority 2: Reinforcing inter-modal coordination**
  To increase the efficiency of Portugal's transport system efforts will be made to increase the interactivity and inter-usage between the various forms of transport. In such a way, measures will be implemented to develop all the means of transport, increase the transferability and reduce the dead time between each transfer. Particular attention will be paid to integrate further the maritime sector within the general transport system.
  - **Measure 2.1: Improving accessibility and intervention at ports**
  - **Measure 2.2: Developing the complementary road network**
  - **Measure 2.3: Developing a national logistics network**

- **Priority 3: Reinforcing internal cohesion**
  Increasing transport links to the rest of Europe also means increasing mobility within the country itself. Special emphasis will be put on upgrading the road and rail network between urban centers as well as the connections between urban and rural areas.
  - **Measure 3.1:** Developing railway lines between cities
  - **Measure 3.2:** Improving roads between cities, intersections and alternative routes
- **Priority 4: Promoting the quality, efficiency, and safety of the transport system**
  The aim is to increase the quality of the services offered via a greater respect for the safety of citizens, increased comfort, and improved timeliness of services, all with as few side effects on the environment as possible. Particular attention will be put on guaranteeing greater safety in the area of heavy transport.
  - **Measure 4.1: Improving the quality and efficiency of the transport system**
  - **Measure 4.2: Improving transport safety conditions**
- **Technical Assistance:** Measures will be equally provided to assist with the management of, information on, implementation of, control and evaluation of all aspects of the program.

The allocation of funds to the priority areas is as shown in Figure 22:

					Unit: 1000 Euros
OP ACESSIBILITY AND TRANSPORT	Total Cost	Public Expenditure			Private Funding
		Total Public Exp.	EU Funds	National Resources	
	1 = 2+5	2 = 3+4	3	4	5
Total ERDF	3.336.117	3.133.217	1.457.234	1.675.983	202.899
Priority area 1	596.485	554.359	162.972	391.387	42.125
Priority area 2	990.905	949.019	504.410	444.609	41.886
Priority area 3	1.162.937	1.094.062	547.661	546.401	68.876
Priority area 4	576.314	526.301	235.084	291.217	50.013
Priority area 5	9.476	9.476	7.107	2.369	0

Figure 22: Allocation of funds for POAT

The ruling Portuguese government is very supportive of further investment in transportation. The government program 2005-2009 states that in the area of transport policy Portugal aims to attain sustainable mobility in order to respond to diversification and intensification of public transport demand. The mobility that has to be achieved is environment friendly, with lower polluting emissions, and with higher integration in trans-European and transnational networks. This government's priorities for the transportation sector are:

- Develop the high speed projects for the national and international connections initiating the construction of the Lisbon/Porto connection;

- ❑ Improve the connections to the Lisbon, Setúbal and Sines harbors, in articulation with the high speed connection Lisbon/Madrid;
- ❑ Continue the extension of the underground network in Lisbon and in Porto and another light rail projects"

5.4.2 High Speed Rail Plans in Portugal

Since the early 1990s High Speed Rail (HSR) technology has become a big policy issue in Portugal. France, Germany and the UK already had working HSR connections. Neighbor Spain started operating its AVE in 1992. This might have influenced the Portuguese decision in 1993 to get a high speed rail line. The Alfa Pendular trains have unfortunately not been the success that the Portuguese had hoped for.

Measure 7 of the current government plan is the implementation of a high speed railway network in order to achieve "a system of competitive and sustainable public transport between the main national and Iberic Peninsula urban poles, integrating an interoperable trans-European network." The companies REFER and RAVE are jointly responsible for the implementation of this measure in the period 2006 to 2015. RAVE is the public company (REFER has 40% share and the Portuguese government 60%) that will implement the HSR network during the next 15-16 years. REFER will to be in charge of the railway infrastructure investments. Involvement of different industrial designers, public works companies, providers of rolling equipment and stock (and universities?) is investigated. The goal of the new investment in HSR is to improve mobility between the main urban centers, with a mode transfer from road and airways to railways that should increase its market part from 4% in 2003 to 26% in 2025. Chief executive officer of RAVE, Jose Braancamp Sobral claims that investment in new HSR track is necessary as the existing inter-city and regional network cannot handle high-speed traffic. Even with the upgrading of key sections, a lack of line capacity would continue to limit the speed of services according to Braancamp Sobral.

Portugal is expected to invest in two new lines for which TGV technology might be used. In the official presentation for these lines on December 13th 2005, the minister of public works, transport and communications, Mario Lino, stated that

- Lisbon-Madrid (207 km track to the Spanish border, see blue line in Figure 23 b) will be prepared for mixed traffic with a maximum speed for passengers of 350km/h. The line will have five stops (Porto, Aveiro, Coimbra, Leiria, Ota New Airport and Lisbon), but the trains will rarely stop in the intermediary stations. The New Airport for Lisbon will be built at the same time in Ota. Expected journey time is 2h45 according to Lino (but in other documents 3h15 is mentioned) carrying 5 million passengers per year. Expected infrastructure costs are 3 billion euro.
- Lisbon-Porto (313 km track, see green line in Figure 23 b) will be prepared for passenger traffic and a maximum project speed of 300km/h. Expected journey

time is less than 1h30 carrying 6 million passengers per year. Expected infrastructure costs are 4.7 billion euro.

The total infrastructure costs will be covered for roughly one third by EU funds and the remainder will be drawn from loans from the European Investment Bank. The loans will be repaid once the trains start running. Construction is expected to begin in 2008 and will be finished in 2014. Rail components will cost additional 600 million euro and rolling stock 480 million. Around 1,500 million euro is expected to be invested until 2009.

Portuguese government estimates that the project will generate an operating cash flow covering 38% of the investment, the EU will contribute 22%, so government needs to get funding for the remaining 40% but private companies are likely to fund 30% of the project. Air traffic reduction estimated by government is -40% on Porto-Lisbon route and -30% between Lisbon and Madrid. Levinson et al. (1997) state that this competition with air might not be in the advantage of HSR as it is better positioned to serve shorter distance markets where it competes with auto travel than longer distance markets where it substitutes for air. If such large air traffic substitution as expected by the Portuguese government is achieved, remains to be seen.

Initially three other links were also planned:

- Porto-Vigo to the north border with Spain (as indicated by the purple line in Figure 23)
- Aveiro-Salamanca (the main freight corridor in the north/centre of Spain as indicated by the yellow line in Figure 23 b)
- Évora-Faro-Huelva (the link with Spain in the South as indicated by the red line in Figure 23 b)

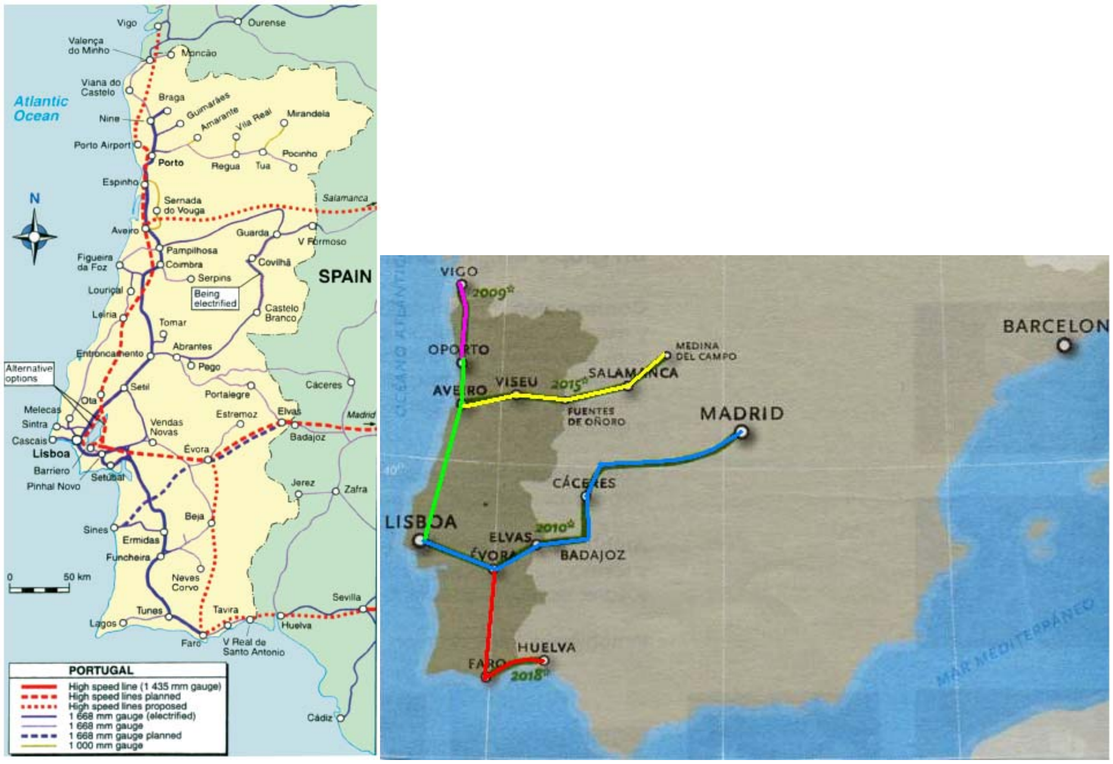


Figure 23 a) and b): proposed HSR links in Portugal

The feasibility of these links is expected to be very low and after fierce political debate in Portugal and Europe, they were dropped / delayed.

The connection with Madrid has been fiercely debated in Portugal. Economically it could be the right thing to do as Spain is the second-largest foreign investor in Portugal and a main source of the country's imports. It is furthermore the single-largest source of tourists to Portugal and is a key export market for Portuguese goods. Although Portugal strives to increase integration in Europe and boost its economy, many people are afraid to be swallowed up by their big neighbor. In what has become known as the 'patriots' manifesto', 40 top economists and businessmen warned in 2003 of the danger of Portugal's 'decision-making centers' –a euphemism for its biggest companies– being moved abroad. Jorge Sampaio, the president of Portugal, commented that 'without centers of decision-making, there is no nation'. Even in the negotiation in of the Lisbon-Madrid track, Portugal preferred another route (through Salamanca instead of Badajoz) but was eventually overpowered by Spain.

The EU stimulates the link to Spain. European expectations for the new HSR lines in Portugal are that:[xxxiii]

- Journey times within the areas served and with North and Central Europe will be dramatically reduced
- Additional capacity and improved quality of service will make a significant contribution to sustainable development by shifting road and air traffic to rail.
- A mixed use (freight/passengers) of the Atlantic branch of the project will increase capacity for goods traffic.
- Positive additional impacts on freight transport will be a reality on other sections by freeing reliable and quality paths on international links. This is especially important in the sensitive area of the Pyrenees, which acts as a brake on economic development and where increasing road traffic cases serious environmental impacts.
- Improved transport links will also provide a substantial boost to economic development in the regions served. The extension of the European standard gauge to the Spanish and Portuguese network will smooth international trade by removing the interoperability barrier at the Spanish-French border.

Despite the effort that High Speed will require over the coming years, REFER will also make major investments in upgrading of the conventional system. As rumors continue that the planned HSR might still be replaced by track upgrading, improvement of conventional rail seems to be a good idea. Very recently (September 21sd 2006) former European Commission Vice-President and current coordinator of High-Speed Rail Links Projects South West Europe, Etienne Davignon, has expressed concerns that the project is behind schedule and not economically viable. He has particularly called into question the amount of money that should be invested from European Union funds for what he terms "purely national stretches of track between Lisbon and Porto." Portuguese government is expected to suggest that the Lisbon-Porto passenger project could be mixed with freight to maximize its profitability, but that this would inevitably mean lowering the projected speed the trains would travel at.

5.5 Chapter conclusion

The political vision of a united Europe through large tangible mutual projects like the railways promoted this mode of transportation. For the poorer countries of the EU, big subsidies and loans are available for rail infrastructure. The boom of air and road traffic and the fear of congestions which might dampen economic growth have further stimulated European countries to look at high speed rail as an alternative mode of transportation. Portugal will have a strong focus on transportation during the next decades. Especially rail will be a key priority and area of investment. Although Portugal has complied with the specified organizational regulations in the European Union, no progress has been made on meeting technological standards. Many changes are being implemented at once in the young democracy. Stress on available professionals and expertise of the country might imply that not much more alterations should be added to the current ones. Technological performance cannot be predicted in advance as has been shown by the case of the APs. Therefore the time should be taken to think over the national interests in the large rail projects. Political pressures from Europe and within the country push for fast implementation of the HSR lines. If this process is too hasty, the new lines might be another failure. Measures should be taken to limit project risks and profit from project opportunities which will be addressed in chapter 7. First, in the next chapter valuation methods that aid the design of transportation systems will be outlined.

Chapter 6: Evaluation of projects

6.1 Introduction

In this chapter, concepts that are vital to the evaluation of projects will be introduced. After having discussed traditional evaluation methods and their strengths and weaknesses in chapter 2, we will explore a different approach to valuation and design of systems called Dynamic Strategic Planning (DSP). In DSP, the concepts of Real Options Analysis (ROA) and Decision Analysis (DA) play a central part. These two methods will be zoomed in on.

6.2 Purpose of evaluation and methods

Evaluation techniques help chose decision makers between different investment opportunities by maximizing the future value that can be realized with the current available budget. It has two objectives:

1. To decide if projects are worthwhile
2. To rank them in order of most to least worthwhile

There is a trade-off between accuracy of an evaluation model and its simplicity. An evaluation model should display the value of a project as accurately as possible. But building a very extensive model might cost a lot of resources and time to build. Also, it may not be very practical for making decisions because of its complexity. Assumptions are made to limit the number of variables in the model so they increase the ease of use but also make it less realistic.

Evaluation methods are based on three different disciplines: engineering, economics, and operations research and can be divided into five categories (De Neufville, 1990):

- **Methods based on engineering economy**, like Net Present Value (NPV), Cost-Benefit Analysis etc.. Engineering economy implies that the stakeholders agree on maximizing monetary profit as the goal, that the outcomes can be modeled and predicted well and are linear with quantity.
- **Decision analysis** emphasizes uncertainty and choices that need to be made. The goal of decision analysis is to define the optimal strategy over time.
- **Decision analysis with utility** differs from regular Decision Analysis in that it assumes that not all quantities of an outcome are valued equally. Utility functions are used to model the lack of comparability between the quantities (non-linearity).
- **Social cost-benefit analysis** is a method of welfare economics. It deals with a single set of non-monetary preferences which can be nonlinear.

- **Welfare economics** deals with multiple stakeholder preferences which cannot be expressed in monetary terms.

The strengths and weaknesses of the methods are summarized in Figure 24.

Approach		Assumptions made				Operational characteristics
Disciplinary basis	Evaluation method	Time value	Uncertain consequences	Nonlinear values	Multiple decision makers	
Engineering economy	Benefit-cost.. etc	X				Easy formulas
OR	Decision analysis	X	X			Probabilities inaccurate
OR	Decision analysis with utility	X	X	X		Utilities approximate
Economics	Social cost-benefit analysis	X		X		Value data difficult to obtain
Economics	Welfare economics	X		X	X	Only general guidelines available

Figure 24: Strengths and weaknesses of evaluation methods (De Neufville, 1990)

When choosing the projects that a company wants to undertake, it should evaluate its explicit and implicit alternatives.

Explicit alternatives are the investment opportunities that are available to the company right now. Usually not all explicit alternatives are actually considered in the evaluation. People within an organization tend to look at the projects that fall within their area of expertise (limited scope) and then only consider a limited number (limited scale). This could lead to sub-optimization for the entire organization.

To avoid sub-optimization, an implicit set of projects is defined. The implicit set consists of projects that might become available to the company in the future. They define the minimum standard of return that is expected from projects within the organization.

6.3 Time value of money

The value of money over time is an important concept in economical project evaluation. Money now has a different value than the same amount of money in the future. The value of future money differs with the opportunities that investors have. It is also called the opportunity cost of capital, but most widely known as the discount rate. The future cash flows are reduced (discounted) to the current point in time. This is the basis for NPV calculations that have been mentioned in chapter 2 but it is also a vital concept in option valuation and flexible design.

The formulas for single amounts of money are:

P = F / CAF ⇔ F= P*CAF

P= Present amount

F= Future amount

CAF= Compound Amount Factor = $(1+r)^N$

r = discount rate

N=number of periods in the future where the Future amount is received

For finite series of equal cash flows, the present value can be calculated by:

$$F = \sum_i R(1+r)^i = R\frac{(1+r)^N - 1}{r}$$

R=P*CRF=$P * \frac{r(1+r)^N}{(1+r)^N - 1}$

For infinite series, the denominator reduces to $(1+r)^N$ as $(1+r)^N >> 1$. This reduces the Capital Recovery Factor CRF to the discount rate r.

For small periods, calculations of series can be simplified by using the approximation $(1+r)^N = e^{rN}$. This can be derived from (1+r)^n=e^[log(1+r)*n] with log(1+r)=r for small r. The "Rule of 72" or "Rule of 70" are based on this equation:

$e^{rN} = 2.0$ when $rN = 0.72$

Actually this is true when the exponent is 0.693 but the approximation of the discounted series is better if 0.72 is used. This means that the present amount doubles when the future amount halves.

6.4 Discount rate

The discount rate is a vital concept for every economic valuation method. The discount rate reflects the possible returns that can be achieved by investing a certain amount of money. It is also called the productivity of capital and is the lowest acceptable rate to investors and the highest rate among the remaining opportunities if more capital were available (De Neufville 1990).

Determining the proper discount rate is difficult and should most definitely not be confused with the interest rate. The interest rate is a flat rate between a lender and a borrower and does not reflect individual opportunities that a person has to multiply his money. People would not borrow money if their investment opportunities were not yielding a higher return than the interest rate. The banks lend out a lower amount of money than what lenders would like so there is a fair the chance is bigger that lenders will actually pay off their debt.

There are two kinds of discount rates:

- Nominal discount rate $=r_n=$discount rate including inflation $= r_r+i$
- Real discount rate $= r_r=$discount rate without inflation= productivity rate

Both rates change over time as opportunities change and the inflation rate fluctuates. Also, different time horizons imply different levels of discount rate. In general, for longer time horizons the risk is higher and the discount rate will be higher.

The discount rate is very important as a determinant of technology which will be illustrated by the following example.

Example: choice of car technology

Let's say you have the choice between a diesel fuelled car and a car that runs on gasoline. The diesel fuelled car costs 20,000 dollars and costs $3,000 annually (insurance and fuel costs). The gasoline car costs 15,000 dollars but costs more to operate 4,000 dollars. We assume that we switch cars every 8 years and the salvage values of both cars are 5,000 dollar then. The difference in net present values for both cars is shown in figure 25.

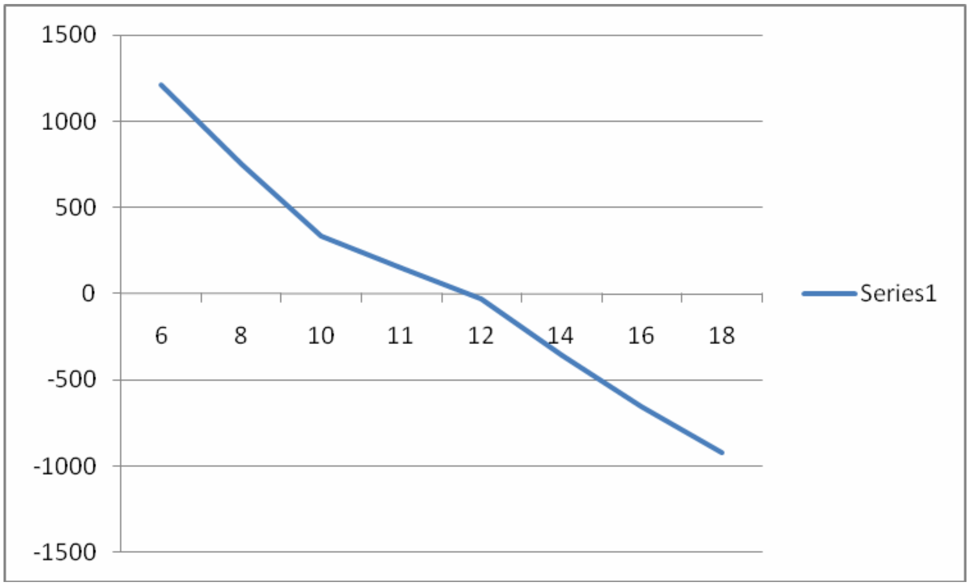


Figure 25: NPV difference between gasoline and diesel technology (Series 1)

The critical discount rate is the discount rate where the net present value becomes zero. When choosing between the technologies in our example, the critical discount rate is slightly less than 12%.

The choice of technology can be a very political choice. The critical discount rate can be manipulated by giving capital subsidies or imposing taxes that prefer one technology over the other. The discount rate that should be applied to a project is also influenced by politics. Higher discount rates reduce the value of future benefits which makes projects with long pay back periods less attractive. Most public projects have long pay back periods. Advocates for long term projects and much government control, propagate low discount rates. Discount rates of about 7% are used in public projects (US government base case) while in business they are 12-20%. De Neufville (1990) pleads for using the discount rate for business in the public sector as the private sector funds the government through taxes. Taxes restrict the opportunities of the private sector. The government should be at least as high as the business discount rate to compensate for the loss of productivity to society.

There are two ways in which to calculate the discount rate:

- Weighted Average Cost of Capital (WACC)
- Capital Asset Pricing Model (CAPM)

6.4.1 Weighted Average Cost of Capital (WACC)

Companies are founded by equity (selling shares of the company) and debt (borrowing money). The Weighted Average Cost of Capital (WACC) reflects the minimum return that a company should have on average to cover the desired productivity rates by equity and debt:

$$WACC = \frac{E}{E+D} r_E + \frac{D}{E+D} r_D$$

Where: r_D=interest rate, r_E=return for shareholders=difference in shares and dividends

The expected return on investment for both equity and debt is a reflection of the confidence that people have in the company. The confidence depends for example on how well-established a company is, if it operates in a stable industry/region, and how strong it is financially and strategically.

The WACC represents the average discount rate for the company. It is an aggregate measure that does not take opportunity cost into account. Also, the individual risk of a project is not reflected in the WACC formula. Finally, it is a historical measure that may not reflect the current situation well.

6.4.2 Capital Asset Pricing Model (CAPM)

The Capital Asset Pricing Model (CAPM) is a more refined way to determine the discount rate as it adjusts the discount rate for risk instead of averaging out projects. The CAPM is based on the principle of risk-aversion. This means that people want a higher compensation for projects with a higher variability in outcomes. The discount rate that is used for projects with a higher variability thus has to be increased.

The risk-free rate is the discount rate if there is no variability. It is a theoretical measure because nothing is really risk-free but in options analysis the rate of US government bonds is used (the rates vary for different time spans).

The higher the variability of project outcomes, the higher the expected return on the investment is. Investors only expect to be compensated for market risk but not for project specific risk. Market risk affects the entire stock market while project risk is diversifiable.

The measure of risk that is used to define the relationship between the market portfolio and the individual project is β_i:

$$\beta_i = \rho_{i,m} \frac{\sigma_i}{\sigma_m}$$

With:

β_i =index of investment risk compared to market portfolio

$\rho_{i,m}$=correlation between market portfolio and project

σ_i=standard deviation of project risk

σ_m= standard deviation of market portfolio risk

The relationship between discount rate and risk is shown in Figure 26

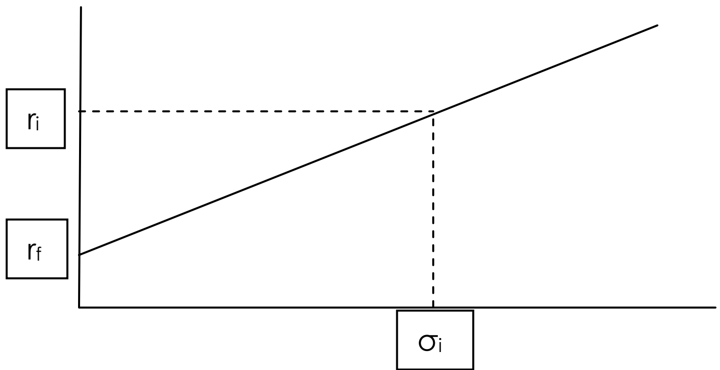


Figure 26: risk premium for projects with higher standard deviation

The security market line defines the relationship between risk and return for projects:

$$r_i = r_f + \beta_i(r_m - r_f)$$

6.5 Design for flexibility: benefits and concepts of flexibility

Because of uncertainty, projects have a distribution of outcomes instead of just one single value. Still, the traditional economic valuation methods only look at the average outcome. Just like in statistics, we should not just look at the average but we also care about the shape and variance of the distribution. It is not only because we might be interested in the maximum amount of money we might lose (Value at Risk) or gain (Value at Gain) with a certain probability. It is also possible to manipulate the distribution so that there is less risk and more gain. With the average value calculations, the different uncertainties are ignored which leaves very little room to take corrective actions. Ignoring variety in outcomes does not mean that it does not exist. It is quite misleading to use the NPV because it covers up the height of the discount rate. The company would still have a higher risk premium than what the average outcome of their projects would suggest. By adjusting the outcome curve to our benefit, the risk is less and according to the CAPM a lower discount rate could be applied due to the lower the risk premium.

The distribution of many projects depends on the development of risk. Risk is a combination of several dimensions of uncertain factors that contribute to the cost or benefits of the system. A combination of variables can multiply the overall effect on the system value. Where there is much deviation, the possibilities of increasing the system value by intervention are the biggest.

The traditional valuation methods don't acknowledge and exploit the contingent nature of projects. As Ron Howard, one of the pioneers of modern decision science, commented in 1994: "the prerogative to recognize and create options is too frequently overlooked in the framing and structuring of decision problems. This is a failure to recognize the sequential nature of most decision situations." (taken from Amram and Kulatilaka, 2000).

Flexibility adds value to an organization in two ways (Amram and Kulatilaka, 1996). First, it provides the company the possibility to defer an investment. When an investment is deferred, the project value could rise because of the time value of money. If the deferred investment is higher than the lost benefits, the project NPV will increase. Second, the development of project uncertainties during the option life can change the value of the project. If the uncertainties develop in our benefit, then the option can be exercised to improve project performance. If the development is negative, then nothing is lost and no further actions have to be taken.

The different uncertainties are translated into an uncertainty outcome probability density function which leads to a different system outcome density function. For the latter PDF, we can cut risks and expand opportunities by flexible management. Another representation of showing the value of the system is the Value at Risk/Value at Gain graph. In Figure 27, is shown how flexible management influences the system performance.

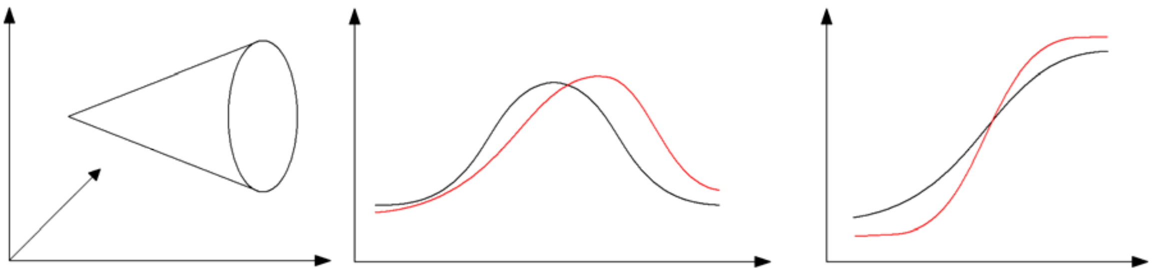


Figure 27: Risk and risk manipulation a) risk develops in multiple dimensions over time, creating a range of possible uncertainty outcomes with occurrence probabilities b) the probability density function of outcomes can be manipulated by flexible design c) this also causes the VAR/VAG function to change.

6.6 Options

The basis of flexible management are options that can be exercised as uncertainties develop over time. An option is the right to take some action before a certain expiration date for a certain price. A financial option provides the holder with the right to buy (call option) or sell (put option) a specified quantity of an underlying asset at a fixed price (called a strike price or an exercise price) at or before the expiration date of the option (Damodaran, 2002).

6.6.1 Payoff diagrams

A payoff diagram shows the value bounds of an option at the expiration time. For call options, it looks as displayed in Figure 28:

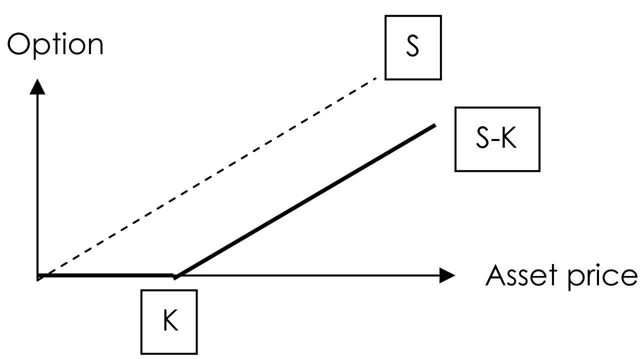


Figure 28: call option payoff diagram with S= asset price, K=strike price

The logic behind the payoff diagram is that it is only rational to exercise the option if the asset price is above the strike price. Under the strike price the payoff is zero, above it it is the difference between strike price and asset price making the payoff the maximum of

(0, S-K). The upper bound for the option value is the asset price as a call option can never be more valuable than the asset that is actually bought. The lower bound is the option payoff. This is a minimum value as there is a series of factors (as modeled by Black-Scholes) that increase the option value.

For put options the option payoff diagram is shown in figure 29

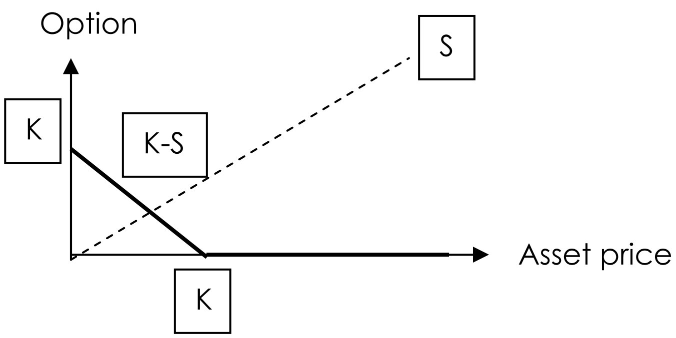


Figure 29: put option payoff diagram with S= asset price, K=strike price

A put option gives a right to sell, which only makes sense if the asset price is below the strike price. Notice that the put option is different from the call option. With the call option, the gains are theoretically unlimited while the losses for the call option are limited. This asymmetry is important in option valuation.

6.6.2 Black-Scholes option valuation model

The work of Black and Scholes published in 1973 shook the core of the financial world. It gave a very accurate way of pricing options under the following assumptions (Rubash, 2007):

- The stock pays no dividends during the option's life. This assumption was later relaxed by Merton in 1973.
- The option can only be exercised at the exercise date (European option)
- Markets are efficient and unpredictable
- There are no commissions for option and share transfers. In 1976 this assumption was relaxed by Ingerson.
- Interest rates remain constant. Merton removed this restriction in 1976.
- Returns are normally distributed.

The foundation of the theory is that an option is implicitly priced when the underlying asset is traded. This concept is called arbitrage enforced pricing and the ability to build a replicating portfolio. The goal thereof is to make a combination of risk-free borrowing/lending and the underlying asset to create the same cash flows as the option being valued.
The formula for option valuation of Black-Scholes is:

$C = SN(d_1) - Ke^{-rt}N(d_2)$

With

C= theoretical call premium
S= current stock price
T= time until option expiration
K=option striking price
r = risk-free interest rate
N(d1)=cumulative standard normal distribution

$$d1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{s^2}{2}\right)t}{s\sqrt{t}}$$

$$d_2 = d_1 - s\sqrt{t}$$

s=standard deviation of stock returns

The formula consists of two parts. The first part calculates the benefit from buying the stock now by multiplying the stock price with change in call premium when the underlying stock price changes. The second part shows the present value of exercising the option on the expiration date. The option value is the difference between the two parts.

The value of options is determined by several factors from the underlying assets and financial markets:

- Current value of the underlying asset
- Variance in Value of the Underlying asset
- Dividends paid on the underlying asset
- Strike price of option
- Time to expiration on option
- Risk-free interest rate corresponding to life of option

6.6.3 Binominal option pricing model with GBM

The Black-Scholes formula is useful but rather difficult. The binominal option pricing model is based on the same logic as Black-Scholes which is building a replicating portfolio. The replicating portfolio is set up by assuming that an asset/stock can either move up or down from the current state. This assumption can be made if the asset follows a Geometric Brownian Motion which most financial variables do.

GBM is also the basis for modeling non-financial variables like travel demand. It is specifically useful if some decision (like if an option should be exercised) must be made based on the expected value of a project. To use Geometric Brownian Motion for the modeling of the numbers of passengers is fairly common in air and rail travel (e.g. Miller et al. 2003, Miller et al.2005, Emery et al. 1996, Pereira et al. 2006).

GBM is the most widely used financial model to simulate the stochastic behavior of assets. The index value of the process is positive which reflects that any asset has a value higher or equal to zero. Variable s that is characterized by a Geometric Brownian Motion (GBM) if it follows the stochastic differential equation:

$$ds_t = \mu s_t dt + \sigma s_t dW_t$$

In this equation μ is the percentage drift or growth rate and σ is the percentage volatility or standard deviation. W_t is the Wiener process or Brownian motion. Geometric means that increments of the GBM are normal relative to the current value. The development of the stochast over time for an arbitrary initial value S_0 is analytically determined by:

$$s_t = s_0 e^{((\mu - \sigma^2/2)t + \sigma W_t)}$$

This equation can be verified by Ito's lemma which proves that the random variable $\log(S_t/S_0)$ is normally distributed with mean $(\mu - \sigma^2 / 2)t$ and variance $\sigma^2 t$. The expected value of this movement is simplified for simulation calculations of the expected value of projects by binominal trees. The binominal trees which will be used in this thesis are the lattice variant of the diffusion model GBM.

A binominal tree with all possible states for two time periods is presented in figure 30.

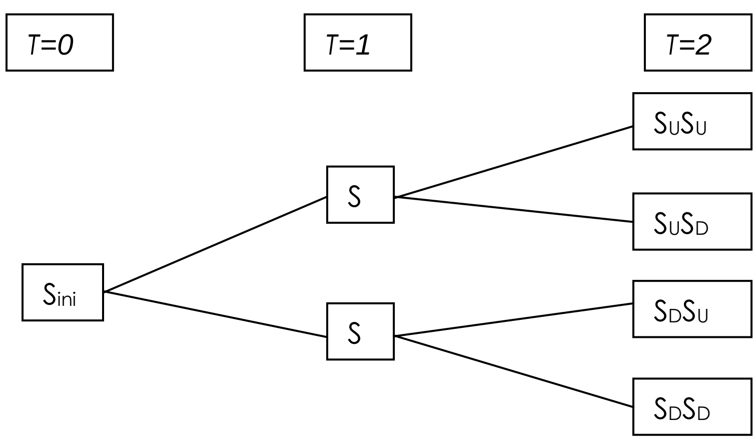
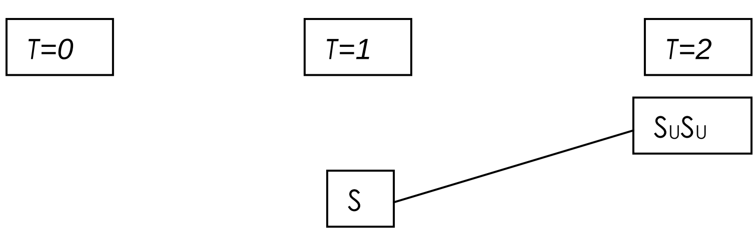


Figure 30: Binominal tree

According to the tree in figure, there would be 2^t different states in each period t. As there is no difference in whether the variable first goes up and then goes down or vice versa, the number of states per period can actually be reduced to t+1 as shown in figure 31.



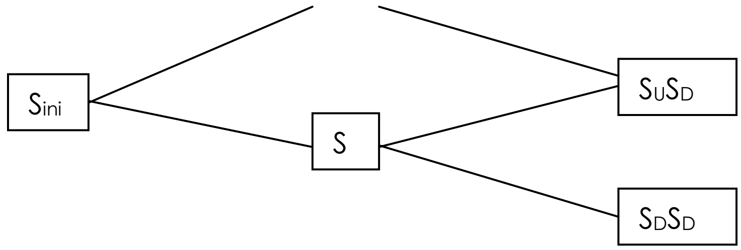


Figure 31: Reduced state binominal tree

The outcomes have a probability density function which can take many different shapes. The variance σ and the growth rate v are important factors in the development of the lattice. As the average increase over one period is:

$$v\Delta t = pLn(u) + (1 - p)Ln(d)$$

and the variance of the distribution is:

$$\sigma^2 \Delta t = pLn^2(d) - (pLn(u) + (1 - p)Ln(d))^2$$

and the values for up and down should 'average out' to one:

$$Ln(u) = -Ln(d) \Rightarrow u = \frac{1}{d}$$

it is possible to solve for the unknowns u, d and p:

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = e^{-\sigma\sqrt{\Delta t}}$$

$$p = \frac{1}{2} + \frac{1}{2}\frac{v}{\sigma}\sqrt{\Delta t}$$

These calculations for u, d and p assume that the PDF has a random aspect to it. This is realistic because only market risk is included and project risk is bypassed. Markets have full information meaning that white noise is filtered and only random noise exists. The variations from the average are therefore random and a Gaussian distribution can be assumed.

With the binominal pricing method the value of asset in period t+1 is S_{up} or S_{down}. Consequently the value of the call option in t+1 is the maximum of the assed value minus the acquisition costs K: C_{up}=max(S_{up}-K,0) and C_{down}=max(S_{down}-K,0). Arbitrage enforced pricing means that the value of the option must be equal to the value of the replicating portfolio. The value of the money for the asset (=a loan) rises with the risk-free interest rate r_f during one year. The proportion of asset (x) and loan (y) to make this replication portfolio is (Cox et al. 1979):

$X*S_{up}+ Y*(1+r_f) = C_{up}$ and $X*S_{down}+ Y*(1+r_f) = C_{down}$

From this x and y can be solved to:

$$x = \frac{C_{up} - C_{down}}{S*(p_{up} - p_{down})}$$

$$y = \frac{1}{1+r_f}\frac{p_{up}*C_{down} - p_{down}*C_{up}}{p_{up} - p_{down}}$$

A difficulty in the binominal model is that it also assumes path independence. While this is true for financial options, it is not always the case for Real Options which we will discuss now.

6.7 Real Options, Decision Analysis and Dynamic Strategic Planning

The future is impossible to forecast accurately as we have shown previously. System design should thus be designed in a way that leaves room to adapt to factors that influence the (financial) performance of the project. This approach develops a technology investment strategy that responds flexible to an uncertain future. It means that losses can be reduced and opportunities can be exploited by keeping uncertainty in mind.

Real Options are related to but not the same as financial options. The term Real Options was coined by Professor Stewart C. Myers in the late 1970s. A real option is the right, but not the obligation, to take an action that will either help maximize the upside or limit the downside of a capital investment (Teach, 2003). Real options differ from financial options because they are not based on tradable assets and there is no market for them.
There are two classes of Real Options (Wang et al., 2005):

- Real Options On the System: these are options that do not influence the technology of the system, usually options to expand or abandon current operations
- Real Options In the System: this kind of options changes the technology of the system

When using Options On Systems, this means that the option, not the obligation, exists to further operate or invest in a system (flexibility of scale). Options In Systems indicate that in the future several different technology scenarios can be covered by the system (flexibility of scope). The distinction between both types of option can be a bit vague sometimes.

The Real Options take a number of forms (Amram and Kulatilaka, 1998):

- Waiting-To-Invest Options: option of delaying to invest in (part of) a project
- Growth Options: entry investment that may create opportunities to pursue follow-on projects
- Flexibility Options: option to reallocate or switch resources
- Exit (or Abandonment) Options: the option to quit the project in response to new information
- Learning Options: initial investment like market studies that creates opportunity to respond better to uncertainties

Real Options Analysis is used together with Decision Analysis to calculate the impact of the possible actions in the states. Compared to the traditional fixed management approaches, Decision Analysis gives a strategy as uncertainties unfold. It is flexible in a way that there is always a contingency plan for limiting risks and exploiting opportunities. To create the flexible strategy, the possible states of an uncertainty, the probability that this state will occur and the impact of states on the performance of the system need to be defined. A decision tree with this information is set up over the lifetime of the project. It consists of Decision and Chance nodes where the Chance nodes have a certain occurrence probability. Each choice node represents a certain total value. Through valuation of the different nodes the system value is maximized. Real Options Analysis differs from Decision Analysis in that it focuses on identifying the possible actions.

The management strategy that is created by combining ROA and DA is called Dynamic Strategic Planning (De Neufville,2000). It is dynamic because it recognizes the fact that the future is uncertain and needs to be managed flexibly instead of fixed. Strategic means the system performance is optimized on a long-term. Planning indicates that a set of steps is designed on what should be done under what circumstance.

Although ROA and DA are central elements of Dynamic Strategic Planning, it involves a total of seven methods for system analysis:

1. Modeling of the system output: For every set of resources the technically efficient solution can be determined through the model. Thus the set of possible designs is established that is considered for further analysis.
2. Optimization of the cost: Every technically efficient solution must be evaluated in order to determine the efficient cost frontier. That means that every level of production is achieved at the least cost.
3. Estimation of probabilities: there are several techniques available for this step: logic, frequency, statistical models and judgment.
4. Decision Analysis: A decision tree with decision nodes, chances nodes and their probabilities is set up. For each point in time an optimal strategy is determined that maximizes system value.
5. Sensitivity Analysis: The states and probabilities that are used in DA are estimated. It is necessary to investigate how sensitive the resulting strategies are to the estimates.
6. Real Options Analysis: Identifying flexibility options and estimating their cost.
7. Analysis of Implicit Negotiation: developing a strategy for the implementation of the technology policy.

The approach to the design and valuation of flexibility in systems can be structured as follows (Greden et al., 2005)

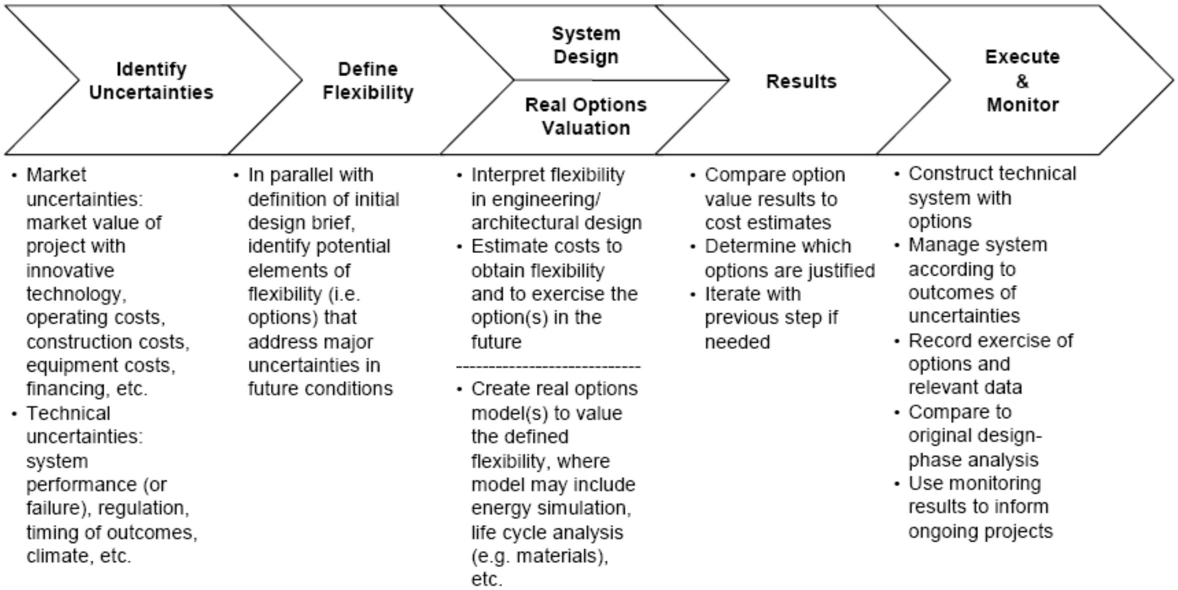


Figure 32: Structure of the design and valuation of flexibility in systems Greden et al. (2005)

This methodology will be applied in the next chapter for High Speed Rail in Portugal.

In system performance valuation and design, NPV is currently the most popular valuation tool (used by 96% of senior executives, Teach 2003) while Real Options are used by less than 9%. It is seen as a complementary tool by 11.4% of CFOs while sensitivity analysis (85.1%) and scenario analysis (66.8%) where much more popular.
If a project has a positive NPV, then value is added to the company. The traditional conception is that the mix of projects with the highest NPV will add the most value. This is not necessarily true as the options that are embedded in the projects are not valued. Thinking in terms of Real Options means making a switch from passive to pro-active management (Teach, 2003). When using NPV, managers assume they commit to a fixed project that does not need steering. The end results are 'known' or at least out of the hands of management after the decision to commit to the project is made. The Real Options approach needs a change in management's attitude. It costs more preparation (gathering information about possible scenarios, identifying Real Options) and maintenance (keeping up with developments of uncertainties and reacting to them). Where with the current management style the 'blame' for unsuccessful projects can be put on the circumstances, the higher involvement of management in Real Options might demand more of managers.

How a pro-active management style could improve the performance of a system can amongst others be shown with the concept of value of information. Let's demonstrate this concept with an example. Say you want to drive up to a holiday ski-vacation in the French mountains. Currently, weather conditions are good and chances of being in an accident with this weather are neglectable. There is a possibility of snow though and with your current tires you would face a greater risk of being in an accident (20%). An accident would damage your car on average by about 3000 dollars. You could buy some winter chains to put on your tires. They would set you back 200 dollars but the chances of being in an accident decrease to 1%. The benefits and costs of the tires are:

	Without chains	With snow chains
Good weather	0	-200
Snow	-600	-230

Figure 33: Cost of choice (chains) in different chance conditions (weather example)

In general the chances of snow are 60% on the mountain. The decision tree looks as follows:

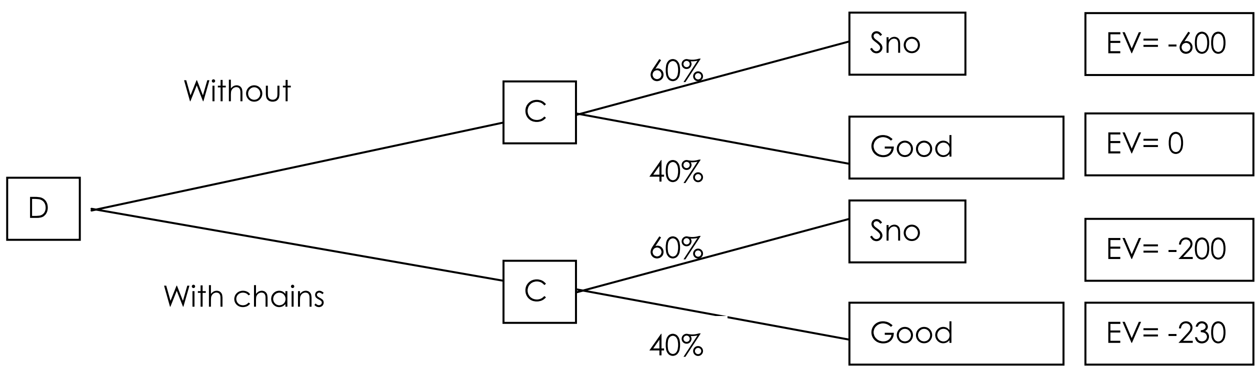


Figure 34: Decision tree in the weather example

The expected value of driving without the chains is -$360 and with the chains it is -$212. To minimize the costs of your trip, it is thus better to go with the snow chains.

If is unfortunate that you don't know for sure how the conditions on the mountain will be during your drive up. You could gather some information about the weather by calling a weather line for the region. Perfect information means that the test that you apply to the situation predicts with 100% the chance outcomes. In our example, the decision tree would change:

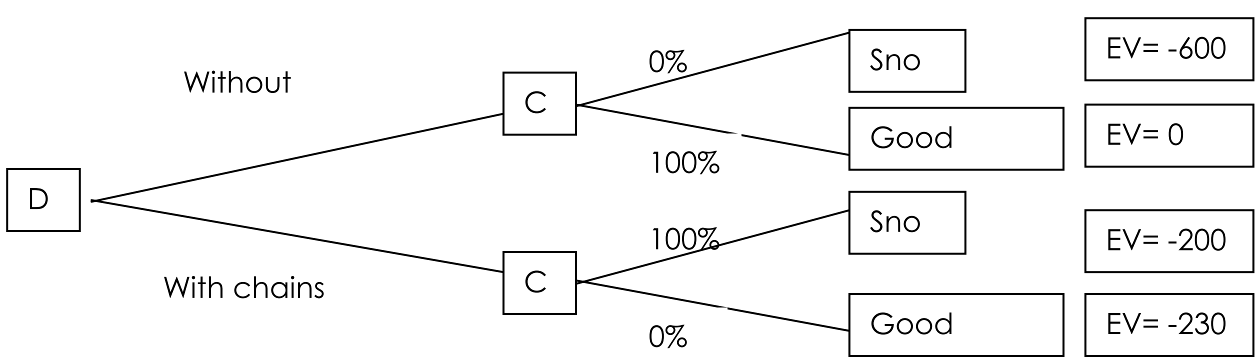


Figure 35: Decision tree with perfect information

You only make the decision to go without chains if you know for sure that the weather will be good. If the weather is bad, then the snow chains are preferred. The expected value of the scenario with perfect information is 60%*-$200+40%*$0=-$120. The value of perfect information is thus $98.

In real life only sample information with a limited accuracy can be obtained. Gathering this information and calculating the consequences for complex systems, can be very pricy. Managers have to decide if a test if worthwhile. The general recommendation is to perform the test if it costs less than 50% of the value of perfect information. In our case, calling the weather service would probably cost much less than $49 so it is worthwhile to perform the test.

6.8 Application of a flexible strategy: the Parking Garage Case

Applying a flexible strategy could improve financial performance. The idea is to enhance the Value curve as shown by De Neufville, Scholtes and Wang (2006). Compared to the original distribution, downside risks, also known as Value at Risk (VAR), are cut and the upside potential, Value of Gain (VAG), is expanded.

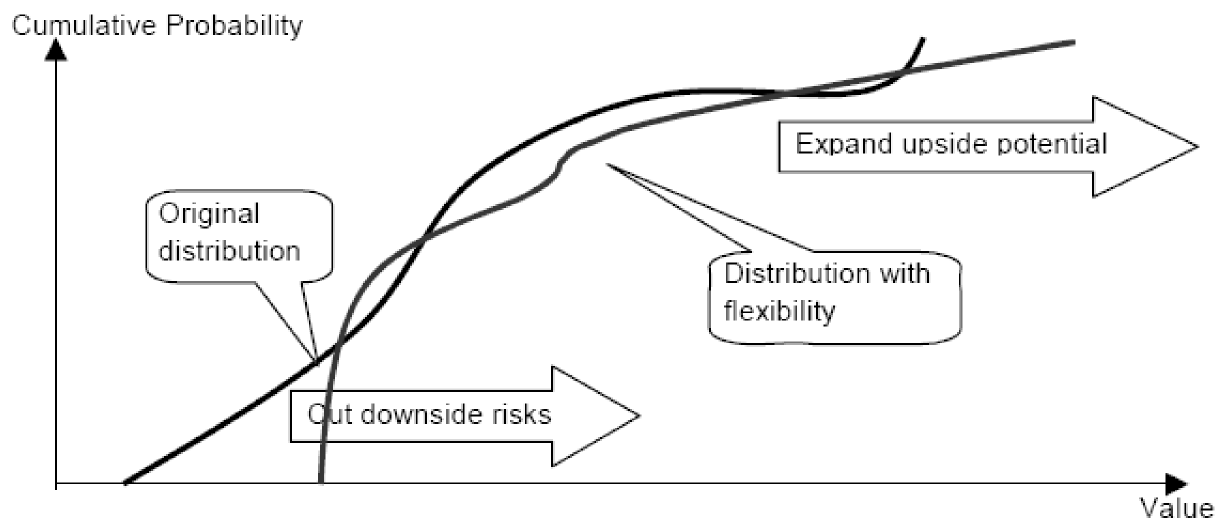


Figure 36: How flexibility in system design improves NPV, De Neufville (2006)

In order to achieve flexibility, an extra effort must be made which is usually a higher initial investment. This can pay off during the system lifetime because of uncertainty as illustrated by the Parking Garage example (taken from De Neufville et al. 2006). This case study demonstrates how flexibility can improve the Net Present Value of a System. In a parking garage, it is uncertain how future demand will develop and how many floor should be constructed optimally. The storage space available in a parking garage depends on the strength of the structure. The thickness of the carrying pillars determines how many floors can be built. The number of floors sets the number of available parking spaces.

In our example, the costs and benefits are as follows. The initial demand is 750 spaces and over the next 10 years demand is expected to rise by another 750 spaces. After year 10, demand might rise by 250 more spaces. Projections could be 50% off and annual volatility for growth is 10%. The annual revenue per parking space used is $10,000 and the discount rate is 12%.The annual lease of the land is $3.6M and annual operating costs (cleaning, staff, etc) are $2,000 per year per space available. Construction cost is $16,000 for each space on ground level and increases with 10% for each space above ground level. One level has a capacity of 200 parking spaces.

In the base case we assume that demand will develop exactly as predicted and that there will be no variability. The net present value of the project is shown for different number of floors in figure 5. The optimal number of floors is six for a net present value of about $6.4M.

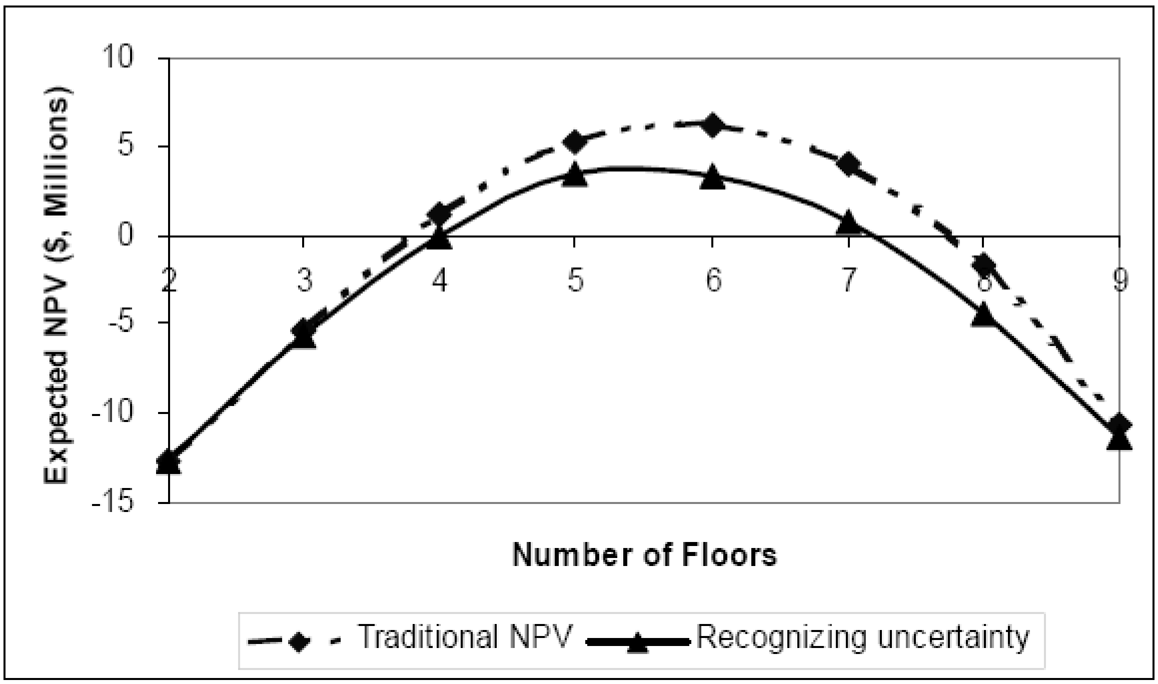


Figure 37: NPV for Garage Example without Real Options

If we introduce uncertainty in demand the NPV per floor and the optimal number of floors changes. Building five floors would be the optimal configuration and the NPV is about 40% less than the performance without uncertainty in the base case.

The difference in NPV can be explained by looking at the capacity restrictions of the base case fixed design. If demand is higher than the number of floors built, the extra revenues cannot actually be collected. On the other hand, if the demand is lower, the capacity of the extra levels just stays unused.

The design opportunity in this example is to build a stronger structure which allows us to build levels later on when there is demand for them. Initially just a few floors are built but there is flexibility to expand. Let's take a look on how the optimal design and the NPV changes.
The NPV rises to an astonishing $10.5M when initially four floors are built with a

strengthened structure that allows for the construction of extra floors. But not only the NPV is better, as can be seen in Figure 38.

Design	Design with Flexibility Thinking (4 levels, strengthened structure)	Design without Flexibility thinking (5 levels)	Comparison
Initial Investment	$18,081,600	$21,651,200	Better with options
Expected NPV	$10,517,140	$3,536,474	Better with options
Minimum Value	-$13,138,168	-$18,024,062	Better with options
Maximum Value	$29,790,838	$8,316,602	Better with options

Figure 38: Performance with Real Options in the Parking Garage case

The example illustrates how adaptation to changing circumstances improves the value of systems under perfect information. Not only the ability to influence the NPV as the project develops contributes to better results. Average (single scenario) evaluation curves can give a very wrong impression of performance in the first place. This is called the flaw of averages (previously mentioned in chapter 2).

6.9 The flaw of averages

Let's take a look at the implications of the flaw of averages for performance. The term flaw of averages is introduced by Savage (2000). It is based on Jensen's inequality (1906) which relates the value of a convex function of an integral to the integral of a convex function:

$$\varphi\left(\mathbb{E}\{X\}\right) \leq \mathbb{E}\{\varphi(X)\}.$$

Markowitz was one of the first economists to use not one average value but also give a measure of deviation from that average (risk). His modern portfolio theory was seen as a breakthrough and he received the Nobel Prize for Economics in 1990. Savage (2000) explains the implications of deviations from the average with the following stock market investment example.

The return for the S&P 500 index was on average 14% since 1952. Suppose you have $200,000 and you want to withdraw a yearly amount so your money lasts exactly 20 years. This means that you can withdraw $30,000 annually if the return is 14% each year. But if the return fluctuates as simulated for start years 1973-1976, the initial amount frequently doesn't last for the desired 20 years (see figure 39).

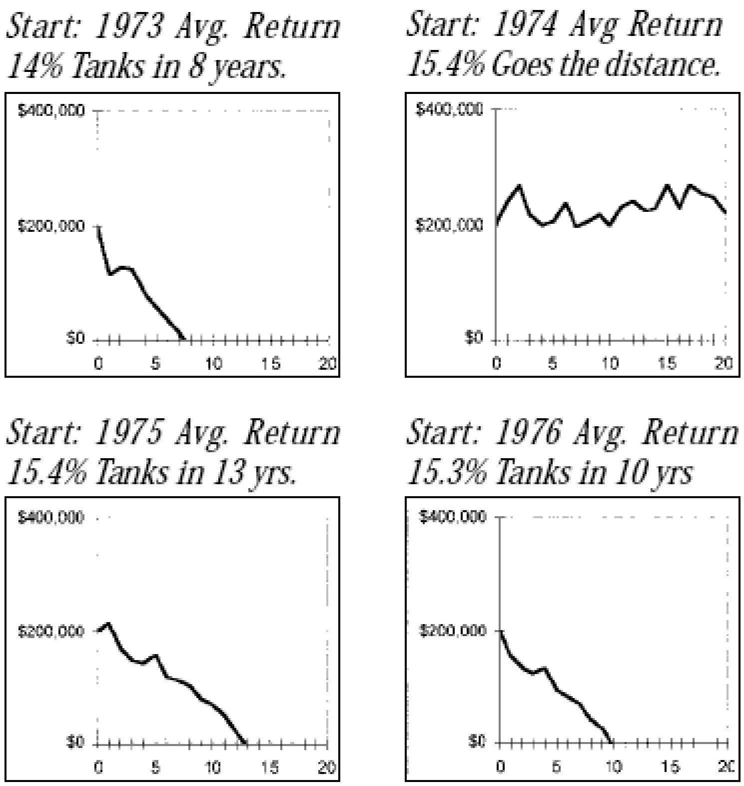


Figure 39: Number of years the investment lasts for different starting years; Savage (2000)

Investing in the future is not only limited to stocks but also important in engineering systems design. Still, the non-linearity concept of system performance

$$E(f(X)) /= f(E(X)$$

is mostly limited to finance applications. In engineering systems design, it is also valuable to make use of it. Using a distribution of expected events instead of averages of these events would first of all give a much more accurate expected value of system performance. Furthermore, a flexible design provides the opportunity to react to different scenarios flexibly and therefore improve system performance. Together, these two arguments make it apparent why it is absolutely necessary to work with distributions of variables instead of a mean value.

6.10 Chapter conclusion

The purpose of evaluation is to decide if projects are worthwhile and to rank them in the order of the most to least worthwhile. Evaluation methods from engineering, economics, and operations research all have their strengths and weaknesses.

The value of time is a most important concept that is vital to a good evaluation method. The discount rate that is chosen to value time, can influence both if projects are worthwhile and their ranking.

As traditional valuation methods don't acknowledge and exploit the contingent nature of projects, a flexible way of executing projects should be considered. Flexibility adds value by the possibility to defer and investment and by reacting to the development of uncertainties during the lifetime of the project.

Flexibility does not just 'happen'. Investments are needed for the opportunity to make decisions flexibly. The net benefit of such investments can be calculated by option valuation based on the Black-Scholes formula. Because this formula is not practical to be used in valuation of projects with several decision possibilities, binominal trees that have the same basis of replicating portfolio are used. Financial assets and many other stochasts like travel demand follow a Geometric Brownian Motion (GBM). The lattice variant of this GBM is incorporated in the formulas of the binominal trees.

In engineering systems, a feasible way of managing flexibility is called Dynamic Strategic Planning (DSP). This method is new because it identifies Real Options, makes decisions when those should be executed and carries out a sensitivity analysis of the parameters used for the Real Option Analysis.

The flaw of averages finally shows that working with average values not only looses value because uncertainties are not managed, but it also is bound to give wrong system value expectations. Therefore, working with average values should be avoided.

While the value of flexibility under perfect information has been investigated for the Parking Garage Case, uncertainties about this information and the modeling can be technological hurdles. Other obstacles in implementing DSP exist for Portuguese rail system design as will be described in the next chapter.

Chapter 7 Improving railway design in Portugal by Dynamic Strategic Planning (DSP)

7.1 Introduction

In this chapter the possibilities of overcoming the challenges of the standard way in which railways are designed by Dynamic Strategic Planning are researched.

The success of being able to manage the Real Options component of DSP will be evaluated on two dimensions as outlaid in the framework in figure 40:

	Policy	Technology
Theory	PT	TT
Reality	PR	RT

Figure 40: Framework for the success of Real Options

One dimension distinguishes between the manageability of the technology that is subject to Real Options and the ability of an organization to actually manage the technology. Manageability of the technology could for example include if the system can be modeled with sufficient accuracy that it can be steered. The ability of the organization to manage the technology is another factor that should be considered.

The second dimension differentiates between the theory as we know it in books and what 'should be possible' versus the actual realization due to limitations like money, time, politics, etc..

These dimensions will be discussed for the Portuguese situation. For the policy components the analysis will be done based on scientific literature and the findings of chapters 4 and 5. Additionally, a case example of a HSR line will be given for the technology components. A direct application of DSP to the technical component of the HSR plans in Portugal has proven to be impossible within this thesis.

For one, there are no accessible, detailed data in English on the costs and benefits of railways in Portugal. Confidentiality is a big issue for most countries (like France and Spain) making it difficult to find a case that gives sufficient insight in the design and evaluation process of the HSR lines in Europe. Eventually, it proved possible to find many research studies for the feasibility of the Dutch high speed rail line (Zuiderzeelijn). This case (Appendix 2) and a simple one model travel demand model will be used as a substitute on pointing out the flaws of the current design strategies and applying DSP. The company Ecorys, which gave advice on the viability of the Zuiderzeelijn, does the high speed rail consultancy work for many European countries (including Portugal) and their overall methodology will most likely be the same in all cases.

Furthermore, we don't want to give the impression that I'm actually redesigning the current HSR plans of Portugal. Instead, we want to find out if it is worthwhile to start thinking flexibly in railway design. A fictitious case might be better in such a situation for creating goodwill on the side of Portuguese expert readers. The data that we use for applying DSP can be seen as a good approximation of an actual case as they are deducted from the Dutch case and scientific papers. No design proposition will be made, instead the fitness of the DSP methodology will be tested for the railways.

DSP can be approached from several viewpoints and usually the cost component is emphasized. We will investigate the benefit side which has not received much attention from governments yet as is shown in the next paragraph.

7.2 Uncertainty management in public HSR project: need for focus on benefits

The modeling of travel behavior is very difficult which is increasingly recognized in large travel projects. Governments and consultancy firms are coming to the realization that there is a second kind of uncertainty that is as least as important as the correctness of the modeling. The variables that are used as input for the model can be highly uncertain. As a solution for this uncertainty, in the Dutch case (Appendix 2) the advice of professor Flyvbjerg has been sought and bandwidths for infrastructure costs have been established.

The common practice in European Railway design is to work with average prognoses for the key variables of the system. There is an increasing awareness in governments and consultancy firms that everything doesn't go as planned and the average approach is insufficient. Still, there is no methodology on how dealing with uncertainty should be incorporated in the design and operation of large transportation projects. The general attitude of railway designers seems to be 'everything can get worse' meaning that the infrastructure costs can rise dramatically. The way that designers insure themselves against this uncertainty is by adding a percentage on top of the certain infrastructure costs (as done by Ecorys in the Dutch case and most probably also in the Portuguese case). Three arguments can be made against this practice.

First, further tests (Learning Options) could be made to estimate the costs of the project better. While these tests are not free, their relatively small costs are an insurance against the potentially disastrously huge costs of just building blindly based on general guidelines for cost estimates. Hotspots, parts of the system which have a large influence on total costs and whose costs are uncertain, are the best candidates for such tests.

Examples are large bridges, railway crossings or parts of track through land with doubtful building quality. Tests can be of both a technical nature as of a political one, depending on how big the risks are. If the tests show that the actual infrastructure costs are much larger than what was estimated in the initial calculations, the project might not be built. In this way the costs can be seen as a flexible design factor in the project instead of a rigid fact.

Second, although the infrastructure costs are indeed very large and have usually proven to be underestimated in most countries, the benefits are just as uncertain as the costs. The multi-billion euro costs appeal more to the imagination of policy makers and the public. They are more tangible and easy to criticize than the benefits that are spread over multiple years and whose amount is uncertain. This excessive focus on costs is unjustified. We should be at least as critical on how certain benefits are because the idea of any project is that benefits should match or exceed costs.

Third, uncertainty should not be seen as something bad by policy makers but as an opportunity to increase the value of the project. Many No-Go (i.e. do not operate) decisions in projects are possible if a loss would be made in that period which would raise the overall project value. From a technology view it is possible to build a test track and see if the desired speed, dependability and infrastructure costs are achieved. A test track is a good first compromise for both the stakeholder forces that are optimistic about building a line as well as those that are against it. Whether the test track is a disaster (No-Go) or a success (Go), the decision making will be more tangible and less based on ideologies. A test track can be seen as an insurance against bad technological results. In addition, the test track could to some degree test assumptions of how many passengers will use the service compared to the other means of transportation. Determining benefits through a test track is much more difficult because there is a transition period of about 5 years and rail lines have network benefits. This means that if less of the network is built, the benefits do not occur fully. Still, the test track is a special kind of test that gives more certainty to the performance (costs and benefits) of the rail system. If the results of the test track are insufficient, billions can be saved from not building and operating the entire line.

Dynamic Strategic Planning improves project performance by pushing rail designers to recognize that there are uncertainties, urging to them quantify these, and make them come up with strategies for handling the different outcomes in the future. The variability in the benefit side has not been explored as much as the costs. Political players have accepted that infrastructure costs of (high speed) trains will be excessive. The political discussion in the Dutch case but also in other documented cases in High Speed Rail design (for instance China) is about the benefits. Many arguments of fairness and non-profit related benefits (travel time reduction, regional development, and environment) dictate national and European debates about whether or not to build high speed trains. It is very strange that while the debate is so focused on the benefit side, uncertainty in these variables has not been incorporated in the design. The applicability of Dynamic Strategic Planning in this thesis is hence focused on the benefit side.

Before making a more elaborate model of travel demand in our example case, a basic application with one variable will be given to enhance the understanding of the reader of the consequences of average strategic planning in transportation. This will also show the theoretic benefits and limitations of Real Options in this field.

7.3 Travel demand in one variable: GDP growth forecasts and travel demand

Using just the GDP for predicting travel demand will increase transparency for the concept that we want to demonstrate, which is if DSP (of which Real Options analysis is a large part) can help improve system value in High Speed Trains. The model that is used by the evaluators of the Dutch high speed train lines, has shown some major flaws (decrease of number of passengers while speed increases and prices are constant) which had to be corrected with expert estimates. This raises serious questions about the overall reliability of the forecasts made for travel demand. GDP is a more general measure for travel demand but its good correlation with actual travel demand is certain. Theoretically, a detailed model might produce a better correlation with the actual travel demand than the GDP but to simplify the problem and not get into a discussion what a fit model is, the GDP will first be used as a single predictor for travel demand.

The Netherlands Bureau for Economic Policy Analysis(CPB) has forecasted three possible long-term scenarios for the development of The Netherlands until 2020 based on which the growth forecast for traffic is made for the high speed connections:

	European Coordination (EC)	Divided Europe (DE)	Global Coordination (GC)
Population (mln)	16.2	17.7	16.9
Housing supply (mln)	7,375	7.663	8,006
Work population (mln)	6.888	7.865	8,029

Employability (mln)	6.334	7.512	7,802
GDP-growth per year 1995-2020	1.5%	2.75%	3.25%

Figure 41: CPB development scenario's for The Netherlands

The evaluators of the high speed rail lines argue that the EC scenario seems the most plausible (maybe as it is the most careful scenario) and it is therefore used as the base case in the performance calculations. The apparently careful approach of estimating benefits is not the best approach as it might dampen project value because capacity can be limited. We will include capacity restrictions for designing for the minimum benefit scenario.

Assuming a single number scenario of average GDP growth without variability, does not cover the possible future scenarios (previously addressed in chapter 6). As we are halfway the forecasted period, it can be shown that the initial forecast for GDP was indeed inaccurate. In figure 42 the actual yearly growth rates for the 1995-2006 are shown.

Year	Realization
2006	2.9
2005	1.5
2004	2.0
2003	0.3
2002	0.1
2001	1.9
2000	3.9
1999	3.5
1998	3.7
1997	3.8
1996	2.7
1995	2.3

Figure 42: Actual GDP growth realizations

These numbers diverge a lot from the both long and short term prognoses for all three scenarios. For instance in 2001, the Central Plan Bureau (CPB) forecasted a GDP growth of 4% where 1.9% would be reached.[xxxiv] The long term prognosis of 1.5% annual growth in the EC scenario is only achieved in 2005 and all other years have much higher or lower growth rates. The average growth in these 12 years is about 2.4% which is almost one percent point higher than the base case EC scenario.

The values of variables used in system modeling are usually assumed to evolve over time with an average constant growth. Average value analysis is performed by Ecorys in the Dutch case too. The travel demand is calculated based on GDP that grows with the precisely the value of one of the three scenarios of the CBP. Another average growth example in the Ecorys model is that prices are fixed and only rise with inflation which is an average number again. In reality, the Dutch Railways (NS) have increased the ticket prices with twice the amount of the inflation (while costs remained the same). Also, fluctuating energy markets in Europe will continue to be a source of uncertainty on railways energy costs. This means that the net cashflow per passenger should indeed be taken to be random (and following a Geometric Brownian motion) instead of fixed.

If it is assumed for now that there is no change in the attractiveness of the competing modes of travel, the total travel demand will be linearly related to the change in total travel demand. (Later on, this restriction will be released.) As the GDP growth has a linear relationship with the total travel demand growth, a change in the GDP would result in a linear change in the travel demand by high speed rail. We will make some initial calculations to test for sensitivity in outcome if a spread of possible GDP values would be used instead of an average value. One way to measure this impact of uncertainty is by using binominal trees which assume a Geometric Brownian Motion (GBM) of the variable (as described in chapter 6).

In paragraph 7.4 we will show the following statements for the simple case of one variable travel demand models when average estimates in system design are used:

- The averages of the base case and the distribution are not equal in HSR demand (see Jensen's inequality).
- Capacity problems with designing for the most careful scenario can lead to a lower result than expected.

In paragraphs 7.5 and further, we will demonstrate how strategic options like the Wait-to-Invest decision significantly increase project value.

7.4 Binominal trees to model travel demand with uncertainty

In this paragraph, we want to outlay how differently the travel demand can develop from the average growth forecast (base case). We will utilize Dutch GDP forecasts for the years 1995-2020 using averages values versus a distribution of values for different growth and uncertainty scenarios. The value of the expected number of passengers in 2020 is related to the number of passengers that will use the high speed rail service.

With GBM and the binominal trees technique, there needs to be an estimate for the variability of the GDP. The standard deviation to be chosen can be a matter of debate because a larger value increases the project performance when flexible benefit planning is used. We will first apply a careful value for the standard deviation of 3% for the calculations (a similar value was calculated from GDP data of The Netherlands) and later adapt this value to 10% (a number which is common in Real Options literature).

Now, it is possible to solve for the unknowns in the binominal tree technique u, d and p in the three CPB scenarios (the numbers are scaled down to half year periods as one year would lead to p-values over 1). The values for 3.25% growth and 3% variability become:

$$u = e^{\sigma\sqrt{\Delta t}} = 1.02$$

$$d = e^{-\sigma\sqrt{\Delta t}} = 0.98$$

$$p = \frac{1}{2} + \frac{1}{2}\frac{v}{\sigma}\sqrt{\Delta t} = 0.68$$

For the DE and GC scenario, the p-values change to 0.82 and 0.88 respectively. The binominal trees that are developed in Excel are too large to be included in this thesis. The Super Solver Statistic Software designed by Jonathan Mun (2006) is used instead to show the development of some of the possible paths from the start value 100 (Figure 43).

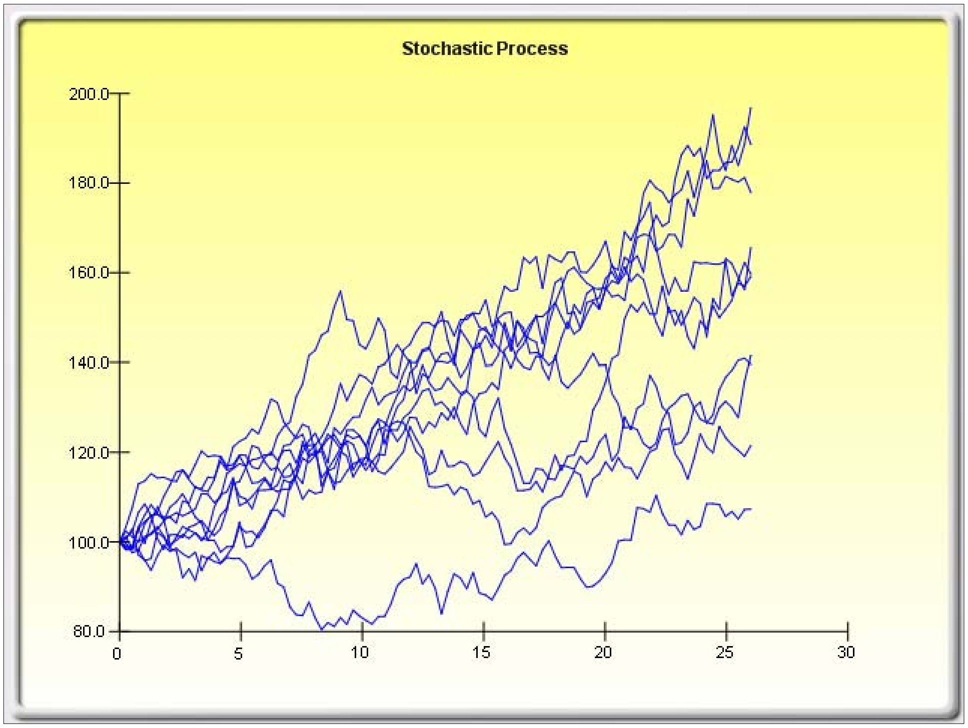


Figure 43: Examples of possible paths of the GDP / travel demand from index 100 for 1995-2020, v=1.5% and σ=3%

The growth paths are calculated with binary trees for the three growth scenarios 1995-2020 the following PDFs and CDFs for the values in 2020 are the result:

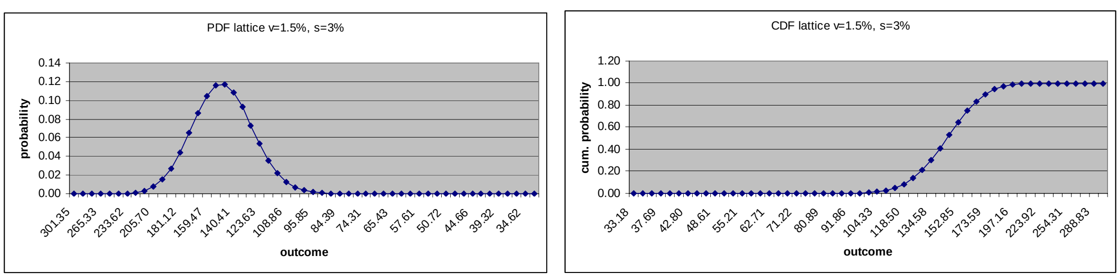


Figure 44 a) PDF and CDF for μ=1.5% and σ=3%

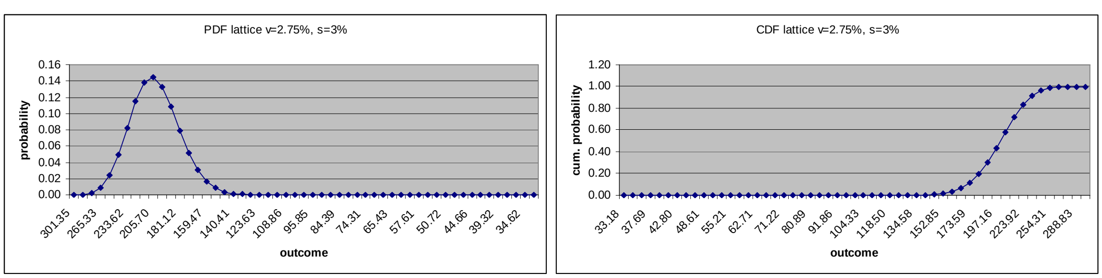


Figure 44 b) PDF and CDF for μ=2.75% and σ=3%

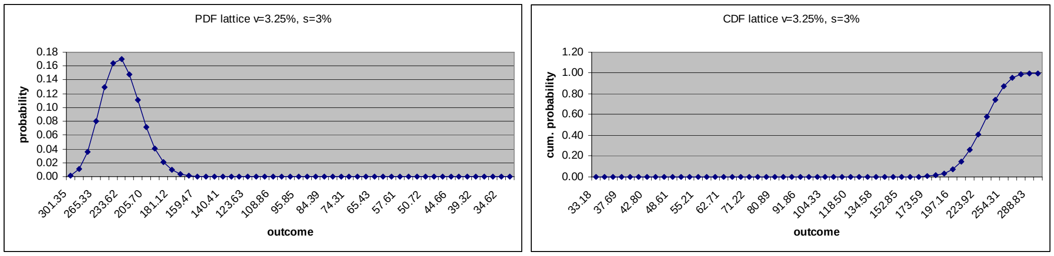


Figure 44 c) PDF and CDF for μ=3.25% and σ=3%

The lattice development again displays Jensen's inequality (the first two columns of Figure 45) although the expected number of passengers for single value calculation and distribution calculation do not differ very much (column III):

Number of passengers in 26 years compared to base year (index=100)	I. Expected average E(f(x))	II. Expected average with uncertainty $f(E(x))_{s=3\%}$	III. Ratio f(E(x)) /E(f(x)) $_{s=3\%}$	IV. s=10% Expected average with uncertainty $f(E(x))_{s=10\%}$	V. Ratio f(E(x)) $/E(f(x))_{s=10\%}$
1.5%	147.27	149.21	1.0132	167.83	1.1397
2.75%	202.46	205.80	1.0165	231.37	1.1428
3.25%	229.69	233.91	1.0184	262.93	1.1447

Figure 45: Expected system index; Jensen's inequality

In general, through simulation it became apparent that that Jensen's inequality is not so 'inequal' for growth of one variable with small standard deviations (up to 5%), small growth rates (up to 5%) and not too long periods (up to 50 years) of concession.

It is very common that in Real Options papers a higher standard deviation than 3% is used for forecasting travel demand. Reasons for doing so might be because the standard deviation is indeed higher but it is also a fact that the Real Options technique becomes more powerful with higher uncertainty.

If one chooses 10% for σ (column IV and V) the value of the benefits increases with about 14%, which is still not a staggering difference in benefits. This result shows two things. First, there is a certain sensitivity to the standard deviation that should not be disregarded. Second, Real Options might help improve project performance, but it does have its limitations. Not every project that makes a loss under average planning can be pulled out of the red numbers by a flexible strategy.

The standard deviation is not the only value that needs careful choosing. The benefits for the railways from 2020 to 2050 depend on the forecasted number of passengers in 2020. The three scenarios provide very different average starting values. It is rather shocking that this number could be 59% higher if one compares the average low growth scenario and the high growth scenario under uncertainty. This could be a severe problem if the low growth scenario is used to design capacity. If not 3% standard deviation but 10% is used, the difference in start value for the benefit stream then becomes 79%.

Next to the starting value in 2020, the benefits in the period 2020-2050 depend on the forecasted growth rates for that period. It is highly unlikely that there are good predictions on such a long term. The short term growth scenarios 1995-2020 provided by the CPB are just some probable ways in which the Dutch economy could develop. There are no chances given as to how likely each scenario will occur because the CPB feels this is impossible to forecast. But isn't almost every scenario to some extent probable then? In 2003 the CPB (Netherlands Bureau for Economic Policy Analysis) released a new growth prognosis for the years 2000-2040. In this prognosis four economic growth scenarios have been distinguished with significantly lower growth forecasts:

- Regional Communities: 0.7% growth per year
- Strong Europe: 1.2% growth per year
- Transatlantic Market: 1.7% growth per year
- Global Economy: 2.1% growth per year

The utter uncertainty about how the economy will evolve on the long (and even on the short) term, leads to close to impossible predictions about the performance of the system when single average 'most likely' numbers are used. This sensitivity in growth rate might be another problem with making decisions in Real Options Analysis as will be elaborated on in the next paragraphs. Another factor of concern should be that if the system is built rigidly for the most careful scenario, it cannot benefit from higher growth rates. The extra costs of building in more flexibility (for instance buying better signaling systems or more train wagons) so that the benefits of higher growth can be reaped should be weighed against the costs. Extra flexibility is not always wanted if the costs are too high but it might pay off to consider it and see if the value of the project is influenced positively.

We have shown that there might be problems with is much uncertainty in the design of rail lines and that planning for average or low capacity may cause underperformance of the system. Now, let's take a look at how options like delaying construction (Waiting-To-Invest) and quitting operations (Exit) can benefit system performance in a more complex model. This will be done with the case study based on the Dutch rail lines. We will address the sensitivity to uncertainty in long term growth and its variation.

7.5 Introduction in application of DSP to an example HSR case

In the case example in the following paragraphs, we will show how to exploit the uncertainty in variables that influence the benefit goal function by two kinds of Real Options:

1. Waiting-To-Invest-Option: The decision to build the system in a certain year can be delayed if the total expected benefits do not outweigh the total costs.
2. Exit-Option: The system is operated under the condition that the societal benefits (revenue and time savings) are larger than the operating costs.

To 'unpoliticize' the discussion, not only the revenue from ticket sales should be included in the calculation of operating value. When benefits like time savings, environmental issues, regional development etc are included in the Real Option decisions, the chances of acceptance of negative decisions like 'don't build' or 'don't operate' should logically be better.

In our model it is imagined that the steps 1 and 2 of DSP ('modeling of system output' and 'optimization of the cost') are such that for our example HSR line, the goal function describes the efficient cost frontier. We wish to focus on benefits so these steps are not very relevant in this application.

The DSP-step 'estimation of probabilities' is performed by modeling Geometric Brownian Motion diffusion through binominal tree lattices. The variables used for the calculation of the probabilities are derived from the Dutch case and scientific papers to make them realistic. Shocks in the demand will not be included because we don't want to get mixed up in political discussions like if there is going to be a higher tax for cars and by what year. Of course shocks that are of a political origin will occur, but we don't want to burden the methodology at this point by adding such shocks. This has the extra benefit that it simplifies the calculations in our simulation program.

Decision Analysis based on expected value of the project under uncertainty will be used to decide whether to exercise an option or not.

Sensitivity Analysis will be performed on the variables taken to calculate the probabilities for the Decision Analysis. There has been much praise for Real Options among academics but applicability concerns have limited its use in business practice. In the case of the railways simple stumbling blocks to applying Real Options are:

- How should one choose the uncertainty of the system (the standard deviation of the growth rates)?
- How does one determine the different growth rate scenarios (average growth values) and their probability distribution in a realistic way?

These two concerns can be addressed through Sensitivity Analysis which will be performed to some extent for our example. Our intention is to show that uncertainty exists and it is not foe but can be a friend as it increases project value if managed properly. An elaborate Sensitivity Analysis is not necessary as we are demonstrating a concept and advising on a methodology instead of on a feasible design proposal.

7.6 Modeling for Real Options Analysis of travel demand for the HSR case

There are two approaches to modeling the value of flexible planning. The first one is mathematical and fits the value of the Real Option into a neat formula which can also be used for sensitivity analysis purposes. An example of this is given by Pereira et al. 2006 who mathematically modeled the value having the Real Option of building an airport at the optimal time. They did this as a function of

- One stochastic factor (the number of passengers) that follows a Geometric Brownian Motion: $dx = \mu_x x dt + \sigma_x x dZ_x$ while the net cash flow per passenger grows constant $dR = \mu_R R dt$
- two stochastic factors (randomness in the number of passengers and the net cash flow per passenger) that follow a Geometric Brownian Motion $dP = (\mu_x + \mu_R + \rho\sigma_x\sigma_R)Pdt + (\sigma_x dZ_x + \sigma_R dZ_R)P$, and
- these two stochastic factors with shocks (events that can influence total net cashflow negatively or positively): $dP = (\mu_x + \mu_R + \rho\sigma_x\sigma_R)Pdt + (\sigma_x dZ_x + \sigma_R dZ_R)P + dqP$

By mathematical manipulation through Ito's Lemma and Ordinary Differential Equations (ODE), they found the construction moment at which the project becomes feasible (at the trigger value P* of the benefits). The values of the three situations mentioned above for infinite and finite concession periods are given in Figure 47.

P*	Infinite	Finite	The variables β, γ, and φ need to be determined numerically from the equations:
X stochast	$\frac{\beta}{\beta-1}\frac{k-\alpha_x-\alpha_R}{e^{\alpha_x n}\mathrm{Re}^{\alpha_R n}e^{-kn}}K$	$\frac{\beta}{\beta-1}\frac{k-\alpha_x-\alpha_R}{e^{\alpha_x n}\mathrm{Re}^{\alpha_R n}e^{-kn}(1-e^{(\alpha_x+\alpha_R-k)(m-n)})}$	$\beta = \frac{1}{2} - \frac{r-\delta_x}{\sigma_x^2} + \sqrt{(-\frac{1}{2}+\frac{r-\delta_x}{\sigma_x^2})^2 + \frac{2r}{\sigma_x^2}}$

X, R stochast	$\frac{\gamma}{\gamma-1}\frac{k-\alpha_P}{e^{\alpha_P n}e^{-kn}}K$	$\frac{\gamma}{\gamma-1}\frac{k-\alpha_P}{e^{\alpha_P n}e^{-kn}(1-e^{(\alpha_P-k)(m-n)})}K$	$\gamma=\frac{1}{2}-\frac{r-\delta_P}{\sigma_P^2}+$ $\sqrt{(-\frac{1}{2}+\frac{r-\delta_P}{\sigma_P^2})^2+\frac{2r}{\sigma_P^2}}$
X, R stochast and X*R with shocks	$\frac{\phi}{\phi-1}\frac{k-\alpha_s}{e^{\alpha_s n}e^{-kn}}K$	$\frac{\phi}{\phi-1}\frac{k-\alpha_s}{e^{\alpha_s n}e^{-kn}(1-e^{(\alpha_s-k)(m-n)})}K$	$\frac{1}{2}\sigma_P^2\phi(\phi-1)+(r-\delta_P)\phi-$ $(r+\lambda_u+\lambda_d)+$ $\lambda_u(1+u)^{\phi}+\lambda_d(1-d)^{\phi}=$ 0

Figure 46: Possible GBM-based models for high speed rail demand

The writers thus propose to delay the decision to build the system until the benefits are high enough to make the project profitable. It is well known that passenger numbers fluctuate and that there are shocks (like taxes on or introduction of new technologies in competing modes) that influence the total profits.

The downside of the mathematical approach is that formulas become very complicated and much less useful if several variables and Real Options opportunities are included. Instead of mathematical deduction, simulation becomes a much better useful way of calculating Real Option value. We will follow a simulation approach in which we will use binominal trees to calculate the expected benefits at a certain point in time.

While the discussion is usually so oriented on intangible benefits like the travel time saved by introducing this new mode, the modeling of the benefits in most models (like the model of Pereira et al.) very focused on the profit from ticket sales. On one hand, this is very understandable as the European Union wants to privatize the railways and then only the profit will matter to the operators. This has not happened fully yet and in many countries the influence of the government in the railways is very large. It is also questionable if a privatization of the railways (with limited or no government subsidy) is actually possible from a financial point of view. Therefore we propose a model like the following to model the social welfare benefits for a country:

$$V_i = T * v_t * n + p * n$$

T= travel time saved per passenger

v_t=value of one hour of travel time

p=net cashflow (profit) per passenger

n= number of passengers

The total social welfare goal function will become:

$$F(V) = K + \sum_{t=tstart}^{tstart+consessionlength} \frac{V_i - O}{(1+r)^i}$$

Where:

K=Infrastructure costs

O=Operating costs

The variables in the function V_i can be modeled with Geometric Brownian Motion and Binominal Trees. To demonstrate an application of Real Options an example that resembles the numbers used by Ecorys for the Dutch High Speed Rail lines is used.

No shocks will be included in the model above as it is very difficult to make plausible forecasts about technological or political shocks. The results obtained without shocks are sufficiently powerful to show that Real Options can make a difference for a project. With shocks (i.e. more uncertainty), the results would just be a bit extremer. For a model that would be used by an organization it is advisable to add shocks for likely events that have a big impact on the system performance. Shocks should not be of the kind mentioned by Pereira et al. (2006). They (and other authors) include shocks in the variables to account for events like terrorist attacks or Olympic Games that could affect the profit made. These events will only have a very temporary instead of a lasting effect on the profit after which the profit will stabilize to its normal value and should therefore not be included. That shocks could be added in the variables can be argued from a more lasting perspective. Competing modes can have two kinds of influence on the rail system performance:

1. Technological or regulatory measures in the other modes affect their price. For instance, cars can become cheaper if fuel-efficient motors are put on the market. But if cars are taxed more, the price of cars increases and rail becomes relatively more attractive.
2. Technological or regulatory measures in the other modes affect the travel time saved. Intelligent Transportation Systems (ITS), e.g., is a technology that would allow cars to travel faster with fewer accidents because computers monitor their position and speed. If more roads are build that relieve congestion and make cars faster, this might also have a negative effect on the number of passengers in the railways.

7.7 Results of a flexible strategy in the HSR case example

The values for the variables used in the case example with the goal function from paragraph 7.6 are shown in Figure 47. We will compare the base case (build now for average growth) with a case where there are two kinds of Real Options (Wait-to-Invest and Exit-Option. The Matlab code can be found in Appendix 3.

		Note:
T	M= 1% Σ= 5% T_0=2 hours	Total time savings of 5 million hours per year is used by the Dutch, which is about T_0*n_0.
v_t	M=1% Σ=2% v_{t0}=9 euro	The value of one hour of travel time is taken at 100% of the average workers pay in the region.
P	M=2% Σ=3% p_0=25 euro	p_0 is a reasonable estimate; in the Dutch case this is zero because the company that exploits the regular railways looses income due to regular train passengers switching to high speed rail.
N	M=0.5-3.5% Σ=10% n_0=3 000 000 passengers/year	n_0 is similar to the number used by the Dutch Railways: 13.000 per day in 2020.
R	8% per year	
T_0*v_{t0}	Value of total time savings in year 0	5 million hours * 9 euro per hour (similar value is used by the Dutch)

K	Present value of the investment cost	3 billion euro
I	Yearly investment	10 million euro
Nconstruction	Number of years for the construction	6 years
Nconcession	Number of years for the concession	60 years
Ndelay	Number of years with possibility to delay	10 years
Nevaluation	Period when reevaluation takes place and a decision can be made about exercising the Real Options.	2 years

Figure 47: High speed rail example settings Note: Problems could occur with using binominal trees if the values of the variables are correlated. The binominal technique used for calculation of the total expected value assumes a zero correlation coefficient. It is known that the values of our goal function have a correlation coefficient larger than zero. Statistical methods like Principal Component Analysis exist to achieve this independence in variables.

The expected results if the rail line is built immediately are -271 million euro. The actual case if the rail line is built immediately, meaning that uncertainty in possible future system values is taken into account, is -180 million euro which is 33% less loss. Jensen's inequality is much larger if the goal function depends on several variables, some of which have larger standard deviations.

With a Real Options strategy for building and operating where the government decides to build and operate as soon as the NPV of the project exceeds 0, the expected value of the project becomes 93 million euro. Real Options seem to provide a lot better results than the traditional design evaluation methods and results are often presented as such in scientific papers. But there is no reason to start cheering yet for the proponents of the High Speed Rail lines.

The first major catch is that the likelihood of the project being built is actually rather small:

Year	2	4	6	8	10
Probability build	0	0	15%	14%	30%

Figure 48: Probability of building the high speed line with Real Options; due to non-linearity the probability of building is smaller in year 8 than in year 6

The NPV is smaller than zero when the line is not built. When a build decision is made, the variables have a NPV greater than zero which ultimately results in a value greater than 0 for the overall project. If the evaluation period for building would be reduced to one year, the chances of building might increase a bit and the NPV would decrease at the same time. Also, the organizational burden (=costs) would increase if the evaluation period is shortened.

Second, there are limitations in the usefulness of the results gained with Real Options as described in the next paragraph.

7.8 Framework analysis of DSP

We will use the findings from previous chapters and our case examples to fill in the fitness of DSP in the framework provided in chapter 7.1. The case example will be helpful for filling in the Technology-Reality (TR) component of the framework.

7.8.1 Technology component-Theory (TT)

The success of the TT part of the Real Options framework is a highly uncertain factor. The benefit model that is used to evaluate Real Options could be very far off reality. Models never really match reality fully but severe modeling problems are very common in travel demand. In the Dutch case for example, the model used by Ecorys and the Dutch government showed incorrect output for expected passenger numbers. Instead, more ‘plausible’ expert estimates have been used for the number of passengers. How dependable these ‘plausible’ numbers that the model produced are is uncertain.

The modeling of the financial performance of HSR is difficult due to two things: the variables (cost-benefit) which need to be included in the model and the factors outside HSR that influence these variables.

Scientific studies (chapter 3) indicate that time savings and ticket sales are the greatest benefits of HSR and these factors are mainly used to make decisions about HSR. One could argue that the goal function should contain more variables like environmental impact, regional impact, labor market impact, etc (like Oosterhaven and Elhorst, 2003, Elhorst et al. 2004). If these factors are wrongly omitted, suboptimal decisions in Real Options Analysis will be made. How large the sub-optimality is depends on the model and the input variables selected.

The other difficulty is in the fact that competing transportation modes influence the HSR benefits and that their relation is not well defined. Many models exist like Cascetta (2001) writes. Uncertainty in transportation mode modeling leads to problems with the accuracy of HSR Real Options assessment. One could state that each mode could be modeled separately and that general estimates for deviation of the benefits could be given just as was done in our case example. This is not the right approach as Martin (1997) shows. Decision making about HSR can be a serious dilemma as it reduces growth in other economic sectors. Martin states that the ridership of the HSR consists largely of diverted travelers from the other modes, and the gains might thus be at the expense of the profitability of these modes. On the whole, there might be no net social gain and consequently no net growth of the social welfare. Real Options should therefore not be applied for the modes of transportation separately. The lack of an integral transportation plan where the interaction between different modes is captured, can lead to optimization per mode but to sub-optimization of the total transportation network. If the government wants to maximize social welfare for the country, the entire transportation network needs to be included in DSP-decision models. This can become a very complex matter and scientists are still adding new ideas on how the interaction between modes exactly is (Vickerman, 2007, shows many different approaches and Florian et al. 1999 displays model evolution). Choices based on an inaccurate model are sure to produce worse output than expected and therefore Real Options valuation on complex, unsure models is dangerous.

A neutral representation of the model and its parameters is difficult as it is. The interests of powerful stakeholders in HSR can influence the modeling in a way that doesn't necessarily strive for the impartially correct solution. This is another factor that might influence the accuracy of Real Options in transportation.

7.8.2 Technology component-Reality (TR)

Even if a model could be made to represent the travel demand under different conditions, the parameters that are to be used as input are uncertain. Many possible scenarios are thinkable (remember for instance the four GDP scenarios given by the CBP in the Netherlands?) and objectively no one knows how large the chances are that they will occur.

This makes Real Options analysis in HSR very tricky because the parameters based upon decisions are made, might very well not correspond with the actual situation. The long term average growth and the uncertainty factors of the model parameters are unknown and the past is a very limited predictor of the future. Actually the same objections that were mentioned for average growth predictions in chapter 3 apply to the parameter estimates in Real Options modeling. In order to make good decisions by using binominal trees, accurate estimates about these values are needed.

To demonstrate this concept, the values that we have taken initially in our example are adapted to two different scenarios (one in which every factor is worse and one in which every factor is better) as shown in Figure 50. The decision processes in both scenarios are performed according to the base scenario.

	Base scenario	Worse case	Better case
T	M= 1% Σ= 5% T_0=2 hours	0.5% 3%	2.5% 10%
v_t	M=1% Σ=2% v_{t0}=9 euro	0.5% 3%	2.5% 5%
P	M=2% Σ=3% P_0=25 euro	1% 1%	3% 5%
N	M=2% Σ=10% n_0=3 000 000 passengers/year	0.5% 5%	3.5% 15%

Figure 49 Alternative long term scenarios for the base case

The expected outcomes for decision making could be quite sensitive under inaccurate information about the average growth and the standard deviation. In the worse case example, the NPV drops to -961 million euro while the building probabilities stay the same. The better case example has a much larger NPV of 1.88 billion euro but the public interest is not served optimally as the building should have been done in more situations (Figure 51) with a lower NPV of 707 M euro:

Year	2	4	6	8	10
Probability	92%	85%	79%	83	78%

Figure 50: Building probabilities in better case example under perfect operating conditions

To show how parameter assumptions in an existent case might not match reality, we will again use the Dutch case as an example. The calculations for traffic flows in the Zuiderzeelijn case have been done on terms that assume a decrease in the attractiveness of cars in the future. Examples of such measures are:

- Car costs are made variable and the costs for using cars rise from 100 in 1995 to 143 in 2020.
- There is a fee of 20cts/km for the use of often congested roads.
- Parking costs increase 50% in real terms.

Public transportation is assumed to become more attractive on the other hand. It is supposed that a speed increase of 5-10% will be achieved in the future and pricing for public transportation increases furthermore only by the inflation rate.

Many other scenarios are possible for the Dutch case as new technologies develop. For example De Neufville et al. 2007) mention Intelligent Transportation Systems (ITS, innovative devices that reduce accidents at highway intersections) as a technology that can increase car speed and make cars more attractive. Recently, the EU has cautioned car manufacturers that it expects cars to become more fuel efficient and environmentally friendly by 2020. Engines that only use 50% of the gasoline of regular engines are being introduced to the markets. Alternative fuels are also being investigated. It is therefore very uncertain if the cost of automobiles will rise as dramatically as prognosed by Ecorys in the Zuiderzeelijn case.

Concluding, if wrong input parameters are used for the model the decision process can become heavily disturbed making Real Options Analysis a much less fit tool than theoretically promised.

The added value of Real Options Analysis furthermore depends on the range of parameters selected. We saw in chapter 7.2 that with one variable and moderate uncertainty, Real Options do not necessarily make a huge difference. The value added by ROA is quite sensitive to the range of variables (their uncertainty and the time period) that is assumed uncertain. Calculation power increases exponentially with the number of variables and the time period. Real Option analysis could therefore become quite pricey which might be another objection against the method.

7.8.3 Policy component-Reality (PR)

There is a huge gap between the theoretical possible benefits of Real Options and the execution by the organization. The idea behind Real Options that is usually promoted is that one must have a plan and must be able to stick to it. Authors like Law et al. (2004) neglect the necessary level of organizational expertise for implementing Real Options so that the real outcome matches the theoretically promised results.

In situations with political pressure from many sides this rigidity condition for economic rationality could be abandoned leading to a lesser financial performance of the system. Paradoxal to this political firmness, with DSP there is a need for operational agility under new, unexpected events which is also a feature that most governmental institutions lack. Adner et al. (2004) warn that "preserving the applicability of Real Options by imposing rigid criteria for abandonment may result in the underutilization of discoveries made in the course of initial investments and search efforts. The organizational rigidity required to maintain the flexibility of abandonment may therefore cause Real Options to be an inferior mechanism of resource allocation relative to other search processes (e.g. March and Simon, 1958; Burgelman, 1983, Kanter, 1988; Lynn, Morone, Plauson, 1996) in many strategic settings". The rigidity-agility capability in decision making that is needed for successful implementation of Real Options like Exit Operations (a.k.a. Abandonment) is not something that can be demanded overnight of organizations. It takes careful redesign of the organizational structure and education of the stakeholders and executers. This can be a trap for many organizations when they walk the Real Options path.

Portugal is juggling many reforms at the same time as described in POAT and the government plans. Massive regulatory changes have been implemented to suit European laws. Investments in new (transportation) technologies are being sought for further boosting the Portuguese economy. Portugal is a young democracy and has come a long way since 1974 but it has made costly mistakes along the way. The rush to innovate has led to commercial failures like the Alfa Pendular trains and the Fertagus track. A hasty implementation of DSP has risks. First, it could lead to the acceptance of projects that are not profitable because the gap between theory and realizations of Real Options is too large. Second, if Real Options are implemented prematurely and not managed well, the methodology might be discarded as useless for future projects. Flexible system thinking has many advantages and it would be a pity to reject it due to a hurried execution.

It is therefore very important to gain more expertise in the field of transportation and Real Options before the methodology is implemented in large HSR projects. Collaborations with American research institutions have been started to increase the knowledge about transportation and DSP. After more experience is gained with the method, from a PR view DSP could work. But at the moment, it would be unwise to commit mega-projects like HSR to this methodology because the expertise is not available in the country.

7.8.4 Policy component-Theory (PT)

Even if Real Options make sense from a practical point of view, how likely are politically motivated actors to commit to flexible investment strategies? A 'We don't know yet' attitude or conditional statements about building large projects like HSR usually does not do too well with voters in elections. It could very well come across as indecisiveness and lack of leadership.

Besides political pressure from voters, Portugal also experiences pressure from Europe. Portugal is highly dependent on funding from the EU for the transportation plans. A flexible system planning approach has not been used on a large scale within Europe. Portugal would have to fulfill a pioneering role in explaining how they want to manage their transportation system. If the country has sufficient political influence to steer the way in which projects are evaluated in Europe is very questionable.

Concluding, it will be very difficult to convince political decision makers to risk committing to such a strategy. While the railways are organizations that depend highly on public funding, DSP might have a hard time to be successful as a strategy. Committing to DSP and then having to change strategy due to political pressure will definitely lead to worse results for Portugal. The feasibility of sticking to DSP for the duration of a project should be examined.

7.9 Chapter conclusion

European countries and consultancy firms have started to acknowledge the existence of uncertainties in railways. Still, the uncertainties are not being managed but a safety buffer is merely added to the costs.

Through two case examples (one simple and one complex) we have shown how benefits may be managed with DSP to increase social welfare as uncertainties develop.

Although theoretically large advantages can be gained through DSP, the fitness of the methodology for HSR in Portugal is not good at this point in time (as can be seen in Figure 51).

From a policy point, the methodology might not receive sufficient political support to be implemented in the first case. Even if it is implemented, the organization needs to have sufficient expertise to handle DSP correctly.

Technologically, modeling problems and parameter estimation problems might prevent a good fit with the promise that DSP seems to make theoretically. These technological problems are most worrisome and before they are solved (if even possible) DSP should not be implemented in mega-projects.

If Real Options are not executed well, either because the technology cannot be managed well, or because the organization is not fit to exercise them, the promised results of Real Options do not match the actual outcome: lower (perhaps even negative) NPV or lower building chances.

	Policy	Technology
Theory	PT: - pressure from voters - pressure from Europe	TT: - model accuracy problems: uncertainty about variables included and interactions between competing modes - special interest pressures
Reality	PR: - political firmness - organizational expertise: agility - many changes at once	TR: - input variables highly uncertain - special interest pressures

Figure 51: Limitations on the success of Real Options in Portuguese railways

Chapter 8 Conclusion and issues for further research

As travel demand increases with rising GDP, countries are looking for fast transportation modes to meet this demand. High Speed Rail is very tempting to build because it is cheaper than Maglev trains and still very prestigious. The downsides are the immense infrastructure costs and uncertain benefits inherent to rail projects which have cause railways to make large debts in the past. European countries are tempted to help the unification and accessibility within Europe by receiving large EU infrastructure subsidies for (high speed rail) transportation projects.

In this thesis ways to enhance the expected value of High Speed Rail projects have been investigated. The problem with the traditional valuation methods is that uncertainty is treated as noise that is remained to be ignored. Risks due to uncertainty are not limited and opportunities are not exploited. In contrast, in advanced flexible planning methods like Dynamic Strategic Planning uncertainty is treated as a system attribute which is to be modeled and explored. DSP can be a powerful tool to recognize uncertainty in high speed rail and act accordingly. In a case example, we have shown how public interests can be attended to by balancing the probability of building and the NPV through Waiting-To-Invest and Exit Options. The initial theoretical results are very hopeful but there are large catches of an organizational and technological nature.

While large theoretical benefits are promised by DSP propagators, in HSR the problems with modeling and estimation of input parameters of the benefits are very likely to undermine the strengths of flexible system planning. Also, political objections from voters and Europe might put pressure on the Portuguese government to reconsider if the methodology is worth to be implemented at all in HSR.

Overall, the answer to the thesis question "Can the performance of (high speed) rail transportation systems be improved with flexible planning techniques for the case of Portugal?" must be answered negatively for the benefits. The methodology is not (yet) suited from a technological point of view to be applied to HSR systems.

Learning Options to manage the cost side of important parts of the infrastructure (like bridges) might be better suited for the methodology. The system parts and their model values are clearly defined and could be objectively determined by architectural, geological and market studies. The information gained will provide more certain and controllable value to the project than the possibilities that Exit and Waiting to Invest Options offer for benefits. Another difference is that Learning Options in infrastructure cost management have a much shorter time span which makes them easier to follow through. Thirdly, both opponents and proponents of HSR might be interested to learn the costs of the project and after Learning Options a political discussion about what to do next will be better facilitated.

Capacity problems in building railways for the most careful scenario have been addressed briefly. Growth options that allow for expansion of the project might help to increase the project value. With railways, capacity is usually not the limiting factor and a higher growth than what is build for is hardly ever realized. This kind of option could be investigated further for HSR but at a first glance it does not seem very promising.

The last kind of options that could be explored theoretically are Flexibility Options that provide the opportunity to switch between modes or train technologies. One could think about building common infrastructure parts that most modes can use before committing to which transportation mode will be developed exactly. On top of that, a country could develop several technologies (e.g. both HSR and Maglev) at the same time and then decide later which to roll out completely. Flexibility Options are quite vague in HSR transportation and have not been explored in detail yet. How it would work in practice and how much value it would add is uncertain.

Although the applications of flexible system planning are limited (to mainly infrastructure cost management) in HSR, the methodology has much theoretical potential and it is therefore recommended that Portugal continues to invest in DSP research. With all types of Real Options, a switch is needed in the minds of people from rigid political leadership to adaptable thinking before DSP can become a popular tool in large governmental projects. Portugal could first make steps to educate governmental staff, politicians and even the public (on different levels of detail of course) about the advantages that flexible planning might offer.

The lack of expertise with the methodology could be overcome by collaborations with DSP-experts in universities and consultancy agencies. The costs of obtaining this aid and the costs of more elaborate modeling should be weighted against the potential benefits and the feasibility of them being implemented. A careful consideration of which areas of DSP are worth developing should be made. We advise to focus on Learning Options in infrastructure management on the short term and continue to explore benefit management through Exit and Waiting-To-Invest options on the long term. Further research is considered necessary on the technological side of benefit system modeling and parameter estimation before Real Options can be applied successfully to benefit management in HSR.

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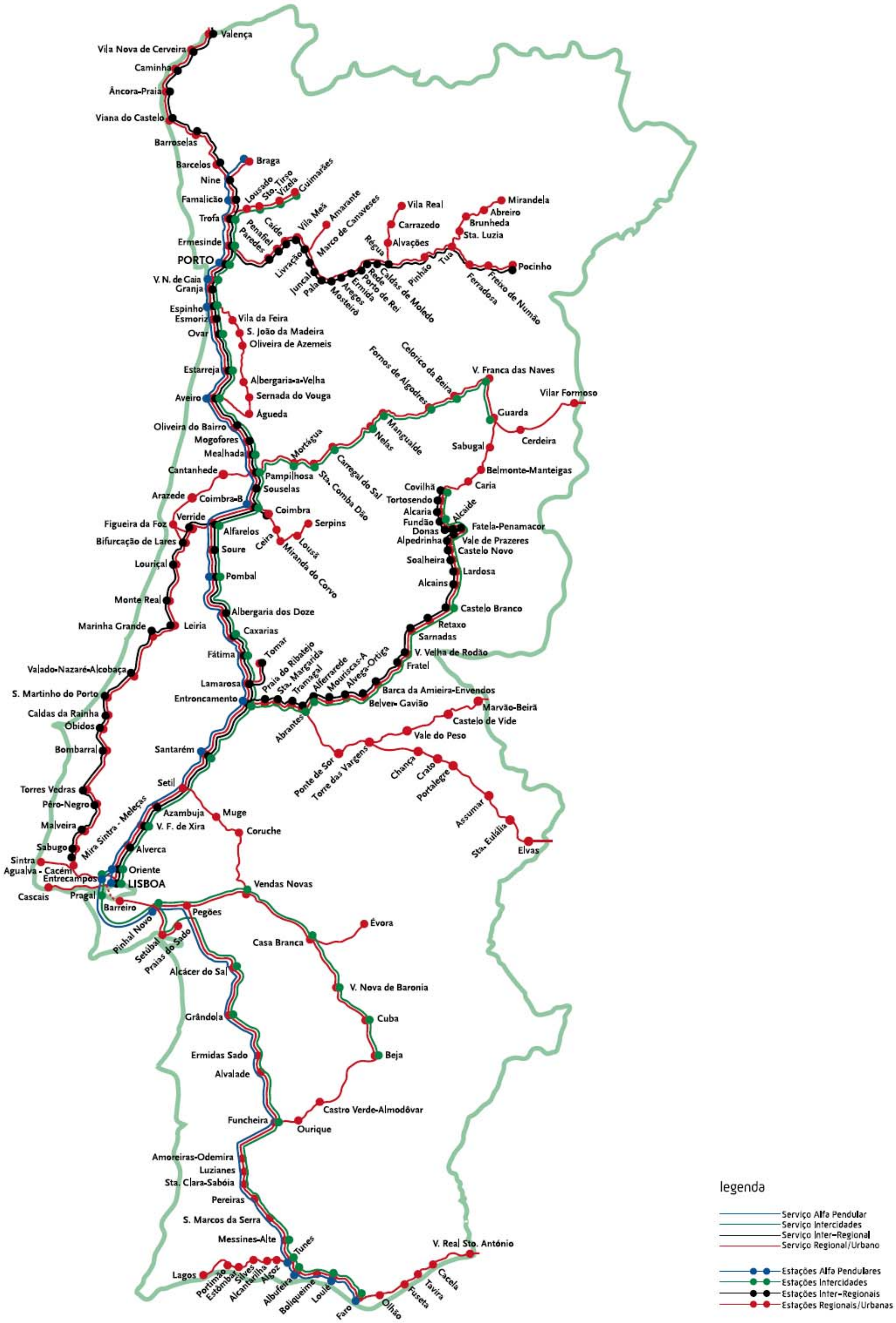
Appendix 1: Detailed view of CP's rail network



Appendix 2: The Dutch case

History of the high speed rail plans in the Netherlands

Two regions have been of concern to the Dutch government since the mid1990s: the North of the Netherlands (the provinces Groningen and Friesland) and the northern part of the economic centre of the Netherlands called Randstad. The high speed transportation plans are meant to strengthen the economic competitiveness of these regions.

In 1998 the committee Langman concluded that the Northern regions of The Netherlands (Groningen and Friesland) have been developing slower than the rest of the country. The North is mainly a production region with traditional agricultural and industrial activities. With increasing competition from countries with lower wages, the future of the North is uncertain.

Noordvleugel, the northern part of the Randstad, is the second region of concern. It has a high population density, a high bruto regional product and can be seen as a knowledgehub which is oriented on knowledge intensive activities. Opportunities for this region are the strong international orientation with large, important ports (Rotterdam) and airports (Schiphol), a good connection to the transnational high-speed rail network, an internet hub, a concentration of knowledge intensive and contact intensive activities and great tourist potential.

Better transportation facilities from and to these two regions have been mentioned as a solution for the problems. Based on this, the following goals relevant to transportation have been formulated for these areas:

- Strengthen the most viable economic clusters in the North (Groningen, Assen, Zwolle, Lelystad, Leeuwarden)
- Concentrate economical development and urbanization in the North
- Stimulate innovation, knowledge and entrepreneurship in the North
- Improve accessibility within the Northern-Netherlands as well as between the North and the rest of the Netherlands.
- Improve the regional accessibility in Noordervleugel where public transportation capacity problems are expected in 2020 and cities are increasingly difficult to reach by car.
- Reduce the well-educated labor shortage in Noordervleugel
- Increase the number of company accommodation areas.

New Maglev Trains and High Speed Rail connections have been investigated as alternatives to the existing Conventional Rail network between the North, Noordvleugel and the Randstad. The costs of Maglev Trains were so immense that this technology was quickly dismissed as an option. High-Speed Rail is an existing technology in the Netherlands as there is a TGV connection from Rotterdam through Brussels to Paris. This technology is better known, its costs are significantly lower and there is a potential network for it as European countries switch to HSR. Unfortunately, neighboring countries to the North like Germany and Scandinavia have no intentions of investing in a high speed rail connection with The Netherlands. As the Zuiderzeelijn has not been included in the Trans-European Network (TEN), it also doesn't receive funding to cover infrastructure costs.

After investigating several alternatives for stimulating the economy of The Netherlands and the poorer northern regions, two types of transportation measures are proposed: faster rail interregional connections between the North and Randstad (design types HST3 or HZL160+) or other regional transportation and regional economical measures.

High Speed Train (HST3) that will require completely new infrastructure; this high-speed line along the A6/A7 highway axis Groningen-Almere-Amsterdam can help boost the economy in the North-Netherlands. Ecorys estimates benefits (time reduction train and car, reliability, net operational result, labor market effects) at almost 1 billion and costs at 3.2 billion euro (infrastructure, maintenance and saved investments). When exogenous risks are accounted for costs rise to 4.1 billion and with a 90% certainty interval ranges from 3.1 to 5.1 billion. The decision uncertainties which have been identified (political decisions that change the design but do not add functionality) add another 1.7 billion euro. The investment that is needed by the government most probably varies between 3.7 and 5.9 billion euro plus the uncertainty of benefits from passenger revenues and the difference between market costs and forecasted costs of infrastructure. Currently, the fastest means of transportation from the North to Amsterdam/Schiphol is by car. The high speed train connection would reduce this minimum travel time with over a third (about 40-48 minutes depending on destination in North).

Hanzelijn 160 plus (HZL160+) will use mostly existing infrastructure; this high-speed line along the A28 highway axis Groningen-Zwolle-Utrecht to benefit from special development of the region. For the Hanzelijn 160+ plans, the current infrastructure is mainly used and upgraded. Speed will be increased from 140 km/h to 160 km/h. This is cheaper than the initial proposal in which the train could reach speeds of 200 km/h. Mainly the costs savings suggested by the Dutch Railroads (Nederlandse Spoorwegen, NS) emerge from altering current safety regulation. For instance the proposal is made not to adjust the leveling of rail crossings which is demanded by the current safety regulations. Also, fewer trains will be traveling per hour. The costs are 3.6 billion euro on average with a 90% certainty margin from 2.6 billion to 4.5 billion. Decision uncertainties can range from -0.5 billion euro to 1.1 billion euro. Total benefits are calculated to be 0.5 billion euro. Public investment ranges from 2.8 to 4.2 billion euro plus an extra uncertainty margin for investment and substitution costs.

To make the current tracks suitable for higher speeds, intensive adaptations of the foundation are necessary as well as adaptations of the track. With Hanzelijn 160 plus, the travel time between Airport Schiphol and Groningen is reduced from over 130 minutes to 119 minutes, a gain of only 11 minutes. The extra number of travelers generated by this reduction is very limited just like the extra jobs created for the Northern regions.

Next to these two projects, other initiatives of stimulating the economy of Flevoland and the Northern regions (Groningen, Friesland and Drenthe) of the Netherlands have been proposed. There are two types of proposed projects. First, regional transportation improvements like building extra capacity on roads that are congested, or upgrading regional train tracks and stations. On the other hand the implementation of new technologies in the field of life sciences, sensor research and the creation of cultural attractions and excellent living conditions are measures that could stimulate the economy of the North.

Appendix 3 Matlab code for simulation programs

```
% This program calculates the value of a HSR project where there is

% an Option to Delay the Investment and an Option to Stop Operating

fprintf('PROGRAM START\n');


% travel time gains in hours/year

Tmu=0.01;

Tsigma=0.05;

T0=2; % travel time gain in year 0

TmuWorse=0.025;

TsigmaWorse=0.10;


% value of one hour of travel time

vt0=9; % euro schatting

vtmu=0.01;

vtsigma=0.02;

vtmuWorse=0.025;

vtsigmaWorse=0.05;


% revenue per passenger

p0=25;

pmu=0.02;

psigma=0.03;

pmuWorse=0.03;

psigmaWorse=0.05;
```

```
% number of passengers
n0=3000000;
nmu=0.02;
nsigma=0.1;
nmuWorse=0.035;
nsigmaWorse=0.15;


%infrastructure costs
K=5000000000; % divided equally per year over constructionperiod
OpCosts=60000000;   % yearly, does not rise with more than inflation for convenience

constructionperiod=6; % in years
concessionperiod=60; % in years
delayperiod=10; % heavily reduced to 10 for simulation simplification purposes
periodtot=constructionperiod+concessionperiod+delayperiod;

time=2;
r=0.08; % r=8%
r=(1+r)^time-1; % r per time years


%------------------------START simple expected calculations---------
IC=0;
for x=1:(constructionperiod/time)
```

```
    IC=IC+K/((constructionperiod*time)*(1+r)^x); %
end;
valuetot=-IC;
valuetotWorse=-IC;

% init normal
n(1)=n0*(1+nmu)^time;
p(1)=p0*(1+pmu)^time;
T(1)=T0*(1+Tmu)^time;
vt(1)=vt0*(1+vtmu)^time;

% init worse
nWorse(1)=n0*(1+nmuWorse)^time;
pWorse(1)=p0*(1+pmuWorse)^time;
TWorse(1)=T0*(1+TmuWorse)^time;
vtWorse(1)=vt0*(1+vtmuWorse)^time;

for i=2:concessionperiod
    n(i)=n(i-1)*(1+nmu)^time;
    p(i)=p(i-1)*(1+pmu)^time;
    T(i)=T(i-1)*(1+Tmu)^time;
    vt(i)=vt(i-1)*(1+vtmu)^time;
    value(i)=(n(i)*vt(i)*T(i)+p(i)*n(i)-OpCosts)/(1+r)^(i+3);
    valuetot=valuetot+value(i);
    % worse scenario
```

```
    nWorse(i)=nWorse(i-1)*(1+nmuWorse)^time;

    pWorse(i)=pWorse(i-1)*(1+pmuWorse)^time;

    TWorse(i)=TWorse(i-1)*(1+TmuWorse)^time;

    vtWorse(i)=vtWorse(i-1)*(1+vtmuWorse)^time;

    valueWorse(i)=(nWorse(i)*vtWorse(i)*TWorse(i)+pWorse(i)*nWorse(i)-
OpCosts)/(1+r)^(i+3);

    valuetotWorse=valuetotWorse+valueWorse(i);

end;

fprintf('The total expected value with simple operating strategy is %6.4f \n',valuetot);

fprintf('The total expected value with simple operating strategy for the worse case is
%6.4f \n',valuetotWorse);

%fprintf('The total expected value with simple operating strategy for the better case is
%6.4f \n',valuetotBetter);

%------------------------END simple expected calculations---------


% -------------------------calculations for vt, p*n and T*n----------------------

% GBM for v(t)

v_up=exp(vtsigma*sqrt(time));

v_down=1/v_up;

vp=1/2+(1/2)*(vtmu/vtsigma)*sqrt(time);

vp % vp should be <1 !!!

v_upWorse=exp(vtsigmaWorse*sqrt(time));

v_downWorse=1/v_upWorse;

vpWorse=1/2+(1/2)*(vtmuWorse/vtsigmaWorse)*sqrt(time);

vpWorse % vpWorse should be <1 !!!


% GBM for p
```

```
p_up=exp(psigma*sqrt(time));
p_down=1/p_up;
pp=1/2+1/2*pmu/psigma*sqrt(time);
pp % pp should be <1 !!!
p_upWorse=exp(psigmaWorse*sqrt(time));
p_downWorse=1/p_upWorse;
ppWorse=1/2+1/2*pmuWorse/psigmaWorse*sqrt(time);
ppWorse % ppWorse should be <1 !!!

% GBM for n
n_up=exp(nsigma*sqrt(time));
n_down=1/n_up;
np=1/2+1/2*nmu/nsigma*sqrt(time);
np % np should be <1 !!!
n_upWorse=exp(nsigmaWorse*sqrt(time));
n_downWorse=1/n_upWorse;
npWorse=1/2+1/2*nmuWorse/nsigmaWorse*sqrt(time);
npWorse % npWorse should be <1 !!!

% GBM for T
t_up=exp(Tsigma*sqrt(time));
t_down=1/t_up;
tp=1/2+1/2*Tmu/Tsigma*sqrt(time);
tp % tp should be <1 !!!
t_upWorse=exp(TsigmaWorse*sqrt(time));
```

```
t_downWorse=1/t_upWorse;
tpWorse=1/2+1/2*TmuWorse/TsigmaWorse*sqrt(time);
tpWorse % tp should be <1 !!!

% build outcome matrix v,n,p and t
vGBM(1,1)=v_up*vt0;
vGBM(1,2)=v_down*vt0;
vGBMWorse(1,1)=v_upWorse*vt0;
vGBMWorse(1,2)=v_downWorse*vt0;

nGBM(1,1)=n_up*n0;
nGBM(1,2)=n_down*n0;
nGBMWorse(1,1)=n_upWorse*n0;
nGBMWorse(1,2)=n_downWorse*n0;

pGBM(1,1)=p_up*p0;
pGBM(1,2)=p_down*p0;
pGBMWorse(1,1)=p_upWorse*p0;
pGBMWorse(1,2)=p_downWorse*p0;

tGBM(1,1)=t_up*T0;
tGBM(1,2)=t_down*T0;
tGBMWorse(1,1)=t_upWorse*T0;
tGBMWorse(1,2)=t_downWorse*T0;
```

```
for i=2:(periodtot/time)
    vGBM(i,1)=vGBM(i-1,1)*v_up;
    pGBM(i,1)=pGBM(i-1,1)*p_up;
    tGBM(i,1)=tGBM(i-1,1)*t_up;
    nGBM(i,1)=nGBM(i-1,1)*n_up;
    vGBMWorse(i,1)=vGBMWorse(i-1,1)*v_upWorse;
    pGBMWorse(i,1)=pGBMWorse(i-1,1)*p_upWorse;
    tGBMWorse(i,1)=tGBMWorse(i-1,1)*t_upWorse;
    nGBMWorse(i,1)=nGBMWorse(i-1,1)*n_upWorse;
    for j=2:(i+1)
        if (i+1)>j
            vGBM(i,j)=vGBM(i-1,j)*v_up;
            pGBM(i,j)=pGBM(i-1,j)*p_up;
            tGBM(i,j)=tGBM(i-1,j)*t_up;
            nGBM(i,j)=nGBM(i-1,j)*n_up;
            vGBMWorse(i,j)=vGBMWorse(i-1,j)*v_upWorse;
            pGBMWorse(i,j)=pGBMWorse(i-1,j)*p_upWorse;
            tGBMWorse(i,j)=tGBMWorse(i-1,j)*t_upWorse;
            nGBMWorse(i,j)=nGBMWorse(i-1,j)*n_upWorse;
        elseif (i+1)==j
            vGBM(i,j)=vGBM(i-1,j-1)*(1-v_down);
            pGBM(i,j)=pGBM(i-1,j-1)*(1-p_down);
            tGBM(i,j)=tGBM(i-1,j-1)*(1-t_down);
            nGBM(i,j)=nGBM(i-1,j-1)*(1-n_down);
            vGBMWorse(i,j)=vGBMWorse(i-1,j-1)*(1-v_downWorse);
```

```
            pGBMWorse(i,j)=pGBMWorse(i-1,j-1)*(1-p_downWorse);
            tGBMWorse(i,j)=tGBMWorse(i-1,j-1)*(1-t_downWorse);
            nGBMWorse(i,j)=nGBMWorse(i-1,j-1)*(1-n_downWorse);
        end;
    end
end;
fprintf('outcome matrices GBM built succesfully\n');

% build probability matrices v,t,p,n
vGBMprob(1,1)=vp;
vGBMprob(1,2)=1-vp;
pGBMprob(1,1)=pp;
pGBMprob(1,2)=1-pp;
tGBMprob(1,1)=tp;
tGBMprob(1,2)=1-tp;
nGBMprob(1,1)=np;
nGBMprob(1,2)=1-np;
% worse
vGBMprobWorse(1,1)=vpWorse;
vGBMprobWorse(1,2)=1-vpWorse;
pGBMprobWorse(1,1)=ppWorse;
pGBMprobWorse(1,2)=1-ppWorse;
tGBMprobWorse(1,1)=tpWorse;
tGBMprobWorse(1,2)=1-tpWorse;
nGBMprobWorse(1,1)=npWorse;
```

```
nGBMprobWorse(1,2)=1-npWorse;



for i=2:(periodtot/time)
   vGBMprob(i,1)=vGBMprob(i-1,1)*vp;
   pGBMprob(i,1)=pGBMprob(i-1,1)*pp;
   tGBMprob(i,1)=tGBMprob(i-1,1)*tp;
   nGBMprob(i,1)=nGBMprob(i-1,1)*np;
   vGBMprobWorse(i,1)=vGBMprobWorse(i-1,1)*vpWorse;
   pGBMprobWorse(i,1)=pGBMprobWorse(i-1,1)*ppWorse;
   tGBMprobWorse(i,1)=tGBMprobWorse(i-1,1)*tpWorse;
   nGBMprobWorse(i,1)=nGBMprobWorse(i-1,1)*npWorse;
   for j=2:(i+1)
      if (i+1)>j
         vGBMprob(i,j)=vGBMprob(i-1,j-1)*(1-vp)+vGBMprob(i-1,j)*vp;
         pGBMprob(i,j)=pGBMprob(i-1,j-1)*(1-pp)+pGBMprob(i-1,j)*pp;
         tGBMprob(i,j)=tGBMprob(i-1,j-1)*(1-tp)+tGBMprob(i-1,j)*tp;
         nGBMprob(i,j)=nGBMprob(i-1,j-1)*(1-np)+nGBMprob(i-1,j)*np;
         vGBMprobWorse(i,j)=vGBMprobWorse(i-1,j-1)*(1-vpWorse)+vGBMprobWorse(i-
1,j)*vpWorse;
         pGBMprobWorse(i,j)=pGBMprobWorse(i-1,j-1)*(1-ppWorse)+pGBMprobWorse(i-
1,j)*ppWorse;
         tGBMprobWorse(i,j)=tGBMprobWorse(i-1,j-1)*(1-tpWorse)+tGBMprobWorse(i-
1,j)*tpWorse;
         nGBMprobWorse(i,j)=nGBMprobWorse(i-1,j-1)*(1-npWorse)+nGBMprobWorse(i-
1,j)*npWorse;
      elseif (i+1)==j
```

```
            vGBMprob(i,j)=vGBMprob(i-1,j-1)*(1-vp);
            pGBMprob(i,j)=pGBMprob(i-1,j-1)*(1-pp);
            tGBMprob(i,j)=tGBMprob(i-1,j-1)*(1-tp);
            nGBMprob(i,j)=nGBMprob(i-1,j-1)*(1-np);
            vGBMprobWorse(i,j)=vGBMprobWorse(i-1,j-1)*(1-vpWorse);
            pGBMprobWorse(i,j)=pGBMprobWorse(i-1,j-1)*(1-ppWorse);
            tGBMprobWorse(i,j)=tGBMprobWorse(i-1,j-1)*(1-tpWorse);
            nGBMprobWorse(i,j)=nGBMprobWorse(i-1,j-1)*(1-npWorse);
        end;
    end;
end;
fprintf('probability matrices GBM built succesfully\n');


%------------ end of vt, p, n and T calculations------------------%


% --------------------- SIMPLE WAY -------------------
% this is the SIMPLE WAY: build in year 0 and then always operate
DomBenefitTot=-IC;
DomBenefitTotWorse=-IC;
for i=(constructionperiod/time):((concessionperiod+constructionperiod)/time-1) %
benefits for 50 years from year 6
    for j=1:i+1      % for each value of time v
        for k=1:i+1     % for each amount of t
            for l=1:i+1    % for each value of p
                for m=1:i+1  % for each amount of n
                    DomBenefit=vGBM(i,j)*tGBM(i,k)*nGBM(i,m)+nGBM(i,m)*pGBM(i,l)-OpCosts;
```

```
          DomProb=vGBMprob(i,j)*tGBMprob(i,k)*pGBMprob(i,l)*nGBMprob(i,m);

          DomBenefitTot=DomBenefitTot+(DomBenefit*DomProb)/(1+r);

DomBenefitWorse=vGBMWorse(i,j)*tGBMWorse(i,k)*nGBMWorse(i,m)+nGBMWorse(i,m)*
pGBMWorse(i,l)-OpCosts;

DomProbWorse=vGBMprobWorse(i,j)*tGBMprobWorse(i,k)*pGBMprobWorse(i,l)*nGBMpr
obWorse(i,m);

DomBenefitTotWorse=DomBenefitTotWorse+(DomBenefitWorse*DomProbWorse)/(1+r);

        end;

      end;

    end;

  end;

end;

DomBenefitTot;

fprintf('Simple building/operating value calculated successfully\n');

fprintf('The project value with simple building and operating strategy are %e \n',
DomBenefitTot);

fprintf('The project value with simple building and operating strategy for the worse case
are %e \n', DomBenefitTotWorse);

% ----------------------END SIMPLE WAY --------------------------

% ----------------------REAL OPTIONS ---------------------------

% initialization of probability & benefits that the line is built in year i

probBuild(1:delayperiod/time)=0;

probWait(1:delayperiod/time)=0;
```

```
TotBenefits(1:delayperiod/time)=0;

% worse

%probBuildWorse(1:delayperiod/time)=0;

%probWaitWorse(1:delayperiod/time)=0; => should be the same because the

%decision is made based on the normal case

TotBenefitsWorse(1:delayperiod/time)=0;



%initialization of total tree value per year

value(1:delayperiod/time)=0;

valueWorse(1:delayperiod/time)=0;

% initialization of total project value

totalvalue=0;

totalvalueWorse=0;


built='NOT';

for i=(delayperiod/time):-1:1 % for each year where delay is possible ---the benefits start in year i

    for j=1:i+1

        for k=1:i+1

            for l=1:i+1

                for m=1:i+1

                    % calculate the value of building in that year

                    [helpvariableONE,helpvariableONEWorse]=rembenefits2Worse2(i,j,k,l,m, vGBMprob,tGBMprob,pGBMprob,nGBMprob, vGBM,tGBM, pGBM,nGBM,vGBMprobWorse,tGBMprobWorse,pGBMprobWorse,nGBMprobWorse, vGBMWorse,tGBMWorse, pGBMWorse,nGBMWorse);
```

```
            helpvariableONE=(helpvariableONE-IC)/((1+r)^i);
            helpvariableONEWorse=(helpvariableONEWorse-IC)/((1+r)^i);
            if helpvariableONE>0 % build in this configuration
              fprintf('enter build cycle for i=%g j=%g k=%g l=%g m=%g \n',i,j,k,l,m);
              treevalue(i,j,k,l,m)=helpvariableONE;
              treevalueWorse(i,j,k,l,m)=helpvariableONEWorse;
              % add the probability that system is built in year i

probBuild(i)=probBuild(i)+vGBMprob(i,j)*tGBMprob(i,k)*pGBMprob(i,l)*nGBMprob(i,m);
              built='';
            else % wait
              fprintf('enter wait cycle for i=%g j=%g k=%g l=%g m=%g \n',i,j,k,l,m);
              % for check purposes add the probability that the
              % system is not built in year i here

probWait(i)=probWait(i)+vGBMprob(i,j)*tGBMprob(i,k)*pGBMprob(i,l)*nGBMprob(i,m);
              treevalue(i,j,k,l,m)=0; % initialization, stays 0 for year=delayperiod/time
because there is no value of not building
              treevalueWorse(i,j,k,l,m)=0;
              if i<(delayperiod/time) % calculate the value for waiting in that year
                for xxj=1:2 % value up_down of v
                  for xxk=1:2 % of t
                    for xxl=1:2 % of p
                      for xxm=1:2 % of n

prob=vGBMprob(xxj)*tGBMprob(xxk)*pGBMprob(xxl)*nGBMprob(xxm);
                        helpvariableTWO=treevalue(i+1,xxj,xxk,xxm,xxl);
```

```
treevalue(i,j,k,l,m)=treevalue(i,j,k,l,m)+prob*helpvariableTWO/((1+r)^(i+1)); % discount for i?

probWorse=vGBMprobWorse(xxj)*tGBMprobWorse(xxk)*pGBMprobWorse(xxl)*nGBMprobWorse(xxm);
                                helpvariableTWOWorse=treevalueWorse(i+1,xxj,xxk,xxm,xxl);

treevalueWorse(i,j,k,l,m)=treevalueWorse(i,j,k,l,m)+probWorse*helpvariableTWOWorse/((1+r)^(i+1)); % discount for i?
                             end;
                          end;
                       end;
                     end;
                   end;
                end;
                %fprintf('done m=%g \n', m);
                % calculate the value of this configuration for year i

value(i)=value(i)+treevalue(i,j,k,l,m)*vGBMprob(i,j)*tGBMprob(i,k)*pGBMprob(i,l)*nGBMprob(i,m); % multiply with the chance that the system is in configuration i,j,k,l,m

valueWorse(i)=valueWorse(i)+treevalueWorse(i,j,k,l,m)*vGBMprobWorse(i,j)*tGBMprobWorse(i,k)*pGBMprobWorse(i,l)*nGBMprobWorse(i,m); % multiply with the chance that the system is in configuration i,j,k,l,m
             end;
             %fprintf('done l=%g \n',l);
          end;
          %fprintf('done k=%g \n',k);
       end;
```

```
        %fprintf('done j=%g \n',j);

    end;

    %fprintf('done i=%g \n',i);

 end;


%------------------------SYSTEM RESULTS---------------------

fprintf('The project value with simple building and operating strategy are %e \n',
DomBenefitTot);

fprintf('With Real Options this changes to: \n' );

fprintf('The project value with Real Options building and operating becomes %e
\n',value(1));

fprintf('The project value with Real Options building and operating in the worse case
becomes %e \n',valueWorse(1));

fprintf('The project has %s been built in some configurations.\n', built);

fprintf('The probability that the system is built in \n year 0 equals %6.4f \n year 2 equals
%6.4f \n year 4 equals %6.4f \n', probBuild(1),probBuild(2),probBuild(3));

fprintf('The probability that the system is NOT built in \n year 0 equals %6.4f \n year 2
equals %6.4f \n year 4 equals %6.4f \n', probWait(1),probWait(2),probWait(3));

fprintf('PROGRAM END\n');

% --------------------------- end of program -----------------


function
[RemBenTot,RemBenTotWorse]=rembenefits2Worse2(i,j,k,l,m,vGBMprob,tGBMprob,pGB
Mprob,nGBMprob, vGBM,tGBM,
pGBM,nGBM,vGBMprobWorse,tGBMprobWorse,pGBMprobWorse,nGBMprobWorse,
vGBMWorse,tGBMWorse, pGBMWorse,nGBMWorse)

% This program helps the main program with calculation of the remaining benefits

% It calculates the benefits from point xi,xxj,xxk,xxm,xxl
```

```
% 'global' does not work in Matlab for some reason, so the GBM variables are inserted

% again in the header of the program and transferred from the main program

% Also other variables like constructionperiod are inserted here because 'global' does
not work.

constructionperiod=6; % in years

concessionperiod=60; % in years

delayperiod=10; % heavily reduced to 10

periodtot=constructionperiod+concessionperiod+delayperiod;

time=2;

r=0.08; % r=8%

r=(1+r)^time-1; % r per time years

OpCosts=30000000;   % yearly, does not rise with more than inflation for convenience


RemBenTot=0; % total remaining benefits initialization

RemBenTotWorse=0; % total remaining benefits initialization


for xi=(constructionperiod/time):((constructionperiod+concessionperiod)/time-1)  % for
remaining periods --note: it takes 6 years to build so benefits start in year 6

  for xj=1:xi+1       % for the number of nodes for v

    sumj=vGBM(i+xi,j+xj-1); % value of v

    sumjWorse=vGBMWorse(i+xi,j+xj-1); % value of v

    for xk=1:xi+1 % for the number of nodes for time t

      sumk=tGBM(i+xi,k+xk-1); % amount of time T

      sumkWorse=tGBMWorse(i+xi,k+xk-1); % amount of time T

      for xl=1:xi+1  % for the number of nodes for price p

        suml=pGBM(i+xi,l+xl-1); % value of price p
```

```
            sumlWorse=pGBMWorse(i+xi,l+xl-1); % value of price p

            for xm=1:xi+1 % for the number of nodes for number of passengers n

               summ=nGBM(i+xi,l+xm-1); % value of passengernumber n

               summWorse=nGBMWorse(i+xi,l+xm-1); % value of passengernumber n

               RemBen=sumj*sumk*summ+suml*summ; % expected benefits from xi,xj,xk,xl,
xm

               RemBenProb=vGBMprob(xi-(constructionperiod/time)+1,xj)*tGBMprob(xi-
(constructionperiod/time)+1,xk)*pGBMprob(xi-
(constructionperiod/time)+1,xl)*nGBMprob(xi-(constructionperiod/time)+1,xm); %
probability of xj,xk,xl,xm in year xi

               RemBenWorse=sumjWorse*sumkWorse*summWorse+sumlWorse*summWorse;
% expected benefits from xi,xj,xk,xl, xm

               RemBenProbWorse=vGBMprobWorse(xi-
(constructionperiod/time)+1,xj)*tGBMprobWorse(xi-
(constructionperiod/time)+1,xk)*pGBMprobWorse(xi-
(constructionperiod/time)+1,xl)*nGBMprobWorse(xi-(constructionperiod/time)+1,xm); %
probability of xj,xk,xl,xm in year xi

               if RemBen>OpCosts % if it adds value to operate in that period

                  RemBenTot=RemBenTot+(RemBen-OpCosts)*RemBenProb/((1+r)^xi); %
total remaining benefits of operating in xi discounted to i

                  RemBenTotWorse=RemBenTotWorse+(RemBenWorse-
OpCosts)*RemBenProbWorse/((1+r)^xi); % total remaining benefits of operating in xi
discounted to i

                  % else dont add value because you dont operate

               end;

            end;

         end;

      end;

   end;

end;
```

Endnotes: non-scientific references in text

For the sake of readability, the non-scientific sources used in this document have been included as endnotes. Many of these sources are websites whose content might change over time. All links mentioned were functional and referring to the correct content when this thesis was turned in (May 2007).

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[i] http://www.fxstreet.com/news/forex-news/article.aspx?StoryId=dd87ac44-c344-4a1a-a57f-1e5e93e65649

[ii] Lesson of Canadian Airport in Terminal Decline, Guardian Unlimited, 9/22/2003; and http://www.airodyssey.net/articles/mirabel.html

[iii] http://en.wikipedia.org/wiki/History_of_rail_transport_in_Great_Britain_to_1830

[iv] http://adcosta.home.sapo.pt/index_e.html

[v] Same as ii)

[vi] Same as ii)

[vii] http://en.wikipedia.org/wiki/Portugal

[viii] http://www.cp.pt/cp/displayPage.do?vgnextoid=70ecab3226ea4010VgnVCM1000007b01a8c0RCRD&lang=en

[ix] http://en.wikipedia.org/wiki/Ford_Model_T

[x] http://en.wikipedia.org/wiki/Douglas_DC-3

[xi] Same as vi)

[xii] Same as ix)

[xiii] http://en.wikipedia.org/wiki/History_of_Portugal#The_First_Republic

[xiv] http://en.wikipedia.org/wiki/TGV

[xv] http://en.wikipedia.org/wiki/Pendolino

[xvi] http://en.wikipedia.org/wiki/InterCity_Express

[xvii] http://en.wikipedia.org/wiki/AVE

[xviii] http://ec.europa.eu/transport/rail/index_en.html

[xix] www.cp.pt

[xx] www.cp.pt

[xxi] http://www.railway-technology.com/projects/alfa/

[xxiixxii] http://www.nationsencyclopedia.com/World-Leaders-2003/Portugal-DOMESTIC-POLICY.html

[xxiii] The transposition of this directive into Portuguese national standards has been done by Decreto-Lei n.º 93/2000, *Diário da República* — I Série A, n.º 119, 23 May 2000.

[xxiv] http://www.uic.asso.fr/

[xxv] http://www.unife.org/

[xxvi] http://www.uitp.com/home/index.cfm

[xxvii] http://www.aeif.org/

[xxviii] http://www.era.eu.int/

[xxix] http://ec.europa.eu/transport/rail/interoperability/doc/ertms_en.pdf

[xxx] http://ec.europa.eu/transport/rail/interoperability/ertms_en.htm

[xxxi] http://ertms.uic.asso.fr/3_gsmr_imple.html

[xxxii] http://ec.europa.eu/regional_policy/country/prordn/details.cfm?gv_PAY=PT&gv_reg=ALL&gv_PGM=1999PT161PO009&LAN=5

[xxxiii] http://ec.europa.eu/ten/transport/revision/hlg/2003_report_kvm_annex_en.pdf

[xxxiv] http://www.cpb.nl/nl/news/2000_22_report.html