UNIVERSITÀ DEGLI STUDI DI ROMA "LA SAPIENZA"

Optimization of the speed of trains on the critical segments

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THESIS

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Abstract

From 1863 which is the starting point of the railway history, many railroads has been built in many different countries, but nowadays because of the introduction of the new technologies which one of its byproducts is higher speed trains, we have been faced by complex situation, 'modern train–old infrastructure'. As we will see in this thesis, updating lines is a long-term issue, and although the milestone of this problem in Italy backs to 1975, but this issue is still an open discussion issue. In this thesis we are trying to propos a solution for this problem.

The philosophy behind this thesis is:

" If I have a limited amount of money, and I have a networks of lines, where should I invest my money? (Which segments would be my choice for optimization?!)"

For answering this question we analyzed most of the Italy network and then chose the 41 main corridors, which can represent of the whole Italy network. Then we examines the factors which can helping us for better understanding for a precise cost benefit analysis of our options, then by a case study and Sensivity analysis we did verification of our data and formulation and in appendix 1 we present quick guide tables.

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To my parents lovely, for their sacrifice.

And my lovely sisters for their love.

And professor Ricci who helped me during all these years such a father.

Chapter 1

- 1.1 Introduction

The oldest known, man/animal-hauled railways date back to the 6th century BC in Corinth, Greece. Rail transport then commenced in mid 16th century in Germany in form of horse-powered funiculars and wagon ways. Modern rail transport commenced with the British development of the steam locomotives in the early 19th century. Thus the railway system in Great Britain is the oldest in the world.

With steam engines, one could construct mainline railways, which were a key component of the Industrial Revolution. Also, railways reduced the costs of shipping, and allowed for fewer lost goods, compared with water transport, which faced occasional sinking of ships. The change from canals to railways allowed for "national markets" in which prices varied very little from city to city. The invention and development of the railway in the United Kingdom was one of the most important technological inventions of the 19th century.

In the 1880s, electrified trains were introduced, leading to electrification of tramways and rapid transit systems. Starting during the 1940s, the non-electrified railways in most countries had their steam locomotives replaced by diesel-electric locomotives, with the process being almost complete by the 2000s.

During the 1960s, electrified high-speed railway systems were introduced in Japan and later in some other countries. Many countries are in process of replacing diesel locomotives with electric locomotives, mainly due to environmental concerns, a notable example being Switzerland, which has completely electrified its network.

Following decline after World War II due to competition from cars, rail transport has had a revival in recent decades due to road congestion and rising fuel prices, as well as governments investing in rail as a means of reducing CO_2 emissions in the context of concerns about warming In contrast to road transport, where vehicles run on a prepared flat surface, rail vehicles are directionally guided by the tracks on which they run.

Tracks usually consist of steel rails, installed on ties (sleepers) and ballast, on which the rolling stock, usually fitted with metal wheels, moves. Other variations are also possible, such as slab track, where the rails are fastened to a concrete foundation resting on a prepared subsurface. Rolling stock in a rail transport system generally encounters lower frictional resistance than road vehicles, so passenger and freight cars (carriages and wagons) can be coupled into longer trains. Power is provided by locomotives, which either draw electric power from a railway electrification system or produce their own power, usually by diesel engines.

Most tracks are accompanied by a signalling system. Railways are a safe land transport system when compared to other forms of transport. Railway transport is capable of high levels of passenger and cargo utilization and energy efficiency, but is often less flexible and more capital-intensive than road transport, when lower traffic levels are considered.

- 1.2 Overview

The first railway in Italy was the Napoli-Portici line, built in 1839 to connect the royal palace of Naples to the seaside. After the creation of the Kingdom of Italy in 1861, a project was started to build a network from the Alps to Sicily, in order to connect the country.

The first high-speed train was the Italian ETR 200, which in July 1939 went from Milan to Florence at 165 km/h, with a top speed of 203 km/h. With this service, the railway was able to compete with the upcoming airplanes. The Second World War stopped these services.

After the Second World War, Italy started to repair the damaged railways, and built nearly 20,000 km of new tracks. The Italian railway system is one of the most important parts of the infrastructure of Italy, with a total length of 24,227 km, which active lines are 16,723 km. The network has recently grown with the construction of the new high-speed rail network. Italy is a member of the International Union of Railways (UIC). RFI, a state owned company, is administers most of the Italian rail infrastructure. The total length of RFI active lines is 16,723 km, which 7,505 km are double tracks. Lines are divided into 3 categories:

- Fundamental lines, which have high traffic and good infrastructure quality, comprise all the main lines between major cities throughout the country. Fundamental lines are 6,131 km long;
- Complementary lines, which have less traffic and are responsible for connecting medium or small regional centers. Most of these lines are single track and some are not electrified;

- Node lines, which link complementary and fundamental lines near metropolitan areas for a total 936 km.

The Italian rail network comprises also other minor regional lines controlled by other companies for a total of about 3,000 km

Figure 1 Italian Rail Network map

- 1.3 Updating History

In 1975, a program for a widespread updating of the rolling stock was launched. However, as it was decided to put more emphasis on local traffic, this caused a shifting of resources from the ongoing high-speed projects, with their subsequent slowing or, in some cases, total abandonment. Therefore, 160 E.656 electric and 35 D.345 locomotives for short-medium range traffic were acquired, together with 80 EMUs of the ALe 801/940 class, 120 ALn 668 diesel railcars. Some 1,000 much-needed passenger and 7,000 freight cars were also ordered. In the 1990s, work started on the Treno Alta Velocità (TAV) project, which involved building a new high-speed network on the routes Milan – (Bologna–Florence–Rome–Naples) – Salerno, Turin – (Milan–Verona–Venice) – Trieste and Milan–Genoa. Most of the planned lines have already been opened, while international links with France, Switzerland, Austria and Slovenia are underway.

Most of the Rome–Naples line opened in December 2005, the Turin–Milan line partially opened in February 2006 and the Milan–Bologna line opened in December 2008. The remaining sections of the Rome–Naples and the Turin–Milan lines and the Bologna–Florence line were completed in December 2009. All these lines are designed for speeds up to 300 km/h.

Other proposed high-speed lines are Salerno-Reggio Calabria, and then connected to Sicily using the future Strait of Messina Bridge, and Naples-Bari.

Chapter 2

2.1 Classification of trains

2.1.1.1.Passenger trains

A passenger train is one, which includes passenger-carrying vehicles, which can often be very long and fast. It may be a self-powered multiple units or railcar, or else a combination of one or more locomotives and one or more unpowered trailers known as coaches, cars or carriages. Passenger trains travel between stations or depots, at which passengers may board and disembark. In most cases, passenger trains operate on a fixed schedule and have superior track occupancy rights over freight trains.

Unlike freight trains, passenger trains must supply head-end power to each coach for lighting and heating, among other purposes. This can be drawn directly from the locomotive's prime mover (modified for the purpose), or from a separate diesel generator in the locomotive. For passenger service on remote routes where a head-end-equipped locomotive may not always be available, a separate generator van may be used.

Oversight of a passenger train is the responsibility of the conductor. He or she is usually assisted by other crewmembers, such as service attendants or porters. During the heyday of North American passenger rail travel, long distance trains carried two conductors: the aforementioned train conductor, and a Pullman conductor, the latter being in charge of sleeping car personnel.

Many prestigious passenger train services have been given a specific name, some of which have become famous in literature and fiction. In past years, railroaders often referred to passenger trains as the "varnish", alluding to the bygone days of wooden-bodied coaches with their lustrous exterior finishes and fancy livery. "Blocking the varnish”, meant a slow-moving freight train was obstructing a fast passenger train, causing delays.

Some passenger trains, both long distance and short distance, may use bi-level (double-decker) cars to carry more passengers per train. Car design and the general safety of passenger trains have dramatically evolved over time, making travel by rail remarkably safe.

2.1.1.2.Long-distance trains

Long-distance trains travel between many cities and/or regions of a country, and sometimes cross several countries. They often have a dining car or restaurant car to allow passengers to have a meal during the course of their journey. Trains travelling overnight may also have sleeping cars. Currently much of travel on these distances of over 800 km is done by air in many countries but in others long-distance travel by rail is a popular or the only cheap way to travel long distances.

2.1.1.3.High-speed rail

One notable and growing long-distance train category is high-speed rail. Generally, high-speed rail runs at speeds above 200 km/h and often operates on dedicated track that is surveyed and prepared to accommodate high speeds. Japan's Shinkansen popularly known as ("bullet-train") commenced operation in 1964, and was the first successful example of a high-speed passenger rail system.

The fastest wheeled train running on rails is France's TGV (Train à Grande Vitesse, literally "high speed train"), which achieved a speed of 574.8 km/h, twice the takeoff speed of a Boeing 727 jetliner, under test conditions in 2007. The highest speed currently attained in scheduled revenue operation is 350 km/h on the Beijing–Tianjin Intercity Rail and Wuhan–Guangzhou High-Speed Railway systems in China. The TGV runs at a maximum revenue speed of 300–320 km/h, as does Germany's Inter-City Express and Spain's AVE (Alta Velocidad Española).

In most cases, high-speed rail travel is time-and-cost-competitive with air travel when distances do not exceed 500 to 600 km, as airport check-in and boarding procedures may add as many as two hours to the actual transit time. Also, rail-operating costs over these distances may be lower when the amount of fuel consumed by an airliner during take-off and climb-out is considered. As travel distance increases, the latter consideration becomes less of the total cost of operating an airliner and air travel becomes more cost-competitive. Some high-speed rail equipment employs tilting technology to improve stability in curves. Examples of such equipment are the Advanced Passenger Train (APT), the Pendolino, the N700 Series Shinkansen, Amtrak's Acela Express and the Talgo. Tilting is a dynamic form of superelevation, allowing both low- and high-speed traffic to use the same trackage (though not simultaneously), as well as producing a more comfortable ride for passengers.

2.1.1.4.Inter-city trains

Trains can be divided into three major groups:
Inter-city trains: connecting cities in the fastest time possible, bypassing all intermediate stations
Express trains: calling at larger intermediate stations between cities, serving large urban communities
Regional trains: calling at all intermediate stations between cities, serving all lineside communities
The distinction between the types can be thin or even non-existent. Trains can run as inter-city services between major cities, then revert to a fast or even regional train service to serve communities at the extremity of their journey. This practice allows marginal communities remaining to be served while saving money at the expense of a longer journey time for those wishing to travel to the terminus station.

2.1.1.5.Regional trains

Regional trains usually connect between towns and cities, rather than purely linking major population hubs like inter-city trains, and serve local traffic demand in relatively rural areas.

2.1.1.6.Higher-speed rail

Higher-speed rail is a special category of trains. The trains for higher-speed rail services can operate at top speeds that are higher than conventional inter-city trains but the speeds are not as high as those in the high-speed rail services. These services are provided after improvements to the conventional rail infrastructure in order to support trains that can operate safely at higher speeds.

2.1.1.7.Short-distance trains

2.1.1.7.1.Commuter trains

For shorter distances many cities have networks of commuter trains, serving the city and its suburbs. Trains are a very efficient mode of transport to cope with large traffic demand in a metropolis. Compared with road transport, it carries many people with much smaller land area and little air pollution.
Some carriages may be laid out to have more standing room than seats, or to facilitate

the carrying of prams, cycles or wheelchairs. Some countries have double-decked passenger trains for use in conurbations. Double deck high speed and sleeper trains are becoming more common in mainland Europe.

Sometimes extreme congestion of commuter trains becomes a problem. For example, an estimated 3.5 million passengers ride every day on Yamanote Line in Tokyo, Japan, with its 29 stations. For comparison, the New York City Subway carries 5.7 million passengers per day on 25 services serving 472 stations. To cope with large traffic, special cars in which the bench seats fold up to provide standing room only during the morning rush hour (until 10 a.m.) are operated in Tokyo (E231 series train). In the past this train has included 2 cars with six doors on each side to shorten the time for passengers to get on and off at station.

Passenger trains usually have emergency brake handles (or a "communication cord") that the public can operate.

2.1.1.7.2.Within cities

2.1.1.7.2.1.Rapid transit

Large cities often have a metro system, also called underground, subway or tube. The trains are electrically powered, usually by third rail, and their railroads are separate from other traffic, usually without level crossings. Usually they run in tunnels in the city center and sometimes on elevated structures in the outer parts of the city. They can accelerate and decelerate faster than heavier, long-distance trains. The term rapid transit is used for public transport such as commuter trains, metro and light rail.

2.1.1.7.2.2.Tram

In the United Kingdom, the distinction between a tramway and a railway is precise and defined in law. In the U.S. and Canada, such street railways are referred to as trolleys or streetcars. The key physical difference between a railroad and a trolley system is that the latter runs primarily on public streets, whereas trains have a right-of-way separated from the public streets. Often the U.S.-style interurban and modern light rails are confused with a trolley system, as it too may run on the street for short or medium-length sections. In some languages, the word tram also refers to interurban and light rail-style networks, in particular Dutch.

The length of a tram or trolley may be determined by national regulations. Germany has the so-called Bo-Strab standard, restricting the length of a tram to 75 meters, while in the U.S., vehicle length is normally restricted by local authorities, often allowing only a single type of vehicle to operate on the network.

2.1.1.7.2.3.Light rail

The term light rail is sometimes used for a modern tram system, despite light rail lines commonly having a mostly exclusive right-of-way, more similar to that of a heavy-rail line and less alike to that of a tramway. It may also mean an intermediate form between a tram and a train, similar to a subway except that it may have level crossings. These are then usually protected with crossing gates. In U.S. terminology these systems are often referred to as interurban, as they connect larger urban areas in the vicinity of a major city to that city. Modern light rail systems often use abandoned heavy rail rights of way (e.g. former railway lines) to revitalize deprived areas and redevelopment sites in and around large agglomerations.

2.1.1.8.Monorail

Monorails were developed to meet medium-demand traffic in urban transit, and consist of a train running on a single rail, typically elevated. Monorails represent a relatively small part of the overall railway field.

2.1.1.9.Maglev

In order to achieve much faster operation over 500 km/h, innovative maglev technology has been researched since the early 20th century. The technology uses magnets to levitate the train above the track, reducing friction and allowing higher speeds. An early prototype was demonstrated in 1913, and the first commercial maglev train was an airport shuttle introduced in 1984.

The Shanghai Maglev Train, opened in 2003, is the fastest commercial train service of any kind, operating at speeds of up to 430 km/h. Maglev has not yet been used for inter-city mass transit routes.

2.1.1.10.Railcar

A railcar, in British English and Australian English, is a self-propelled railway vehicle designed to transport passengers. The term "railcar" is usually used in reference to a train consisting of a single coach (carriage, car), with a driver's cab at one or both ends. Some railways, e.g., the Great Western Railway, used the term Railmotor. If it is able to pull a full train, it is rather called a motor coach or a motor car.The term is sometimes also used as an alternative name for the small types of multiple unit which consist of more than one coach.

2.1.11.Freight Train

A freight train (also known as goods train) uses freight cars or freight wagons (also known as trucks or goods wagons) to transport goods or materials (cargo) – essentially any train that is not used for carrying passengers. Train transports much of the world's freight, and in the United States the rail system is used more for transporting freight than passengers.

Under the right circumstances, transporting freight by train is highly economic, and also more energy efficient than transporting freight by road. Rail freight is most economic when freight is being carried in bulk and over long distances, but is less suited to short distances and small loads. Bulk aggregate movements of a mere 32 km can be cost effective even allowing for trans-shipment costs. These trans-shipment costs dominate in many cases and many modern practices such as Intermodal container freight are aimed at minimizing these.

The main disadvantage of rail freight is its lack of flexibility. For this reason, rail has lost much of the freight business to road competition. Many governments are now trying to encourage more freight onto trains because of the benefits that it would bring.

There are many different types of freight trains, which are used to carry many different kinds of freight, with many different types of wagons. One of the most common types on modern railways are container trains, where containers can be lifted on and off the train by cranes and loaded off or onto trucks or ships.

In the U.S. this type of freight train has largely superseded the traditional boxcar (wagon-load) type of freight train, with which the cargo has to be loaded or unloaded manually. In Europe the sliding wall wagon has taken over from the ordinary covered goods wagon.

In some countries "piggy-back" trains or rolling highways are used: In the latter case trucks can drive straight onto the train and drive off again when the end destination is reached. A system like this is used through the Channel Tunnel between England and France, and for the Trans-Alpine service between France and Italy (this service uses Modular road trailer carriers). "Piggy-back" trains are the fastest growing type of freight trains in the United States, where they are also known as "trailer on flatcar" or TOFC trains. Piggy-back trains require no special modifications to the vehicles being carried. An alternative type of "inter-modal" vehicle, is designed to be physically attached to the train. The original trailers were fitted with two sets of wheels — one set flanged, for the trailer to run connected to other such trailers as a rail vehicle in a train; and one set tyred, for use as the semi-trailer of a road vehicle. More modern trailers have only road wheels and are designed to be carried-on specially adapted bogies (trucks) when moving on rails.

There are also many other types of wagon, such as "low loader" wagons or well wagons for transporting road vehicles. There are refrigerator cars for transporting foods such as ice cream. There are simple types of open-topped wagons for transporting minerals and bulk material such as coal, and tankers for transporting liquids and gases. Today, however, most coal and aggregates are moved in hopper wagons that can be filled and discharged rapidly, to enable efficient handling of the materials.

Passengers who do not wish to pay money, or do not have the money to travel by ordinary means sometimes illegally board freight trains. This is referred to as "freight hopping" and is considered by some communities to be a viable form of transportation. A common way of boarding the train illegally is by sneaking into a train yard and stowing away in an unattended boxcar; a more dangerous practice is trying to catch a train "on the fly", that is, as it is moving, leading to occasional fatalities. Railroads treat it as trespassing and may prosecute it as such.

2.2 Classification of routs

2.2.1.Background

Initially, the ICC classed railroads by their annual gross revenue. Class I railroads had an annual operating revenue of at least $1 million (83,619,04.17 Euro), while Class III railroad incomes were under $100,000 per annum (83,619.03 Euro). All such corporations were subject to reporting requirements on a quarterly or annual schedule. If a railroad slipped below its class qualification threshold for a period, it was not necessarily demoted immediately. For instance, in 1925, the ICC reported 174 Class I railroads, 282 Class II railroads, and 348 Class III railroads.
Since dissolution of the ICC in 1996, the Surface Transportation Board (STB) has become responsible for defining criteria for each railroad class. The bounds are typically redefined every several years to adjust for inflation and other factors.

2.2.2.Classification history

The initial $1 million criterion (83,619,04.17 Euro) established in 1911 for a Class I railroad was used until January 1, 1956, when the figure was increased to $3 million (equal to $26,427,173 today) (22098146.17 Euro). In 1956, the ICC counted 113 Class I line-haul operating railroads (excluding "3 class I companies in systems") and 309 Class II railroads (excluding "3 class II companies in systems"). The Class III category was dropped in 1956 but reinstated in 1978. By 1963, the number of Class I railroads had dropped to 102; cut offs were increased to $5 million by 1965 (equal to $37,998,944 today)(31774349.03 Euro), to $10 million in 1976 (equal to $42,087,719 today)(35193343.09 Euro), and to $50 million in 1978 (equal to $183,596,939 today)(153521982.61 Euro), at which point only 41 railroads qualified as Class I.In a special move in 1979, all switching and terminal railroads were re-designated Class III, including those with Class I or Class II revenues.Class II and Class III designations are now rarely used outside the rail transport industry. The Association of American Railroads typically divides non–Class I companies into three categories:
Regional railroads: operate at least 350 miles or make at least $40 million per year(33447612.68 Euro per year).Local railroads: non-regional but engage in line-haul service.Switching and terminal railroads: mainly switch cars between other railroads or provide service from other lines to a common terminal.

2.2.3.Classes

2.2.3.1.Class I

In the United States, the Surface Transportation Board defines a Class I railroad as "having annual carrier operating revenues of $250 million (209047579.23 Euro) or more in 1991 dollars", which adjusted for inflation was $452,653,248 (378504262.90Euro) in 2012. According to the Association of American Railroads, Class I railroads had a minimum carrier operating revenue of $346.8 million (USD) (289990801.90 Euro) in 2006, $359 million in 2007 (300192323.77 Euro), $401.4 million in 2008 (335646793.21 Euro), $378.8 million in 2009 (316748892.04 Euro), $398.7 million in 2010 (333389079.35 Euro) and $433.2 million in 2011 (362237645.29 Euro).

In early 1991, two Class II railroads, Montana Rail Link and Wisconsin Central, asked the Interstate Commerce Commission (ICC) to increase the minimum annual operating revenue criteria (then established at US$93.5 million) (78183794.63 Euro) to avoid being redesigned as Class I, which would have resulted in increased administrative and legal costs. The Class II maximum criterion was increased in 1992 to $250 million annually (209047579.23 Euro), which resulted in the Florida East Coast Railway having its status changed to Class II. Rail carriers with less than $20 million (16723806.34 Euro) in revenue are designated as Class III.

In Canada, a Class I rail carrier is defined (as of 2004) as a company that has earned gross revenues exceeding $250 million (167417814.59 Euro) (CAD) for each of the previous two years.Class 1 railroads are some of the most efficient forms of transportation, moving a ton of freight almost 500 miles (804.672 kilometres) with each gallon of diesel fuel.In 2013, eleven railroads in North America were designated as Class I. In the United States, Amtrak and seven freight railroads are designated Class I based on 2011 measurements released in 2013.

2.2.3.2.1.Class II

A Class II railroad in the United States hauls freight and is mid-sized in terms of operating revenue. As of 2011, a railroad with revenues greater than $37.4 million (31268550.03 Euro) but less than $433.2 million (362180103.50 Euro) for at least three consecutive years is considered Class II. Switching and terminal railroads are excluded from Class II status.

Railroads considered by the Association of American Railroads as "Regional Railroads" are typically Class II.

2.2.3.2.2.Current Class II criteria

The last major change of the upper bound for a Class II railroad was in 1992, when the Florida East Coast Railway was changed from a Class I railroad to Class II. A previous change in 1991, which prevented two railroads-- Montana Rail Link and Wisconsin Central—from becoming Class I, was made at the request of the two railroads, as they did not wish to take on the extra cost and paperwork associated with Class I status. Changes since then have been adjustments for inflation.

2.2.3.3.Class III

A Class III railroad has annual operating revenue of less than $20 million (1991 dollars). Class III railroads are typically local short-line railroads serving a small number of towns and industries or hauling cars for one or more railroads; many Class III railroads were once branch lines of larger railroads or abandoned portions of main lines. Many Class III railroads are owned by railroad holding companies.

Chapter 3:

- 3.1 a brief survey on the Italy railway network

In this thesis, as it can be seen in figure3.2, we selected 41 random corridor of the entire Italy network railway in different classes. In our selected space we have all the speed classes (we have the routs with the maximum speed of 70 km/h to the speed of 180 km/h). Then we gather all the data (speed and distance) during the routs and then we ranked them based on the portion of the maximum speed.Then the magnificent data showed up:

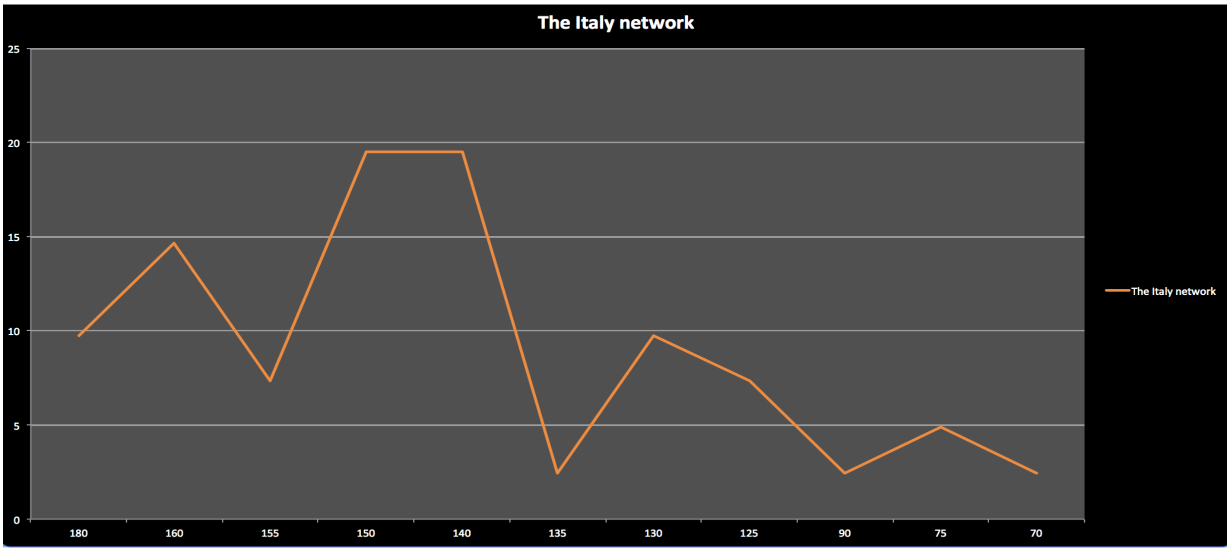

Figure 3.1

As we can see in figure 3.1, the rails with the maximum speed of 150 and 140 kilometers per hour are the most common railways in the Italy by around 20 percent of all routs, then the corridors with 160 kilometers per hour by around 15 percent are the second common maximum speed in the Italy network and then the 130 kilometers per hour with 10 percent are the third common speed and the 155 kilometers per hour and 125 kilometers per hours by around 10 percent are the next most common and then the 75 kilometers per hour by just 5 percent of the whole Italy network. And finally there are lines by 90 kilometers per hour and 70 kilometers per hour and 135 kilometers per hour, which usually placed in the specific geographic situations, by just around 3 percent of the whole Italy network.

Figure3.2

3.2. Microanalyses of the lines

In Italy railway network, each corridor has its own story. As it mentioned above, the rails with the maximum speed of 150 and 140 kilometers per hour are the most common railways in the Italy by around 20 percent of all routs. Lets begin with the 140 kilometers per hour class.

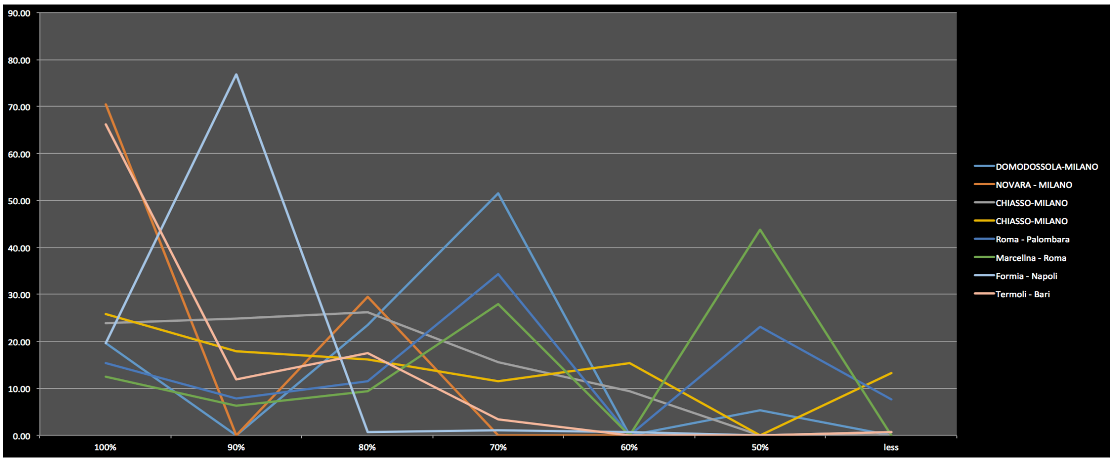

Figure3.3

As we can see in the Figure3.3 usually we have 3 main classes (based on the maximum speed) in this common maximum speed category. Shockingly although we recognizes lines by their maximum speed, mostly the trains moves by just 70 percent of maximum speed and then by just 50 percent of their maximum speed. Just between 12 to 25 percent of the lengths the train moves by its maximum speed, although in some cases exceptionally we can see the maximum speed of the line in the 70 percent of its whole lengths which in the most of the times these lines goes to Milano!

The next astonishing lines are those with 150 kilometers per hour.

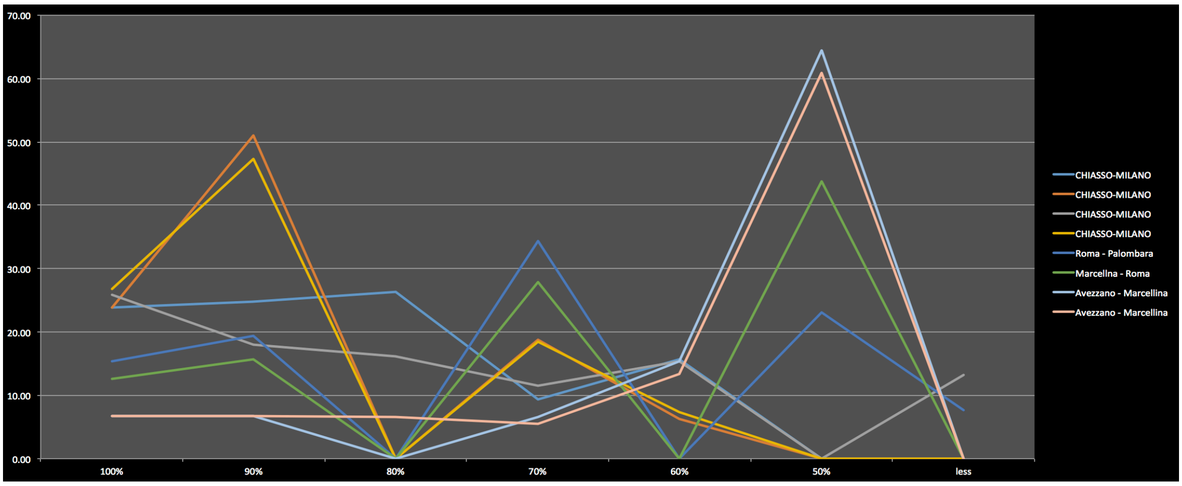

Figure 3.4

As we can see in the figure 3.4, with some negligible changes, we can see the same trend with the respect to the lines by 140 kilometers per hour.

In the 150 kilometers per hour lines, usually the trains will run with half of the maximum speed and then they will run by the 70 percent of the maximum speed and then the 90 percent of the maximum speed. For example lets take a more in depth look at the Avezzano – Marcellina corridor, in this line for about 70 kilometers the train will run by 50 percent of the maximum speed and then run 14 kilometers by just 60 percent of the maximum speed and then just 10 kilometers for each 70, 80, 90, and 100 percent of the maximum speed.

The next crucial corridor is the line by the 160 kilometers per hour maximum speed. As we can see in the Figure 3.5, although like other lines the train will run by the maximum speed in just the period between 15 to 30 of all the whole rout but in this classification almost all the trains will run the proportion of the whole lengths by the 80 percentage of the maximum speed, then the 90 and 100 percentages of the maximum is so common in the whole route, and significantly, some lines which goes to the Milan has different patterns, they run more than half of the whole length by the maximum speed !

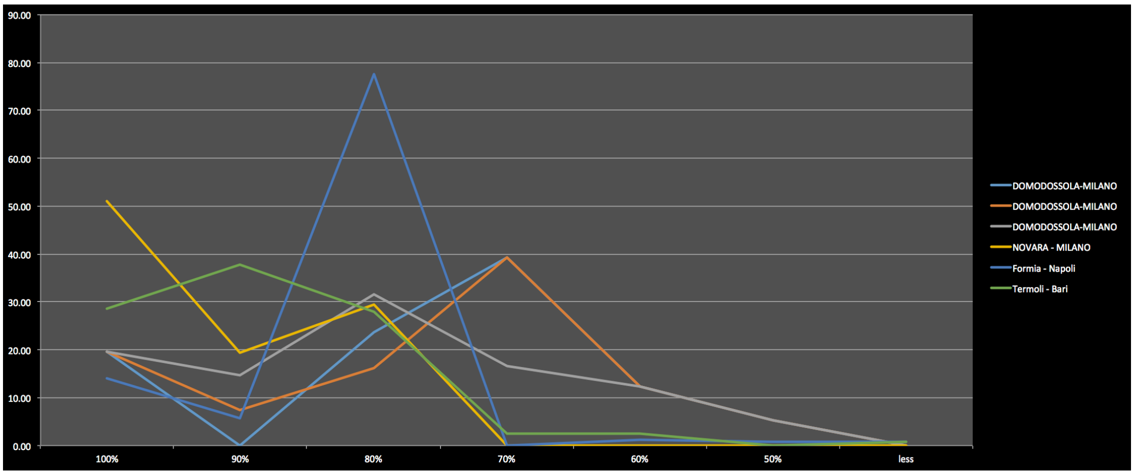

Figure 3.5

Then, as we can see in the figure 3.1, 10 percent of the whole railway coridors in the italy will run by 130 kilometers per hour maximum speed. But in this case we can see the same story in comparison with other significant corridors with higher maximum speed. As we can see in the figure 3.6 , only arround 10 percent of the length will be run by the maximum speed while the speed on the 60 percent of the whole length will be 60 percent or even the half of the maximum speed and the residuals will be 70 percent of the maximum speed (20 percent of the whole length) and then 50 percent of the maximum speed with arround 5 percent of the whole length .

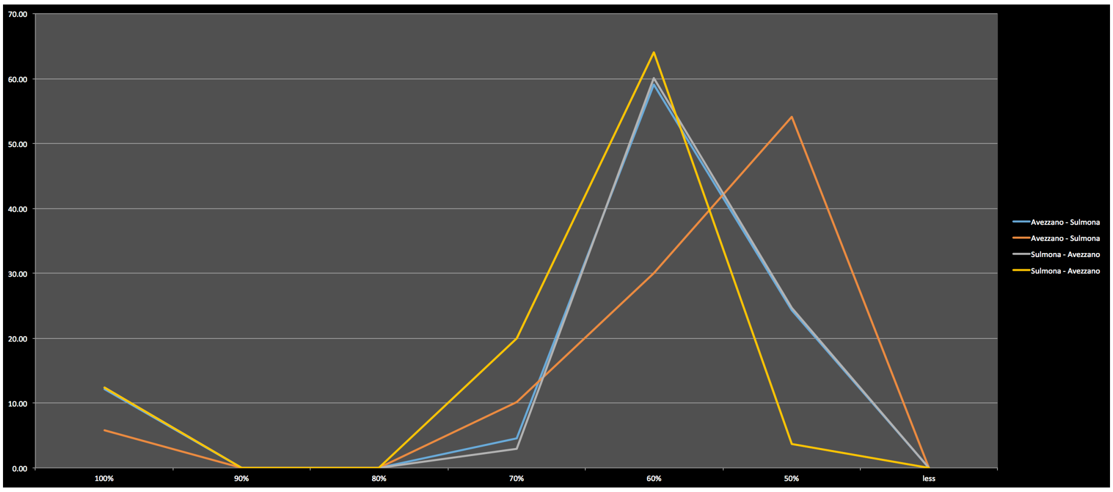

Figure 3.6

The next important corridor is the 180 kilometers per hour maximum speed one. In this length, as we can see in the figure 3.7, there are two different patterns, first the corridors which will goes to Milan. In this corridor, as same as other corridors which goes to Milano, the most proportion of the length will run by the maximum speed and the residuals usually pass by the 80 percent of the maximum speed, on the other hand we can see the corridors which are located on the center or south of the Italy which they will run by 70 percent of the maximum speed.

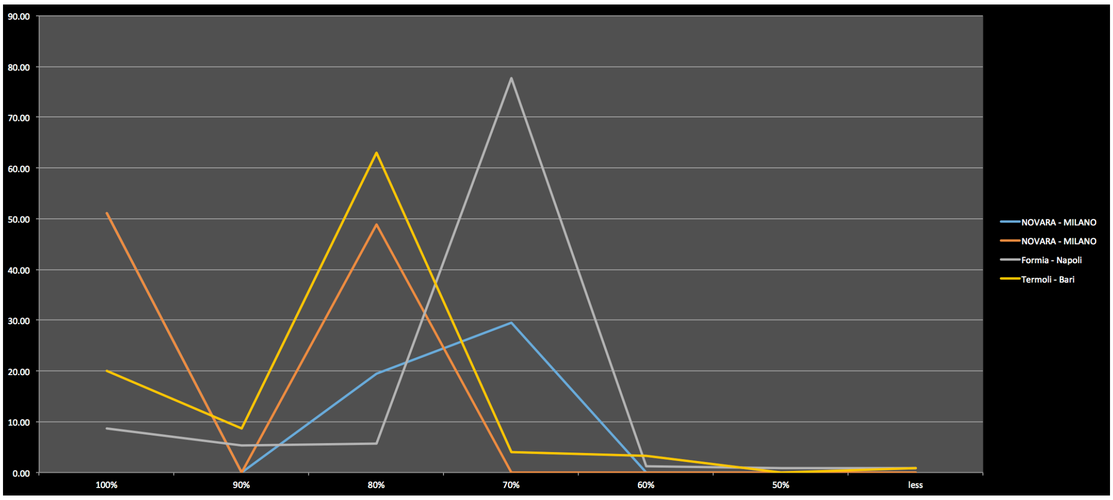

Figure 3.6

The next important categories in the Italy network are those by 125 and 155 kilometers per hour maximum speed. First lets take a more in depth look to the 125 kilometers per hour corridor. As we can see in the figure 3.7, only near 10 percentage of the whole length will pass by maximum speed (125 kilometers per hour), and around 65 percentage of the whole passage will be passed by the 60 percent of the maximum speed. Then between 20 to 30 percent of the whole length will pass by the 50 percent of the maximum speed and then around 5 percent of the whole length will be passed by the 70 percent of the maximum speed.

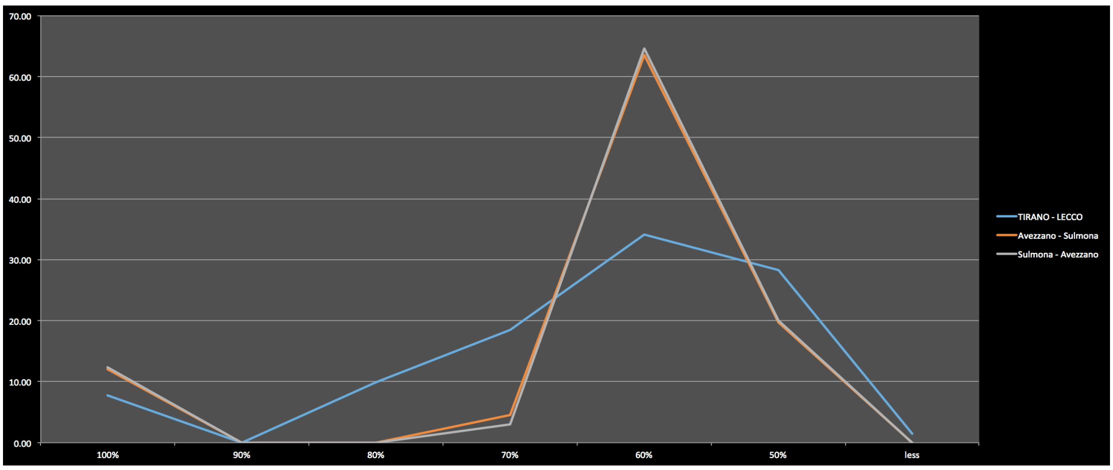

Figure 3.7

On the other hand, we have the corridor by 155 kilometers per hour maximum speed. As it shown in the figure 3.8, we can see the same scenario in this corridor as the same in the whole Italy railway network. The corridors that will their destination or they origin are Milano will run faster than other corridors, in this figure, the 50 percent of the whole length will pass by 90 percent of the maximum speed and the residuals will be pass by 100 and 70 percent of maximum speed while in the other corridors the 30 percent of the whole lengths by the 70 percent of the maximum speed and then by 50 percent of the maximum speed and even in some situation by less than 50 percent of the maximum speed.

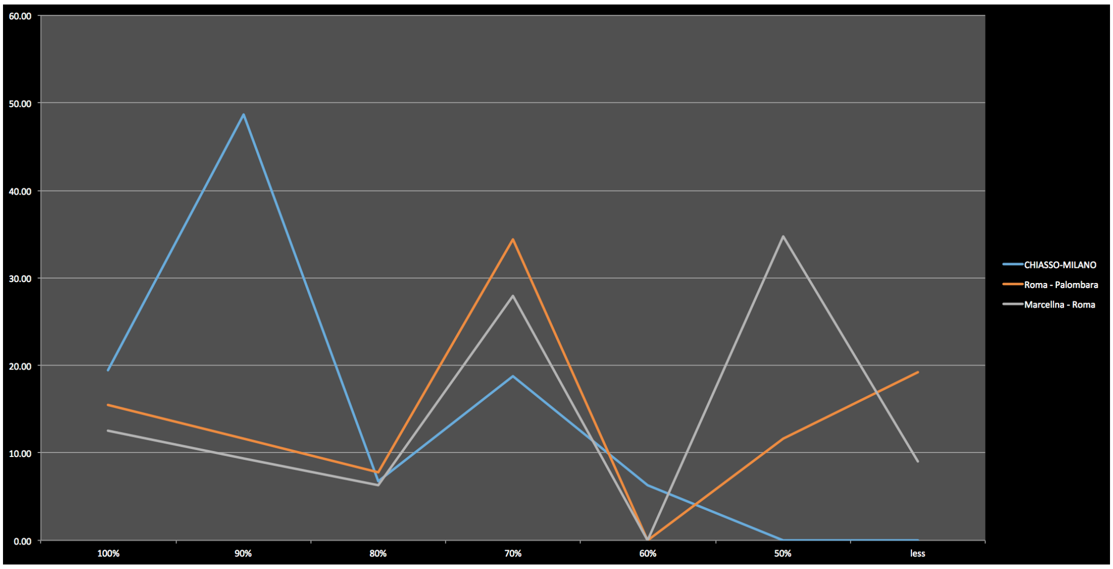

Figure 3.8

As we can see in the figure 3.1, the corridors with 75 and then 135 and 90 and 70 kilometers per hour are last most common maximum speed corridors in the italy. As we can see in the figure 3.9, the corridor with the 75 kilometer per hour maximum speed, the 30 percent of the length will run by 70 percent and then 90 percent of maximum speed while only 10 percent of the length run by the maximum speed and the residual will be pass by 50 percent and less.

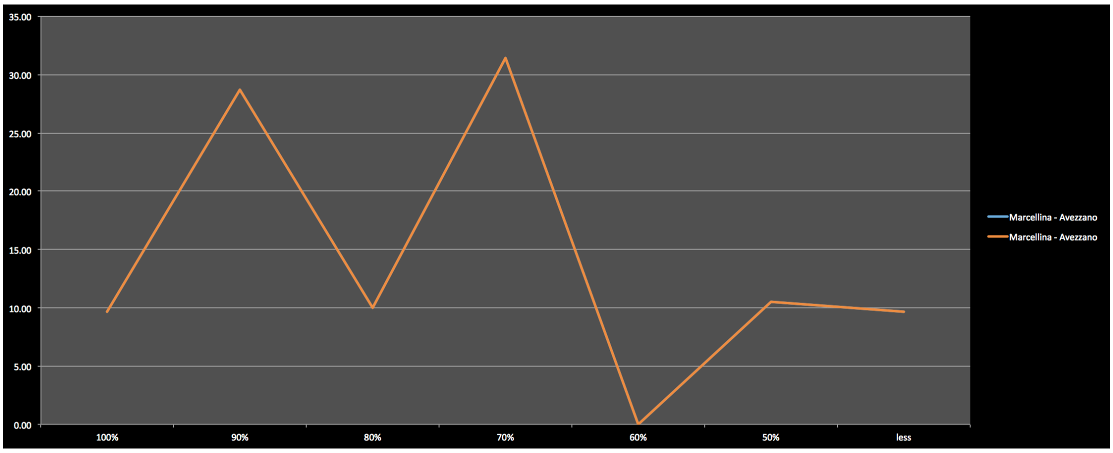

Figure 3.9

Then the corridor with 90 kilometer per hour, as it has been shown in the figure 3.10, they run around the 55 percentage of the whole length by the 80 percent of the maximum speed and then more than 30 percent of the whole length by the maximum speed. And only 10 percentage of the whole lane will be run by 70 percent of the maximum speed.

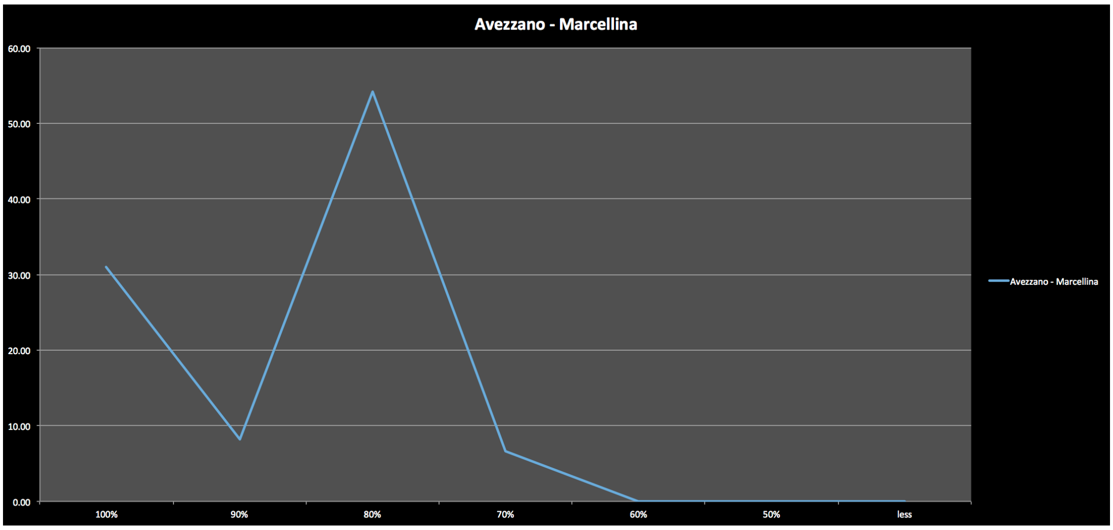

Figure 3.10

The next crucial corridor, as shown in the figure 3.11, is the one with 135 kilometers per hour maximum speed. In this case, only 10 percentage of the whole length will pass by the maximum speed, most of it (more than 60 percent of the whole length) will be run by only 50 percentage of maximum speed and then 30 percentage of the whole passage will be run by 70 percentage of maximum speed.

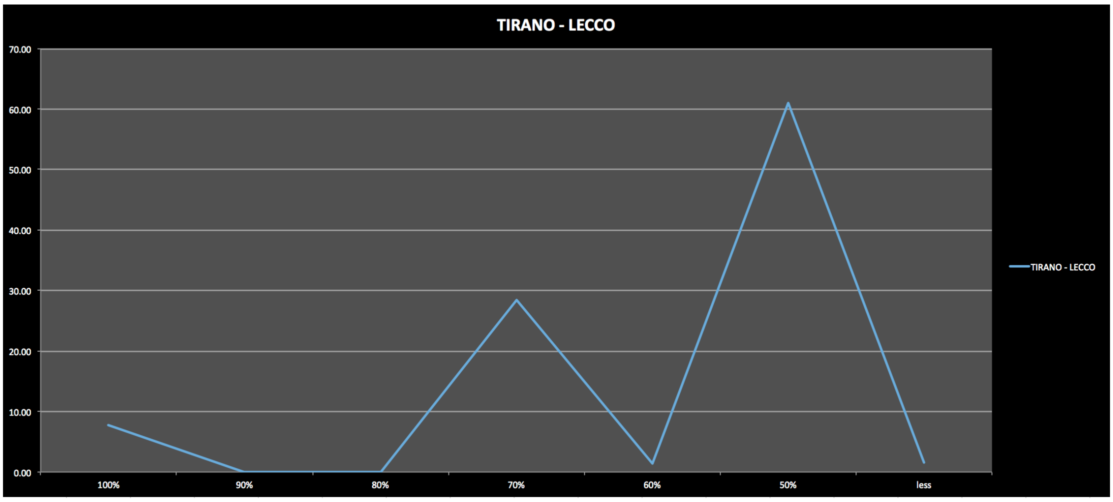

Figure 3.11

The last but not the least, is the 70-kilometer per hour corridor. As it has been shown in the figure 3.12, around 30 percent of the whole length will be run by the 90 and then 70 percent of the maximum speed and then the whole residuals will be run by 100 and then 80 and then 50 and then the less than maximum speed.

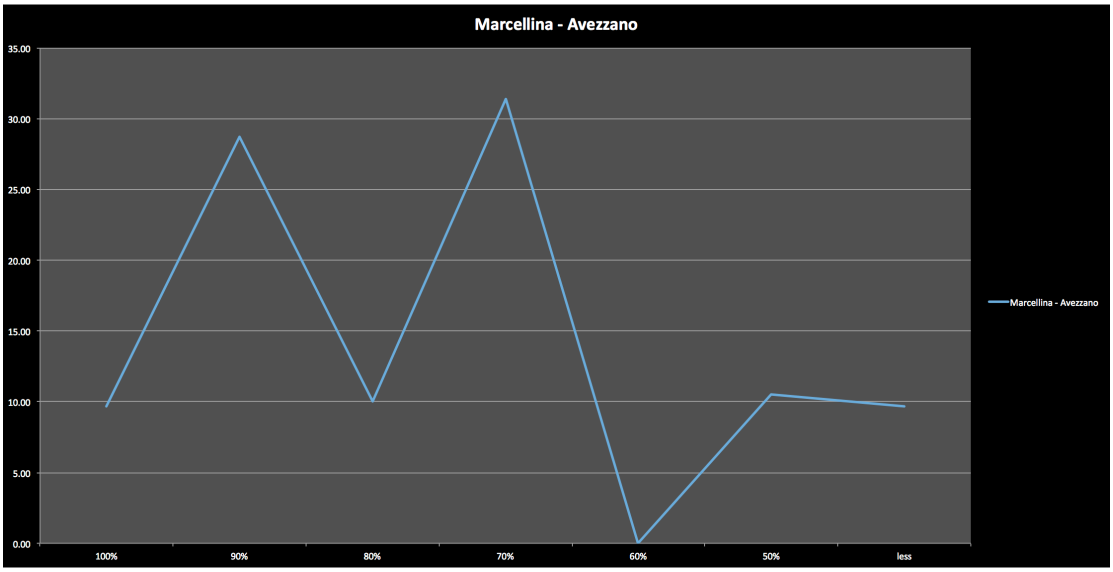

Figure 3.12

Chapter 4

4.1.Benefits of the optimization

The principal benefits are:

- Time savings
- Additional capacity;
- Reduced externalities from other modes
- Generated traffic
- Wider economic benefits.

Each of these elements will be discussed in turn.

4.1.1. Time savings

When it comes to valuation, time savings are generally split into business, commuter and leisure. There is extensive research on the valuation of time savings; the current valuations used in rail schemes in Britain are as shown in table 4.1. The high value for business time is based on the fact that much business travel takes place during working hours and directly reduces labor productivity, although questions have been raised on whether the full business value of time should be applied in this case on two grounds:

—Many long distance business trips start and end outside normal working hours; and

— When travelling by train it is possible to work on the way.

However, research has shown that firms are willing to pay the sort of rate deduced from current valuations even under such circumstances, presumably because of the benefits they perceive in shortening long working days and having staff less tired.

The most recent review of evidence on values of time undertaken for the British government (ITS 2003), and which led to the adoption of the values shown in table 4.1, gave careful consideration to what was likely to happen to the value of time over time. The advice given by the British Department for Transport is that working time values, which are based on the wage rate, should rise in proportion to GDP, whilst non-working time values have an elasticity of 0.8 to GDP. Thus long term growth of values of time is assumed to be in the range of 1.5-2% per annum. Additional capacity is obviously only of value if demand is exceeding the capacity of the existing route.

4.1.2. Additional capacity

But in those circumstances by relieving existing lines of traffic for other types of service, such as suburban passenger or freight. Where the effect is to allow rail to carry traffic, which would otherwise use other modes, the benefits may be quantified as the net user benefits plus net reduction in externalities minus the net cost of the change of mode. There is also clear evidence that running rail infrastructure less close to capacity benefits reliability; it may also lead to less overcrowding on trains. Both of these features are highly valued by rail travellers and especially business travellers. It should be noted that capacity constraints also make the alternative of upgrading existing infrastructure more problematic; for instance, running higher speed tilting trains on infrastructure shared with slower traffic may not be feasible. Typically a substantial proportion, but not all, of the new traffic attracted to rail will be diverted from other modes, mainly car and air. To the extent that infrastructure charging on these modes does not cover the marginal social cost of the traffic concerned, there will be benefits from such diversion. Estimation of these benefits requires valuation of marginal costs of congestion, noise, air pollution, global warming, and external costs of accidents and their comparison with taxes and charges.

Standard Valuations	**(£ Per hour, 2002 market prices)**	**(€ Per hour, 2002 market prices)**
Leisure	4.46	5.04
Commuting	5.04	5.69
Business	39.96	45.15

TABLE 4.1: Value of time saving for rail passengers in the UK

INFRAS/IWW (2000) provides estimates of marginal external cost per passenger km for two European corridors, including accidents and environmental cost but excluding congestion. These are reproduced in table 4.2. On longer distances, the advantage over air diminishes since most of the environmental costs of air transport are incurred during takeoffs and landings.

4.1.3.Reduced externalities from other modes

In the case of air, the absence of fuel tax means that there is normally no charge for environmental externalities, although this is crudely allowed for in some countries (including Britain) by a departure tax. (Value added tax [VAT] at the standard rate should not be seen as an externality charge since it does not influence relative prices, except when charged on some modes and not others; in some cases in Europe VAT is charged on domestic rail and air fares, in some on rail but not air and in others on neither).

External costs (euros/1,000 pass-km)		
	Paris-Vienna	Paris-Brussels
Car	40.2	43.6
Rail	11.7	10.4
Air	28.7	47.5

TABLE 4.2: external costs

4.1.4.Generated traffic

The other key issue for air is charging for slots at congested airports. The allocation of slots by grandfather rights and charging structures, based on average costs of running the airport (or less where there are subsidies), mean that charges may not reflect congestion costs imposed on other planes, the opportunity cost of slots or the costs of expanding capacity. A further may therefore be the release of capacity at airports for use by other, typically longer distance flights. Generated traffic leads directly to benefits to users, which are generally valued at half the benefit to existing users according to the rule of a half. But there has been much debate as to whether these generated trips reflect wider economic benefits that are not captured in a traditional cost benefit analysis. Leisure trips may benefit the destination by bringing in tourist spending; commuter and business trips reflect expansion or relocation of jobs or homes or additional economic activity.

4.1.5.wider economic benefits

The debate on these issues centers on whether these changes really are additional economic activity or whether such activity is simple relocated. In a perfectly competitive economy with no involuntary unemployment, theory tells us that there would be no net benefit. In practice, there are reasons why there may be additional benefits.

Firstly, if the investment relocates jobs to depressed areas, it may reduce involuntary unemployment. The experience of Lille, which has been regenerated by its location between Paris, Brussels and London, is often cited as an example. However, if the depressed areas are at the periphery, this is the opposite of what is desired. Railway may also allow for expanded market areas and the exploitation of economies of scale, reducing the impact of imperfect competition, and encouraging the location of jobs in major urban centers where there are external benefits of agglomeration. Any such impacts are most likely to be found in the case of service industries.

There are additional benefits for the above-mentioned reasons, but that the effects are very variable and difficult to predict. They are likely to be much less important than the direct transport benefits; typically they will also apply to alternative transport infrastructure investments, so that whilst they improve the case for transport investment as a whole.

Another key factor influencing the outcome of an appraisal is the choice of discount rate. Low discount rates favor capital-intensive investments. Practice varies substantially within the European Union. In Britain the current practice is to discount at a pure time preference rate of discount of 3.5%, reducing to 3% after 30 years, but to allow for capital shortages by requiring a benefit/cost ratio of at least 1.5 and preferring projects where it is at least 2. DG Region recommends a 5% social discount rate.

4.2.Empirical examples

The Atkins study took place in a context of rapid growth in rail passenger and freight traffic in recent years, leading to severe overcrowding on both long distance passenger services and London commuter services, and a lack of capacity for further growth in freight. Thus a major objective of the scheme was to relieve existing routes, as well as provide faster more competitive services between the major cities. This rather general remit led to the need to generate and study a wide range of options. Altogether some fourteen options were studied in depth, the main issues being whether to have a single route north from London which might split further north to serve cities up the east and west sides of the country, or to have two separate routes, and how far north to go. The obvious starting point would be a new route from London to the heavily populated West Midlands. The further north the line was extended, the less heavily used the new sections would be, but this effect might be offset by the fact that these extensions attract additional traffic on to the core part of the network. It is a characteristic of Britain geographically that a single line could serve the major cities of London, Birmingham, Leeds, Newcastle, Edinburgh, and Glasgow, whilst a conventional or high-speed branch would serve Manchester.

It was forecast that the new line, if built to its extremities, would attract nearly 50 million passenger trips per year in 2015, although most of these would only use part of the route. This high figure reflects the high population density of Britain, and the large number of origin-destination pairs that the line would serve. Of these around two thirds would be diverted from existing rail routes, and the remainder split almost equally between diversion from other modes and newly generated trips. Most of the forecast diversion occurred from car the forecast of diversion from air was surprisingly low.

The original appraisals were undertaken with a life of 30 years and a discount rate of 6%; the British government has subsequently modified its practice to have a life of 60 years and a discount rate of 3.5%. Despite the simultaneous introduction of a big allowance for optimism bias in the estimates of costs (67% in the case of capital costs plus a 25% program bias), the result is a substantially higher ratio of benefits to costs in subsequent appraisals. Results of the appraisal of two options are shown in table 3.4. Option 1 (minimum investment) is the line from London to the West Mid- lands, which is the obvious first phase of any high-speed rail program in Great Britain, and it has seen to be well justified in its own right. But option 8 (maximum investment), the extension through Manchester on the West Coast route and right through Scotland via the East Coast, with an incremental benefit-cost ratio representing good value for money. It is obviously important, however, to examine the issue of timing and phasing. The study showed that, if feasible, immediate construction of the whole line was the best option.

A number of other factors have added to the case since the original appraisal. Firstly is the failure to upgrade the East Coast Main Line, an investment that was assumed to be part of the base case in the study. Whilst this should certainly still be considered as an option, given the delays and cost over runs with the upgrading of the parallel West Coast route compared to the more satisfactory experience in the construction of the wholly new high speed line to the Channel Tunnel, it is less likely to be favored now. At the same time, the government has announced its intention of introducing nationwide road pricing within the next ten years.

Although net revenue more or less covers operating costs for both options, the capital cost can only be justified by non-financial benefits and released capacity. A breakdown of the composition of costs and benefits for option 1 is given in table 4.3. Some 78% of benefits take the form of time savings and reduced overcrowding with 19% due to increased net revenue and only 3%

	Option 1	**Option 8**
Net revenue	4.9	20.6
Non-financial benefits	22.7	64.4
Released capacity	2.0	4.8
Total benefits	29.6	89.8
Capital costs	8.6	27.7

Net operating costs	5.7	16.3
Total costs	14.4	44.0
NPV	15.3	45.7
B/C	2.07	2.04

Table.4.3. Breakdown of the composition of costs and benefits

Taking the form of reduced road congestion and accidents. The value of the released capacity was not included in this analysis, but adds some 7% to the overall benefits.

On balance it was thought that the non-quantified environmental benefits were slight. It is an interesting question whether more of the user benefits could be captured as revenue by more sophisticated yield management techniques than the simple fare structure model. They might also boost benefits by increasing diversion from air; in the study this was found to be rather small on the assumption that rail fares would on average exceed those by air for traffic between London and Scotland.

In summary, then, this study of Britain found a strong case for high speed rail, based on the high patronage that could be attracted by a single line

TABLE 3.5: Cost benefit analysis results, option 1 (% of Total Benefits or Costs)	
Benefits – Revenue	
HSR Revenue	64%
Classic rail revenue	–45%
Net rail revenue	19%
Benefits – Users	
Journey time/reduced overcrowding	76%

Accidents	2%
Total User Benefits	78%
Benefits – Non-users	
Journey time/veh operating costs	3%
Total Non-User Benefits	3%
Present Value Benefits	100%
Costs	
Capital	69%
HSR operating	41%
Classic operating	–9%
Present Value Costs	100%

Linking most of the major conurbations of Britain, in the context of growing demand leading to severe overcrowding and shortages of capacity on the existing infrastructure.

On the other hand we can see the Spanish experience was carried out between 1987 and 1993.

Regarding the impact of the Madrid-Seville Rail on other transport operators, the main effects, which must be considered, are those on air transport (Iberia and airports), on conventional railways, and on road transport. For air transport between Madrid and Seville, demand downshift of 50%, diminishing the load factor and flight frequency. The Seville airport suffered a reduction of 25% in its use, as Madrid-Seville represented 50% of airport traffic. Given the investments, which were carried out in the airport of Seville to accommodate the peak of demand induced by the exhibition EXPO-92, and more recent investment at Barajas airport in Madrid, it is unlikely that this diversion will significantly reduce congestion although it will certainly reduce pollution from air transport.

For conventional railway transport, RENFE was also affected by the introduction of the new product. The Madrid-Seville, Madrid-Malaga and Madrid-Cordoba links were amongst the main twenty lines of the company. Conventional trains have lost the major part of their traffic in this corridor; therefore an efficient solution might be to consider the closure of the conventional infrastructure. However, the impossibility of carrying goods on the new infrastructure makes this scenario unfeasible.

The long distance services and bus transport are hardly substitutes at current prices. In commuter services, and taking into account the low prices introduced by RENFE, bus operators are certainly affected.

Benefits of diverted traffic are not limited to time savings (22.5% of total benefits). The reduction in operating cost in other transport modes is also important. The shift to Rails of journeys by car forms 8.9% of the total benefits; cost savings from railway and air transport yield benefits of 9.4 and 9.6% respectively. The savings in bus operator costs are not significant. Benefits from the reduction in congestion and accidents are only 4.6% of the benefits.

Construction costs in Spain are typically much lower than in Britain due to reduced population density. But the key reason for the poor performance of the Madrid-Seville line is the low traffic volume, which has only recently reached 5 million passengers p.a. more than 10 years after opening.

Chapter 5

5.1 The Guide Tables

5.1.1. The Cost analysis

As we saw in the experimental experiences, each option has its own dark and bright sides. When we want to evaluate an engineering option we should have a clear understandings of the cost and benefits of the options.

Usually the simple part of the making cost benefit analysis is to calculation the cost. In this part we examines the finished project and then by using the methods in the engineering economy books calculate the present value for doing the same project now.

In the cost sector, the most crucial part is construction (optimization) cost; this cost usually takes 64 percent of the whole cost, the second main cost is the train purchase, usually for every 125 kilometers long we consider the cost of purchasing one train, As we are optimizing the present lines, we did not consider the cost for buying the new trains (although the final aim of this research is to reach the optimize level which we could put one extra train on the corridor), then the cost for the maintenance, this cost is 11 percent of the whole cost in the project life. Although in some countries such as Iran the maintenance cost is much more higher than the standard value (some of it because the political problems and economic sanctions), and finally we have the operation cost which is the less consuming resources with just 9 percentage of the whole budget.

As we are going to propose new methods for the optimization and based on our data we cannot have the exact value of the whole budget, so based on mathematical methods we defined the percentage of each cost based on the construction (optimization cost). In this new method the maintenance cost is 17 percentage of the construction cost and the operation is 15 percentage of the construction cost.

5.1.2. The Benefits analysis

On the other hands, we should consider the benefits of the projects. As mentioned in the forth chapter, the most important output of the optimization is time savings. Our best efforts is to save time as much as possible, but the main question is, how to convert the time concept to money concept for doing cost benefit analysis. For solving this question we used, table 4.1 in the fourth chapter.

The next step was Estimation of benefits of marginal costs of congestion, noise, air pollution, global warming, and external costs of accidents.

Unfortunately, in most of the cases, there is not specific evaluation for calculating mentioned effects as same as the value of time, and we have to assess the above effects in any specific project. After evaluating different projects in different countries we divided the effects in the seven main categories:

- Congestion
- Accident
- Residual value
- The positive impacts on conventional trains
- The effects on air transport
- The effects on road transport (transportation by car and bus)
- The environmental effects (air and noise pollution)

Based on our research in similar projects we recommends formulation for the benefits for the air transportation after optimization, this formulation (As we can see in Figure 5-1) represent the percentage of the improvement in the air transportation.

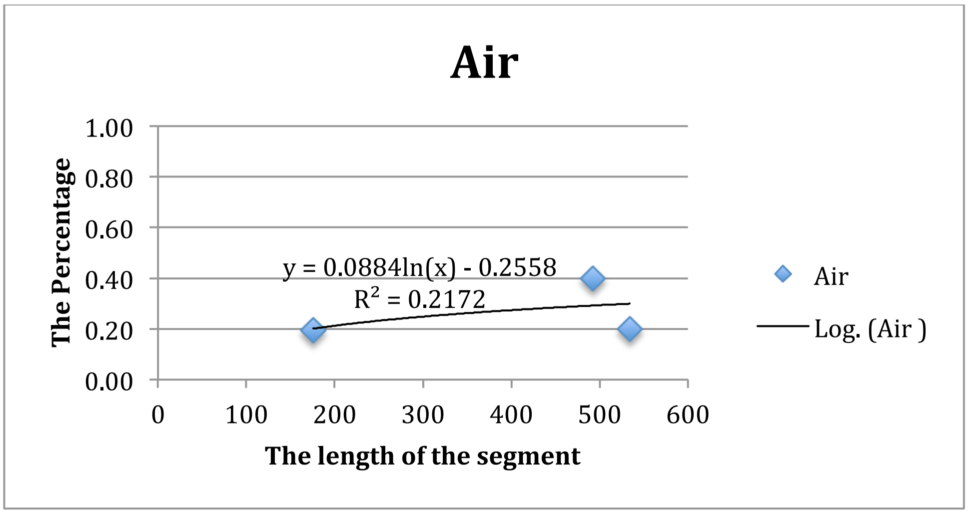

Figure 5-1.

After air transport, we examined the road transport, by merging the bus transportation and car transportation.

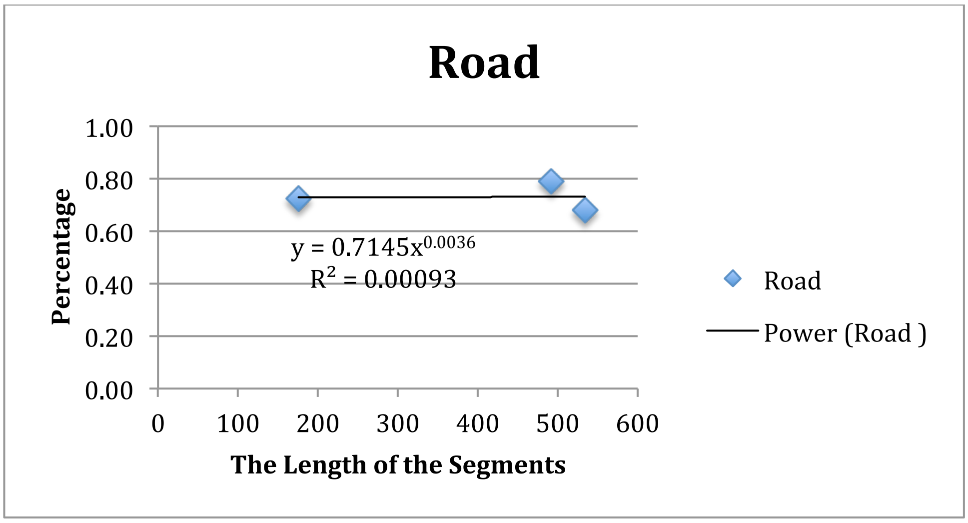

Figure 5-2.

As we can see in figure 5-2, the optimizing has positive effects on the road transport modes.

The next important category is the impacts of optimization on the rails. As the optimization will offer faster service, the customers will prefer rails much more than before, figure 5-3 shows the analysed data and formulation.

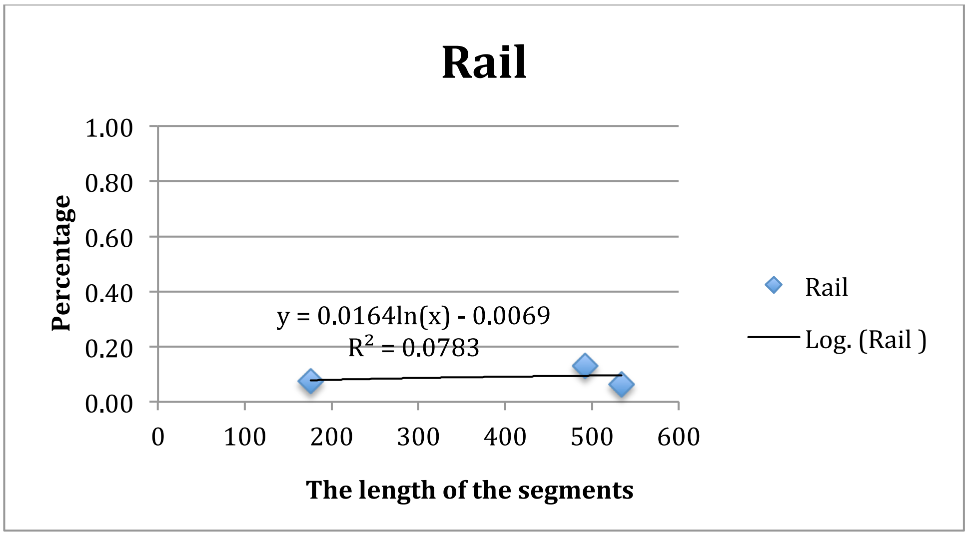

Figure 5-3

As we can see in figure 5-3, the optimizing has positive effects on the rail transport modes.

And finally pollution, air and sound pollution are the main significant pollutions, which in the decision making process plays a key roll. After analysing different projects in al over the world, as we can see in the figure 5-4, we obtained the proper relation between the length of the segment, which has been optimized, and the percentage of improvement (reduction of the pollution).

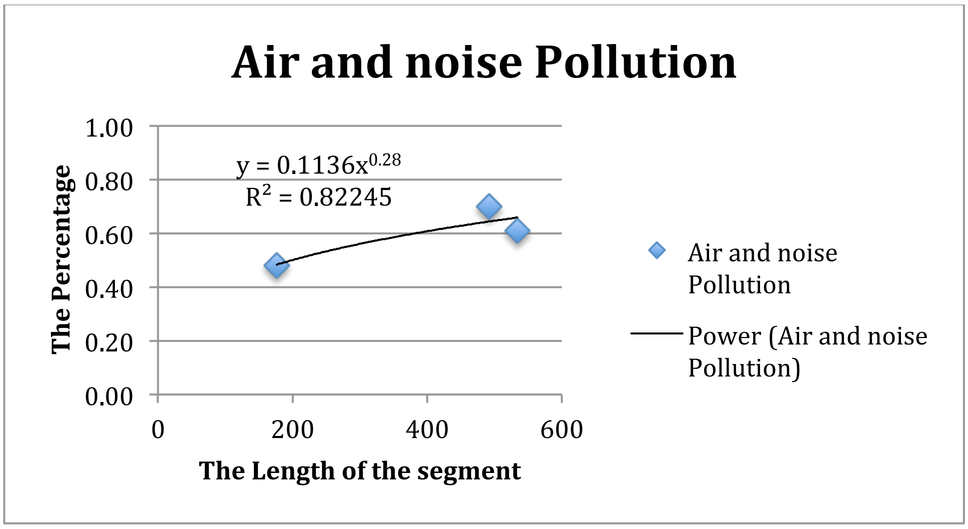

Figure 5-4

And finally based on below formulations we made our ranking tables:

Improvement in air transportation

$$Y = 0.0884\ln(x) - 0.2558 \qquad \text{Equation 5-1}$$

Improvement in Road

$$Y = 0.7145x^{0.0036} \qquad \text{Equation 5-2}$$

Improvement in Rail

$$Y = 0.0164\ln(x) - 0.0069 \qquad \text{Equation 5-3}$$

Reduction of air and sound pollution

$$Y = 0.1136x^{0.28} \qquad \text{Equation 5-3}$$

- 5.1.3 Tables

All the tables are represented in the Appendix.1.

5.2.Case Study

Based on the mentioned theory, we choose a corridor as an example for implementation of proposed theory:
Project characteristics:

Marcellina to Avezzano Corridor

This rout is 80.1 kilometers and we have three classes:
Class A, with maximum speed 140 kilometers per hour
Class B, with maximum speed 150 kilometers per hour
Class C, with maximum speed 150 kilometers per hour

And we can see the variation of speed in the Marcellina to Avezzano corridor in graph 5-5 and the percentage of the speed and lengths in the table 5-1:

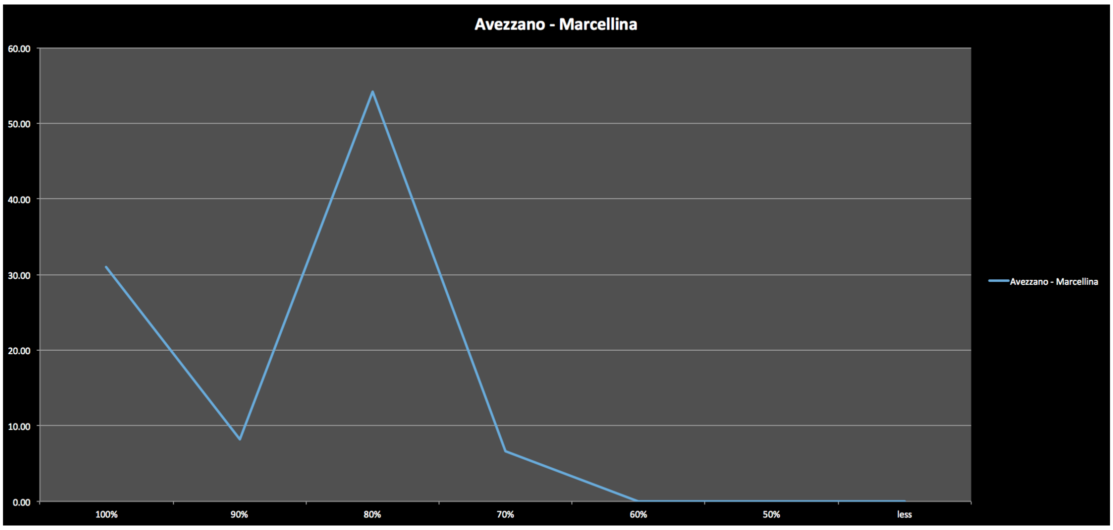

Figure 5-5. The variation of the speed on the Marcellina to Avezzano Corridor

As we can see in the Figure5.5, there is a big variation of speed on the line, and in just around 10 percent of the rail we can see the maximum speed, while we have around 30 percent of the all length 90% of maximum speed and around 32 percent, 70% maximum speed. Therefore we choose the second critical segment with around 32 percent and around 20 kilometers; on the other hand we consider the last category (with less than 70 kilometers with 6 kilometers). So we now have two options for our investment. The small railroad length 5.99 kilometers with 9.68 percentage of the whole length, and the 19.48 kilometers with 31.42 percentage of the whole length.

Speed Percentage	V	X	X/SUM	X percentage
100%	75	5.99	0.096612903	9.66
90%	67.5	17.8	0.287096774	28.71
80%	60	6.21	0.10016129	10.02
70%	52.5	19.48	0.314193548	31.42
60%	45	0	0	0.00
50%	37.5	6.52	0.10516129	10.52
Less	Less than 70	6	0.096774194	9.68

Table 5-1. The percentage of the speed and lengths

Length (Km)	6	19.48
Costs		
Infrastructure	12,455,869.54	40440056.46
Trains	0.00	0
Maintenance	2,796,394.52	9078960.88
Operation	2,381,426.05	7731696.582
	17,633,690.12	57,250,713.92
Benefits		
Congestion	1,175,822.78	3817504.633
Accidents	1,005,918.69	3265882.668
Air and sound pollution	278,761.57	905045.895
Residual value	6,289,760.50	20420755.74
Conventional train	9,226,937.96	30522628.07
Car (Road)	1,040,681.70	3390369.557
Air transport	3,145,733.28	11391103.28
	22,163,616.47	73,713,289.84
B/C	1.26	1.287552326

Table 5.2. The comparison of both scenarios

As we can see in the table 5.2, in the first look if we investing in the second scenario it is more economical but we did not considered two main factors yet.

First, the value of money in the time, as the transport project life cycle is 30 years and the rate of money for such projects is 4 percentages we will have:

$57,250,713.92 \times (1+0.04)^{30} = 185,686,822.97$

$17,633,690.12 \times (1+0.04)^{30} = 57,193,066.62$

$73,713,289.84 \times (1+0.06)^{30} = 566,566,743.48$

$22,163,616.47 \times (1+0.06)^{30} = 170,351,479.84$

In this new situation we have the cost benefit ratio for the first option 2.978533761, while for the second option we have 3.051195203. Still the second option is the better one but there is another one main factor: the percentage of the whole length.

For the first scenario we need 17,633,690.12 euro to optimize 9.68 percentage of the whole length while for the optimization of the 31.42 percentage of the whole length we need 57,250,713.92. While this price is slightly more than the standard price by 57,234,386.41.

It should be mentioned that when we are choosing our segment (In the situation which we have two similar option we should choose that one which has the lower speed on the segments)

Therefor, although in the first look the second scenario was better, but after considering all circumstances the first scenario was the better choice. It should be mention that in this modern era, thanks to dramatic improvement of science and new and updated formulas, we cannot find any best solution any more. We can just seeking for the Better solution.

The most important thing about these tables, we used this tables based on our valid money. For example if we have enough money for optimizing 60 kilometers we will not make comparison between 6 or 60 kilometers, we will make comparison in the range of 55 to 60 kilometers or for choosing 3 project with the length around 20 kilometers among the whole Italy network.

Chapter 6

6.1.Sensivity Analysis

6.1.1.Overview

A mathematical model (for example a climate model, an economic model, or a finite element model in engineering etc.) can be highly complex, and as a result its relationships between inputs and outputs may be poorly understood. In such cases, the model can be viewed as a black box, i.e. the output is an "opaque" function of its inputs.

Quite often, some or all of the model inputs are subject to sources of uncertainty, including errors of measurement, absence of information and poor or partial understanding of the driving forces and mechanisms. This uncertainty imposes a limit on our confidence in the response or output of the model. Further, models may have to cope with the natural intrinsic variability of the system, such as the occurrence of stochastic events.

Good modeling practice requires that the modeler provide an evaluation of the confidence in the model. This requires, first, a quantification of the uncertainty in any model results; and second, an evaluation of how much each input is contributing to the output uncertainty. Sensitivity analysis addresses the second of these issues (although uncertainty analysis is usually a necessary precursor), performing the role of ordering by importance the strength and relevance of the inputs in determining the variation in the output.

In models involving many input variables, sensitivity analysis is an essential ingredient of model building and quality assurance. National and international agencies involved in impact assessment studies have included sections devoted to sensitivity analysis in their guidelines. Examples are the European Commission (see e.g. the guidelines for impact assessment), the White House Office of Management and Budget, the Intergovernmental Panel on Climate Change and US Environmental Protection Agency's modeling guidelines.

6.1.2.Settings and constraints

The choice of method of sensitivity analysis is typically dictated by a number of problem constraints or settings. Some of the most common are:

Computational expense. Sensitivity analysis is almost always performed by running the model a (possibly large) number of times, i.e. a sampling-based approach. This can be a significant problem when, a single run of the model takes a significant amount of time (minutes, hours or longer). This is not unusual with very complex models.

The model has a large number of uncertain inputs. Sensitivity analysis is essentially the exploration of the multidimensional input space, which grows exponentially in size with the number of inputs.

Computational expense is a problem in many practical sensitivity analyses. Some methods of reducing computational expense include the use of emulators (for large models), and screening methods (for reducing the dimensionality of the problem).

Another method is to use an event-based sensitivity analysis method for variable selection for time-constrained applications. This is an input variable selection (IVS) method that assembles together information about the trace of the changes in system inputs and outputs using sensitivity analysis to produce an input/output trigger/event matrix that is designed to map the relationships between input data as causes that trigger events and the output data that describes the actual events. The cause-effect relationship between the causes of state change i.e. input variables and the effect system output parameters determine which set of inputs has a genuine impact on a given output. The method has a clear advantage over analytical and computational IVS method since it tries to understand and interpret system state change in the shortest possible time with minimum computational overhead.

Nonlinearity: Some sensitivity analysis approaches, such as those based on linear regression, can inaccurately measure sensitivity when the model response is nonlinear with respect to its inputs. In such cases, variance-based measures are more appropriate.

Model interactions: Interactions occur when the perturbation of two or more inputs simultaneously causes variation in the output greater than that of varying each of the inputs alone. Such interactions are present in any model that is non-additive, but will be neglected by methods such as scatterplots and one-at-a-time perturbations. The effect of interactions can be measured by the total-order sensitivity index.

Given data: While in many cases the practitioner has access to the model, in some instances a sensitivity analysis must be performed with "given data", i.e. where the sample points (the values of the model inputs for each run) cannot be chosen by the analyst. This occur when a sensitivity analysis has to be performed retrospectively, perhaps using data from an optimization or uncertainty analysis, or when data comes from a discrete source.

6.1.3.Application

In this project we used the sensitivity analysis to measure the accuracy of our data and proposed formulation.
Therefor we used our data on the 5th kilometer of a hypothetic corridor. In this scenario we put the costs and the benefits of optimization of that segments and for doing the calculation we used -10% and -20% and then +10% and +20% of the cost and benefits value to consider the best (the highest value of the benefits and lowest value of costs) and the worst (the lowest value of the benefits and the highest value of the cost) scenarios.

	Ratio	Cost				
	2.222336992	7625742.208	8578959.984	9532177.76	10485395.54	11438613.31
	16946969	2.222336992	1.975410659	1.777869593	1.616245085	1.481557994
	19065340.12	2.500129116	2.222336992	2.000103293	1.81827572	1.666752744
Benefits	21183711.25	2.77792124	2.469263324	2.222336992	2.020306356	1.851947493
	23302082.37	3.055713364	2.716189657	2.444570691	2.222336992	2.037142242
	25420453.5	3.333505488	2.963115989	2.66680439	2.424367627	2.222336992

Table 6-1 the sensitivity analysis

In this part we used the sensitivity analysis to have a clear understanding for the entire situation. The best scenario is when the benefits are in their highest value (+20 percent) while the Cost experiencing its lowest value (-20 percent), which the benefit cost ratio is 3.3335, from the economic decision making point of view is the perfect decision.

On the other hand we would have the situation, which our cost is in its highest value (+20 percent), while the benefits are extremely low (-20 percent). In this situation although the ratio is not comparable with the best scenario, but still making the optimization decision from engineering and economical point of view is still reasonable.

6.2. Conclusion

From 1863 which is the starting point of the railway history, many railroads has been built in many different countries, but nowadays because of the introduction of the new technologies which one of its byproducts is higher speed trains, we have been faced by complex situation, ‘modern train–old infrastructure’. As we saw in this thesis, updating lines is a long-term issue, and although the milestone of this problem in Italy backs to 1975, but this issue is still an open discussion issue. In this thesis we tried to propos a solution for this problem.

The philosophy behind this thesis is:

“ If I have a limited amount of money, and I have a networks of lines, where should I invest my money? (Which segments would be my choice for optimization?!)”

For answering this question first we analyzed most of the Italian railway corridors and choose 41 corridors. Then we gathered data from the variation of speed with the respect to the length on the trains in each one of those corridors.

Then we identify the factors, which influence our decision to choosing the most critical segment. First we focused on the cost (which is the main first step in any decision making process). We calculate the Construction (optimization) cost and the cost of the maintenance and the cost for the operation. Although we calculate the cost of purchasing a train per kilometers but we did not used it because although we could make a long distance optimization but the variation of speed during the line was so high, even after optimization, and we could not consider one extra train on the line and we just could use the advantages of the optimization on the present line with its present trains and just using the time saving of the current situation.

Then we focused on the benefits of the optimization that was really complicated and time-consuming method. In this step we should evaluate the impacts of our decision on the other systems. The first important issue was time saving. After optimization we can save time, but really how we can compare the millions cost of construction the new infrastructures by minutes. For solving that problem we used the table 4.1. Then we calculate the optimization effects on accidents, road transport, air transport and even the present profitability of the current railway system.

After that, as in civil engineering projects the construction are time taking, for example when we consider 40 years of life cycle, 5 years is for construction and 35 years for operation, we used the proposed methods and formulation in the engineering economic books to adapt the investing money by time and We used 4% discount rate (based on: Guide to Cost-Benefit Analysis of Investment Projects)

Then all the needed ratios for taking decisions were presented in the Appendix 1. And then for checking the effectiveness of the tables we did a case study and presenting the results in the chapter5. And finally for the checking the stability of the results and the formulation we did the sensitivity analysis and the output data showed that this tables are reliable even in the harsh situation.

Appendix 1. Tables

Length (Km)	1	2	3	4	5
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.218069918	1.233737567	1.243066585	1.249751691	1.254972289
	2.15698933	2.184734002	2.201254066	2.213092224	2.222336992
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	69,476.55	62,482.43	58,873.21	56,506.58	54,774.41
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,493,628.01	1,510,724.96	1,520,726.04	1,527,821.92	1,533,325.91
Road	172,539.13	172,890.32	173,095.76	173,241.52	173,354.57
Air transport	432,283.89	467,876.28	488,696.49	503,468.67	514,926.86
	3,579,844.58	3,625,890.99	3,653,308.49	3,672,955.67	3,688,298.74
	20,560,805.73	20,825,272.87	20,982,745.05	21,095,588.48	21,183,711.25

Length (Km)	6	7	8	9	10
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.259259504	1.262898869	1.266061849	1.268859581	1.271368256
	2.229928901	2.236373582	2.241974668	2.246928962	2.251371388
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	53,422.82	52,322.92	51,400.75	50,610.23	49,920.77
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,537,822.99	1,541,625.23	1,544,918.87	1,547,824.07	1,550,422.86
Road	173,446.95	173,525.05	173,592.71	173,652.38	173,705.77
Air transport	524,288.88	532,204.36	539,061.05	545,109.09	550,519.24
	3,700,898.64	3,711,594.55	3,720,890.38	3,729,112.77	3,736,485.64
	21,256,078.68	21,317,510.52	21,370,901.07	21,418,126.28	21,460,472.27

Length (Km)	11	12	13	14	15
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.273642408	1.275722425	1.277639061	1.279416278	1.281073112
	2.255398515	2.259081863	2.262475891	2.265623031	2.268556996
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	49,311.13	48,765.97	48,273.89	47,826.19	47,416.12
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,552,773.75	1,554,919.95	1,556,894.26	1,558,722.18	1,560,423.94
Road	173,754.06	173,798.14	173,838.70	173,876.25	173,911.20
Air transport	555,413.32	559,881.27	563,991.38	567,796.74	571,339.46
	3,743,169.25	3,749,282.32	3,754,915.21	3,760,138.36	3,765,007.71
	21,498,859.56	21,533,969.89	21,566,322.37	21,596,321.47	21,624,288.54

Length (Km)	16	17	18	19	20
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.28262494	1.284084362	1.285461833	1.286766123	1.288004662
	2.271305013	2.273889395	2.276328655	2.278638324	2.280831562
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	47,038.29	46,688.38	46,362.86	46,058.80	45,773.78
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,562,015.83	1,563,511.17	1,564,921.03	1,566,254.63	1,567,519.82
Road	173,943.90	173,974.62	174,003.58	174,030.97	174,056.96
Air transport	574,653.44	577,766.45	580,701.48	583,477.77	586,111.63
	3,769,568.45	3,773,857.62	3,777,905.93	3,781,739.17	3,785,379.18
	21,650,483.13	21,675,117.92	21,698,369.38	21,720,385.56	21,741,291.89

Length (Km)	16	17	18	19	20
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.28262494	1.284084362	1.285461833	1.286766123	1.288004662
	2.271305013	2.273889395	2.276328655	2.278638324	2.280831562
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	47,038.29	46,688.38	46,362.86	46,058.80	45,773.78
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,562,015.83	1,563,511.17	1,564,921.03	1,566,254.63	1,567,519.82
Road	173,943.90	173,974.62	174,003.58	174,030.97	174,056.96
Air transport	574,653.44	577,766.45	580,701.48	583,477.77	586,111.63
	3,769,568.45	3,773,857.62	3,777,905.93	3,781,739.17	3,785,379.18
	21,650,483.13	21,675,117.92	21,698,369.38	21,720,385.56	21,741,291.89

Length (Km)	26	27	28	29	30
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.294357052	1.29527314	1.296156446	1.297009248	1.297833595
	2.292080536	2.293702769	2.295266949	2.296777113	2.298236887
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	44,366.66	44,171.06	43,984.15	43,805.26	43,633.78
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,573,991.21	1,574,922.10	1,575,819.14	1,576,684.69	1,577,520.89
Road	174,189.89	174,209.01	174,227.44	174,245.22	174,262.39
Air transport	599,583.76	601,521.69	603,389.13	605,191.03	606,931.84
	3,804,048.52	3,806,740.86	3,809,336.85	3,811,843.19	3,814,265.90
	21,848,519.11	21,863,982.52	21,878,892.57	21,893,287.72	21,907,202.54

Length (Km)	31	32	33	34	35
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.298631334	1.29940414	1.300153533	1.300880896	1.301587497
	2.299649544	2.301018049	2.302345092	2.303633126	2.304884392
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	43,469.17	43,310.96	43,158.69	43,011.99	42,870.49
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,578,329.68	1,579,112.78	1,579,871.79	1,580,608.13	1,581,323.13
Road	174,279.01	174,295.09	174,310.68	174,325.81	174,340.50
Air transport	608,615.57	610,245.83	611,825.92	613,358.84	614,847.32
	3,816,610.42	3,818,881.65	3,821,084.08	3,823,221.76	3,825,298.43
	21,920,668.24	21,933,713.07	21,946,362.68	21,958,640.45	21,970,567.74

Length (Km)	36	37	38	39	40
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.302274493	1.302942949	1.303593845	1.304228085	1.304846504
	2.306100942	2.307284661	2.308437284	2.309560412	2.310655526
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	42,733.86	42,601.81	42,474.07	42,350.39	42,230.54
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,582,017.98	1,582,693.80	1,583,351.59	1,583,992.29	1,584,616.77
Road	174,354.77	174,368.65	174,382.16	174,395.32	174,408.15
Air transport	616,293.86	617,700.77	619,070.16	620,403.97	621,704.02
	3,827,317.47	3,829,282.03	3,831,194.98	3,833,058.98	3,834,876.48
	21,982,164.11	21,993,447.53	22,004,434.54	22,015,140.40	22,025,579.21

Length (Km)	41	42	43	44	45
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.305449878	1.306038924	1.306614311	1.307176661	1.307726555
	2.311723995	2.312767093	2.313786002	2.314781827	2.315755594
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	42,114.32	42,001.52	41,891.96	41,785.49	41,681.95
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,585,225.83	1,585,820.22	1,586,400.61	1,586,967.66	1,587,521.97
Road	174,420.66	174,432.87	174,444.79	174,456.44	174,467.83
Air transport	622,971.96	624,209.34	625,417.61	626,598.10	627,752.05
	3,836,649.76	3,838,380.94	3,840,071.97	3,841,724.69	3,843,340.80
	22,035,764.05	22,045,707.04	22,055,419.47	22,064,911.85	22,074,193.97

Length (Km)	46	47	48	49	50
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.308264536	1.308791112	1.309306759	1.309811923	1.310307025
	2.316708264	2.317640738	2.318553859	2.319448417	2.320325156
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	41,581.20	41,483.09	41,387.52	41,294.36	41,203.50
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,588,064.10	1,588,594.56	1,589,113.86	1,589,622.45	1,590,120.76
Road	174,478.96	174,489.86	174,500.53	174,510.97	174,521.21
Air transport	628,880.65	629,984.97	631,066.04	632,124.82	633,162.21
	3,844,921.90	3,846,469.48	3,847,984.94	3,849,469.59	3,850,924.67
	22,083,274.99	22,092,163.50	22,100,867.53	22,109,394.62	22,117,751.85

Length (Km)	51	52	53	54	55
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.31079246	1.311268599	1.311735795	1.312194378	1.312644662
	2.321184776	2.322027936	2.322855258	2.323667328	2.324464702
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	41,114.84	41,028.29	40,943.76	40,861.17	40,780.43
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,590,609.21	1,591,088.17	1,591,558.01	1,592,019.06	1,592,471.65
Road	174,531.24	174,541.08	174,550.73	174,560.20	174,569.50
Air transport	634,179.05	635,176.15	636,154.25	637,114.08	638,056.29
	3,852,351.34	3,853,750.69	3,855,123.75	3,856,471.50	3,857,794.86
	22,125,945.90	22,133,983.05	22,141,869.23	22,149,610.03	22,157,210.74

Length (Km)	56	57	58	59	60
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.313086943	1.313521503	1.313948607	1.314368509	1.314781448
	2.325247905	2.326017435	2.326773762	2.327517335	2.328248579
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	40,701.47	40,624.22	40,548.62	40,474.60	40,402.11
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,592,916.09	1,593,352.66	1,593,781.64	1,594,203.29	1,594,617.85
Road	174,578.63	174,587.60	174,596.41	174,605.07	174,613.59
Air transport	638,981.52	639,890.37	640,783.42	641,661.20	642,524.23
	3,859,094.70	3,860,371.85	3,861,627.09	3,862,861.16	3,864,074.77
	22,164,676.37	22,172,011.66	22,179,221.11	22,186,308.98	22,193,279.32

Length (Km)	61	62	63	64	65
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.315187654	1.315587342	1.31598072	1.316367985	1.316749326
	2.328967897	2.329675676	2.33037228	2.331058059	2.331733346
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	40,331.08	40,261.47	40,193.22	40,126.29	40,060.63
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,595,025.56	1,595,426.63	1,595,821.29	1,596,209.74	1,596,592.16
Road	174,621.96	174,630.20	174,638.31	174,646.29	174,654.14
Air transport	643,372.99	644,207.95	645,029.55	645,838.22	646,634.34
	3,865,268.58	3,866,443.25	3,867,599.37	3,868,737.52	3,869,858.26
	22,200,136.00	22,206,882.66	22,213,522.82	22,220,059.79	22,226,496.75

Length (Km)	66	67	68	69	70
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.317124921	1.317494941	1.317859552	1.318218909	1.318573162
	2.332398459	2.333053701	2.333699363	2.334335721	2.334963042
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	39,996.19	39,932.95	39,870.85	39,809.86	39,749.95
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,596,968.74	1,597,339.66	1,597,705.09	1,598,065.17	1,598,420.08
Road	174,661.88	174,669.50	174,677.00	174,684.40	174,691.69
Air transport	647,418.31	648,190.49	648,951.23	649,700.86	650,439.71
	3,870,962.11	3,872,049.58	3,873,121.16	3,874,177.29	3,875,218.42
	22,232,836.72	22,239,082.61	22,245,237.17	22,251,303.05	22,257,282.78

Length (Km)	71	72	73	74	75
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.318922455	1.319266926	1.319606707	1.319941924	1.320272698
	2.335581579	2.336191577	2.33679327	2.33738688	2.337972624
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	39,691.07	39,633.21	39,576.33	39,520.39	39,465.37
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,598,769.96	1,599,114.94	1,599,455.16	1,599,790.75	1,600,121.84
Road	174,698.88	174,705.96	174,712.95	174,719.84	174,726.64
Air transport	651,168.07	651,886.25	652,594.52	653,293.16	653,982.42
	3,876,244.97	3,877,257.36	3,878,255.95	3,879,241.14	3,880,213.27
	22,263,178.79	22,268,993.40	22,274,728.83	22,280,387.24	22,285,970.66

Length (Km)	76	77	78	79	80
Costs					
Infrastructure	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26	2,075,978.26
Trains	0.00	0.00	0.00	0.00	0.00
Maintenance	466,065.75	466,065.75	466,065.75	466,065.75	466,065.75
Operation	396,904.34	396,904.34	396,904.34	396,904.34	396,904.34
	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35	2,938,948.35
	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76	9,532,177.76
B/C	1.320599148	1.320921384	1.321239514	1.321553644	1.321863871
	2.338550709	2.339121333	2.339684687	2.340240955	2.340790314
Generated traffic costs savings					
Congestion	195,970.46	195,970.46	195,970.46	195,970.46	195,970.46
Accidents	167,653.11	167,653.11	167,653.11	167,653.11	167,653.11
air, sound pollution	39,411.25	39,357.99	39,305.57	39,253.98	39,203.17
Residual value	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42	1,048,293.42
Conventional train	1,600,448.54	1,600,770.97	1,601,089.25	1,601,403.46	1,601,713.73
Road	174,733.36	174,739.98	174,746.52	174,752.97	174,759.34
Air transport	654,662.55	655,333.79	655,996.36	656,650.50	657,296.40
	3,881,172.69	3,882,119.72	3,883,054.69	3,883,977.90	3,884,889.64
	22,291,481.06	22,296,920.35	22,302,290.34	22,307,592.79	22,312,829.37

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