FH Vorarlberg
University of Applied Sciences

Study of the best solutions to increase the use of railways as a strategy to attract passengers to public transport

Master Thesis

Submitted in fulfilment of the International Management and Leadership Master

University of Applied Sciences Vorarlberg. Course 2020/21

Submitted to
Dipl.-Ing. Wilfried Manhart MBA

Handed in by
Joaquim Font Canyelles

Dornbirn, 7.1.2022

Abstract

English

Observing the ratios of the rail usage in terms of passenger travelled per km and per capita, we see that there are huge differences between countries, so some railway systems are performing better in catching passengers than others. By analysing the factors that make the railways attractive for users, and setting standard values for these factors, we can analyse how well a system is performing. This paper has investigated those factors and developed an assessment tool that will inform about the required improvements, so in a later stage specific strategies can be developed to increase the performance in order to attract more passengers. Spain will be used as case study, since the country has specially low passenger rail usage compared to other countries even though the large investments in high speed lines the country undertook in the last decades.

German

Gemäss die gefahrenen Personen pro km und pro Kopf, so stellt man fest, dass grosse Unterschiede zwischen den Ländern gibt, sodass in einigen Ländern ist die Eisenbahnleistung viel besser als in anderen. Durch die Analyse der Faktoren, die die Eisenbahnen für die Nutzer attraktiv machen, und Standardwerte für diese Faktoren festlegen, kann die Leistung eines Systems analysiert werden. Der Artikel hat diese Faktoren untersucht um eine Bewertungsmethode entwickelt, das über die notwendigen Verbesserungen informiert. Auf dieser Basis können spezifische Strategien zur Leistungssteigerung entwickelt werden, um mehr Fahrgäste anzuziehen. Als Fallstudie werden die Eisenbahnen Spaniens herangezogen, da das Land im Vergleich zu anderen Ländern eine besonders niedrige Nutzung zeigt, obwohl das Land in den letzten Jahrzehnten viel in Hochgeschwindigkeitsstrecken investiert hat.

Table of Contents

Index of figures

Index of tables

1. Introduction to the topic

The passenger transport around the world has been doubling since the year 2000. The need for travel is crucial in our globalized an interconnected planet and thus it is of higher interest to develop systems to respond to this increasing demand into efficient and socio-environmentally respectful ways when connecting people around the globe.

Railways are the fourth most used transport system after private cars, air and buses. Conventional and high-speed rail represent the 15% of the total passenger-kilometre travelled on a global base, and in 2016 the two systems transported a total of 3.9 trillion passenger-kilometres. Nowadays, these systems account for the 90% of all travellers by rail even considering the extensive metro rapid rail systems around the world [1], revealing the important role the conventional and high speed railways play.

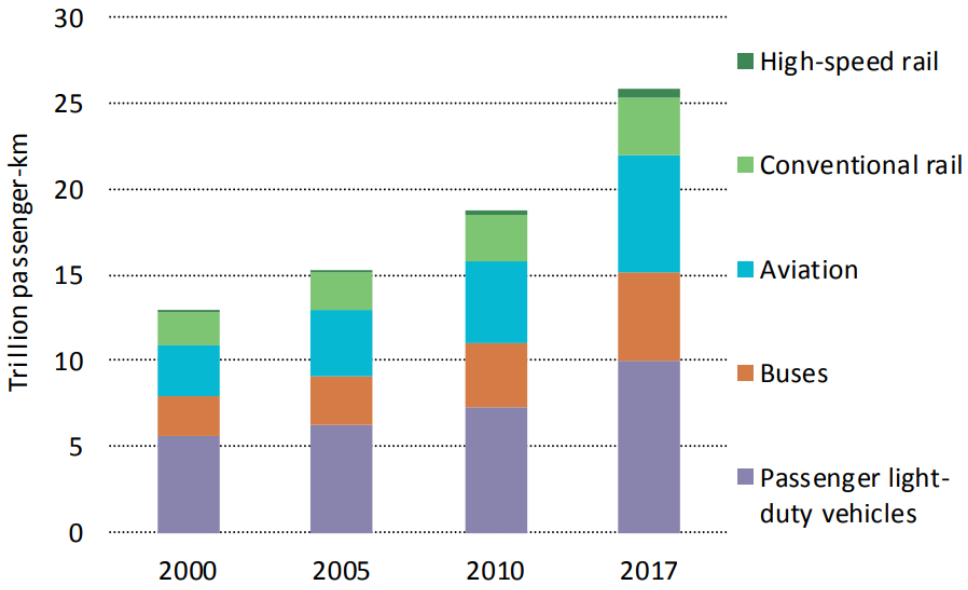


Figure 1: Non-urban transport activity by mode on a global scale, 2000-2017. Source: [1]

However, even though the passengers travelling with rail increased an average of 4% every year since 2000, this growth is comparatively lower compared to air travel. Indeed, aviation became a serious threat to railways at the second part of the 20th century.

According to Z. Tomes (2006) [2], railways follow the product life cycle curve and in developed countries tey experienced a decline in the second part of the 20th century, after reaching a maturity peak around 1930. Indeed railways achieved the largest extend of network at the beginning of the 20th century, but between 1960 and 1990 a great amount of the lines were closed. The author points some determinants causing the decline, mainly the road competition and lack of railways flexibility.

Graph 1: Product life cycle curve (Railways, Europe and USA, based on sales in real terms)

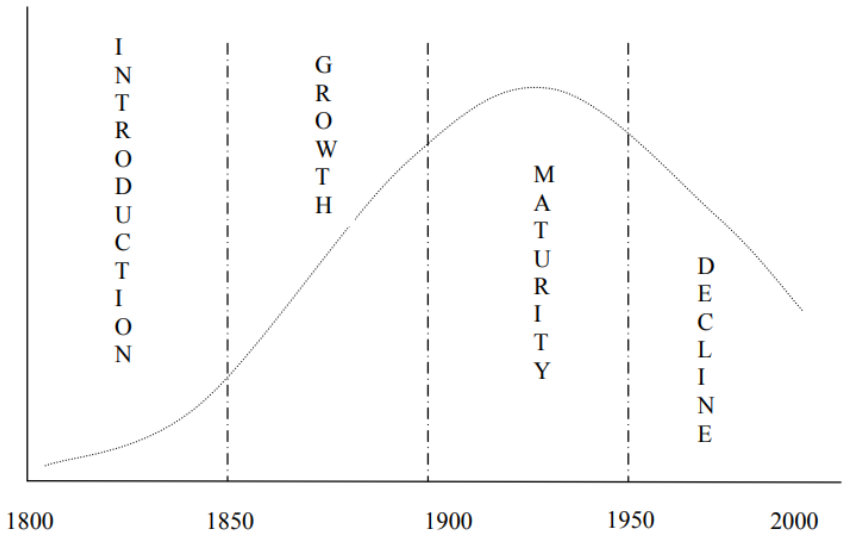


Figure 2: Product lifecycle curve applied on railways. Source: [2]

Between the 1970s and 1980s, which was the era of major fall of the railways, passenger transport experienced a growth of around 50% [3]. This was the moment in history when railways lost the dominant position they have had in the transportation and alternative modes of transport caught the increasing global demand. In those decades, the economic development and regulation politics which abandoned the rail, boosted the development of the automobile market bringing to an enormous growth in the indices of motorization. Later, when the globalization started in the 1990s, the intensification of the demand for transoceanic travel lead to a rapid expansion of the aviation. In short, these are the historical reasons making railways to be a step behind the other two major transport modes, even though they have the characteristics to offer the best qualities to get an efficient transport: they are fast, safe, efficient and sustainable.

In Europe, compared to air, the railways were the public transport mode carrying the most of the passenger volume until 2003, when the air transport surpassed the rail and continued an exponential increase tendency, especially from 2013 onwards, being consolidated as the major transport mode in terms of passenger-km.

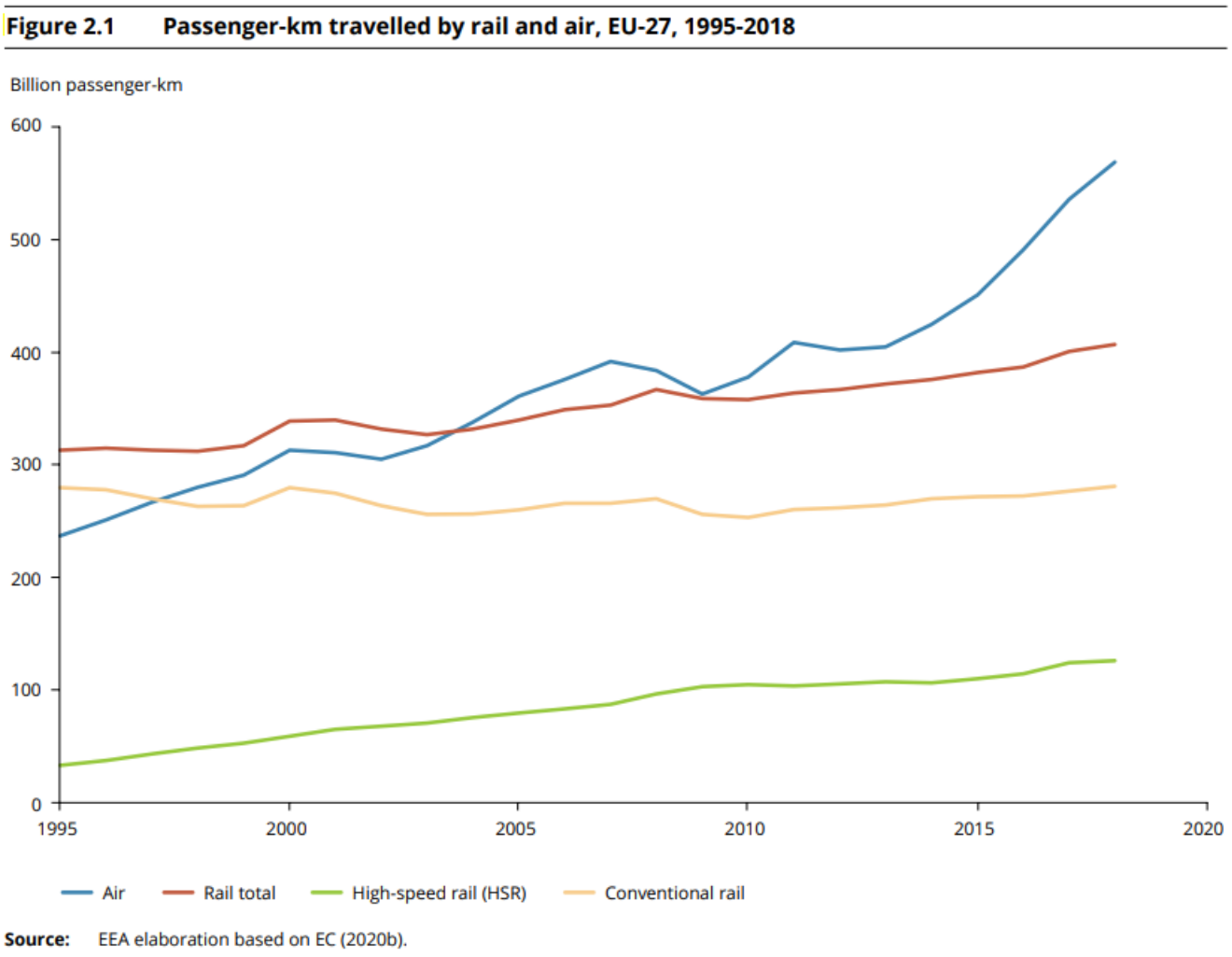


Figure 3: Evolution of the passenger volume for the different transport modes. Source: [4]

Considering the pollutant emission of both aviation and rail, it is demonstrated that air transport is largely much more polluting than railways, even more than the diesel trains [4]. International aviation is responsible for the 1,9% of the total transportation emissions of CO_2 (carbon dioxide) in Europe, and for the 5,5% of the NOx (nitrogen oxides, the most relevant component of the air pollution), whilst diesel railways account for the 0,1% and the 0,7% respectively (measures of 2018).

Instead, the tendency of the railways is to move towards the maximum sustainability. The passenger rail traffic volumes that grow the most in the last 20 years are the conventional electric and the high sped electric railways. In 2016, the 75% if the passenger rail volume was transported in electrical trains, an increase of 60% from 2000. Thus, railways are the only mode of transport widely electrified today. This reliance on electricity also entails highest efficiency, making railways the most energy diverse motorized mode of transport, since the energy production can come from several sources, not depending exclusively of combustibles like airplane and road vehicles.

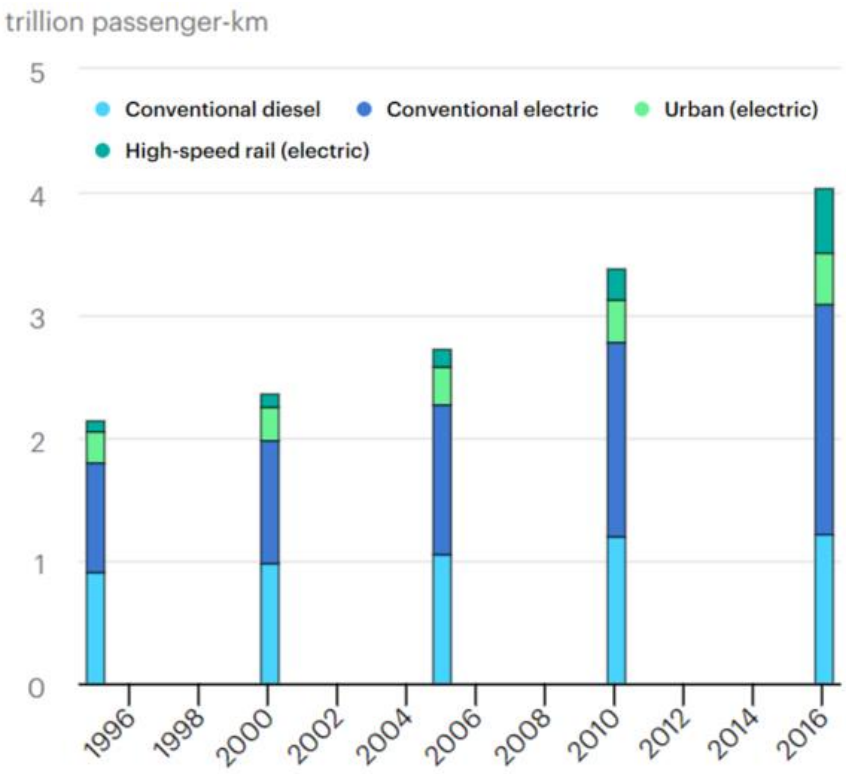


Figure 4: Passenger rail transport activity by energy type, 1995-2016, worldwide. Source: [1]

Therefore, rail transport is the only solution to respond to the global mass transport demand in a sustainable way. However, railways are normally in direct competition and thus in a free and globalized market, users have the power to choose their preferred transport modes based in multitude of other factors, where normally lower cost solutions prevail. Even though environment impact is an important aspect in the today's user decision, railways are not always the most attractive mode for passengers. Consequently, pursuing an increase of the rail passenger usage require the creation of strategies to make railways more attractive to customers.

2. Introduction

This section presents the justification, motivation and goals of the thesis, the research questions and research process, the scope of the study and the expectations and methodology of the interviews.

2.1 Motivation

I have been working in the railway industry for almost 10 years, with experiences in Spain, France and Switzerland. I already specialized in railways in the last courses of my studies of Industrial Engineering, so rail transport is not only my professional sector but also my vocation and motivational force in life.

As I am currently living in Switzerland, I am constantly amazed about how this country developed an efficient rail network, even in the less populated zones. Although I experienced this feeling in all central European countries and very specially Germany and Austria, it's in Switzerland where I perceived an extraordinary effort to bring the railway transport into a next level of efficiency. That contrasts with the situation in Spain, my homeland, where efforts have been centred in building extremely expensive new high speed lines without achieving a relevant increase of the rail transport usage as this paper later shows. These facts are combined with the usual perception of the Spanish rail travellers, complaining about the quality of the transport, suggesting there are potential improvements to be done which could encourage people to travel more often by trains instead of flying and driving.

Thus, my motivation is to contribute improving the future of global transport by developing efficient, modern, attractive, safe, competitive and environment-friendly railways.

2.2 Research concept

The goal of the thesis is to develop an assessment model to evaluate a railway system to show the priority needs to improve performance in order to increase rail usage. This model will be based on theoretical framework. For that a systematic research process has been followed. This is based in three steps:

- **The first step is to establish the relevance of the objective.** The aim is to understand why the railways can be more beneficial than other transport systems. To answer this question, a literature review on comparative studies between different modes of transport will be conducted to find the advantages of rail transport against the others. Usual attributes such as safety, sustainability or transport capacity will be confronted with data to confirm them. The first step is the basis and starting

point of this project, so to make sure that what we pursue, so the increase of railways usage, has clear social, economic and environmental benefits.

- **The second step of the research is understanding user behaviour.** The aim of this step is to recognize the drivers and disincentives for the people to move with rail transport, to understand why people in some cases feel attracted to travel by train, while in other are reluctant and use more other types of transport. To answer this question, at first a research of literature has been performed to stablish the relation with demand, as there are several academic studies investigating this issue. Drives for the use of railways, so the reasons why people are motivated to travel by train, as well as the disincentives, so the barriers that make people refuse travelling by train will be collected. This part will then explore what are the features of a railway system that can contribute the most to the attraction of the demand. This will serve to get the reference frame for the rest of the study.
- **The third step is estimating impact of performance improvements on usage.** Once the drives and barriers for the use of railways are clearly identified, it can be studied what could be done to boost the drives and remove the barriers. For that, specific academic works that studied the relation between performance improvement and increase of usage will be used as basis. The aim is to understand which are the factors that contribute to the most to the attraction of the passengers to the railways, either to improve the network, the operation, the services, the pricing or the way they interact with the customers, and that an improvement on the quality of this factors will be reflected to an increase of the passengers to the railways.

After the research is concluded, the assessment model will be built. For that the paper is structured in four main parts. The first sections are extracting information from relevant literature and statistics sources. Secondly, the paper moves to the creation of an assessment model using the theory and data from first part to evaluate railway system. Afterwards this model will be verified using the Spanish situation, analyzing whether the finding from first parts make sense in the context of customer preferences and actual railway usage in Spain. Finally, the assessment model will be applied to the railways in Austria and to the regions of Vorarlberg and Catalonia.

2.3 Scope

The present thesis is a study about the passenger rail transport in regional and long distance travel. Thus, it does not cover commuter, rapid or urban rail systems, neither freight transport. Even though there is no consensus about the definition of regional and long distance travel, for the present thesis, the following type of railways are considered:

- regional trips over distances of 50-100 kilometres, not involving the movement inside the cities
- long distance interurban journeys over 100 kilometres.

Both categories might include conventional railways and high-speed either daytime or night-time.

The factors external to the railways such as the economic activity, level of competition from other transport modes will not be considered in the present study. Although these are relevant to determine the rail usage of a country or region, the thesis will be focused specifically on the internal factors of the railway. Considering that the paper is based on the analysis of the rail system in the area of the European Union, where similar socioeconomical condition between areas are observed, extern factors differences are less relevant than in other regions of the world.

The master does not take into account the impact of the Covid-19 pandemic on the transportation. There has been a massive impact in the passenger traffic due to the reduction of the regional and international travel, especially in 2020. The most recent data collected considered in the present study will be therefore from 2019.

Even though a lot of data will be displayed in the present study, no quantitative analysis will be performed and all the numbers and information will be described and analysed qualitatively.

3. Comparative advantages of the railways

Trains are usually described as fast, clean, safe and fair mean of transport. These are the main reasons why trains have been extensively used as a mass transport system since the beginning of the 19th century, when the first railways emerged in Western Europe. The target of this section is to analyse these facts and thus to justify the advantages of the railways with supporting data regarding the efficiency, environment, safety, speed and transport capacity.

3.1 Transport capacity

A train vehicle can carry a big number of passengers. According to the Brand and Preston (2003) [5], rail systems have the highest passenger capacity compared to other modes whatever the case of urban or interurban mobility is considered:

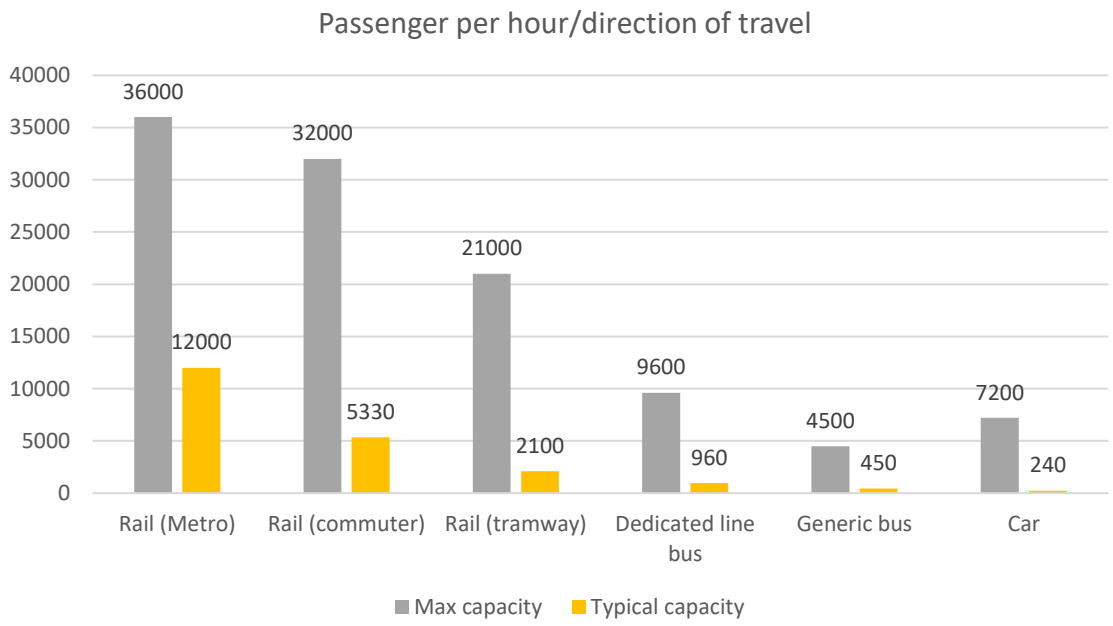


Figure 5: Comparison of passenger capacity per hour between transport modes. Source: [5]

The passenger capacity of railways depends however very much on the rail track (single track railway limit very much the capacity of the line), conditions of the infrastructure, signalisation, traffic management and the rolling stock used.

3.2 Speed of the vehicles and travel time

Nowadays, trains are the fastest commercial land transport systems. Most of conventional trains have commercial max. speeds above 150 km/h and modern high speed rail reach maximum speeds of more

than 250km/h. Being a guided transport and thanks to the reduced drag of the wheel-to-rail contact compared to tire-to-asphalt, which have a much higher friction, rail systems can be designed for much higher speeds than road vehicles [6].

Modelling travel speeds of different transport modes and land-use types.

Transport modes	Speeds (km/h)
HSR train I	300
HSR train II	250
CR train	120
Motorway	110
National highway	80
Provincial highway	70
City and county highway	40
Streets	30
Rail buffer of barrier	0.15
Motorway buffer barrier	0.1

Figure 6: Maximum speeds for the different land transport modes. Source: [6]

Additionally, thanks to the contemporary high speed systems, many rail connections are also faster than flying. Bleijenberg [7] analysed the time travel between city centres using rail and air transport. It was demonstrated that up to a distance of 700 km, the train can offer an equal travel time as aviation. Thanks to that, in many trips between the centres of big cities rail time travel is shorter than flying, especially because traveling to and from the airports is and additional time consumer in large metropolitan areas. In Europe, the following are the major rail connections between cities that are faster than aviation:

City pair	Distance	Time rail	Time air
Milano - Rome	474 km	4:00	5:25
Barcelona - Madrid	483 km	3:05	4:40
Lyon - Paris	407 km	2:55	4:50
London - Paris	348 km	3:15	5:05
Amsterdam - Paris	402 km	4:10	4:50
Brussels - Paris	251 km	2:00	4:25
Marseille - Paris	638 km	4:20	5:05
Brussels - London	350 km	2:45	4:55
Bordeaux - Paris	508 km	3:00	5:00
Lisbon - Porto	277 km	3:20	4:30
Berlin - Hamburg	255 km	2:10	5:05

Figure 7: Connections between cities in which travel time using high speed rail is faster than air. Source: [7]

3.3 Environmental effects

The United Nations (2014) [8] compared the carbon dioxide emissions of 5 different transport modes. From them, rail has the lowest ratio of CO_2 emission. Indeed, most of the modern railways are electrified and thus the origin of the electricity used can be obtained from renewable or less polluting sources. Instead, the airplanes' fuels and the road cars combustion engines are highly polluting.

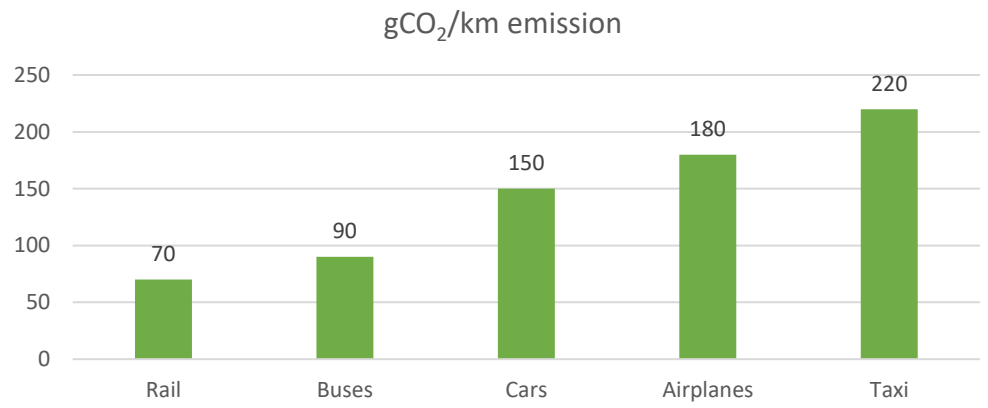


Figure 8: Comparison of the CO_2 emission per distance between transport modes. Source: [8]

The estimation made by the European Environment Agency gives even more extreme values, with only 14 CO^2 per passenger-km for trains against the 158 g of CO2 per passenger-km of cars and 285 g CO2 per passenger-km on flights [9].

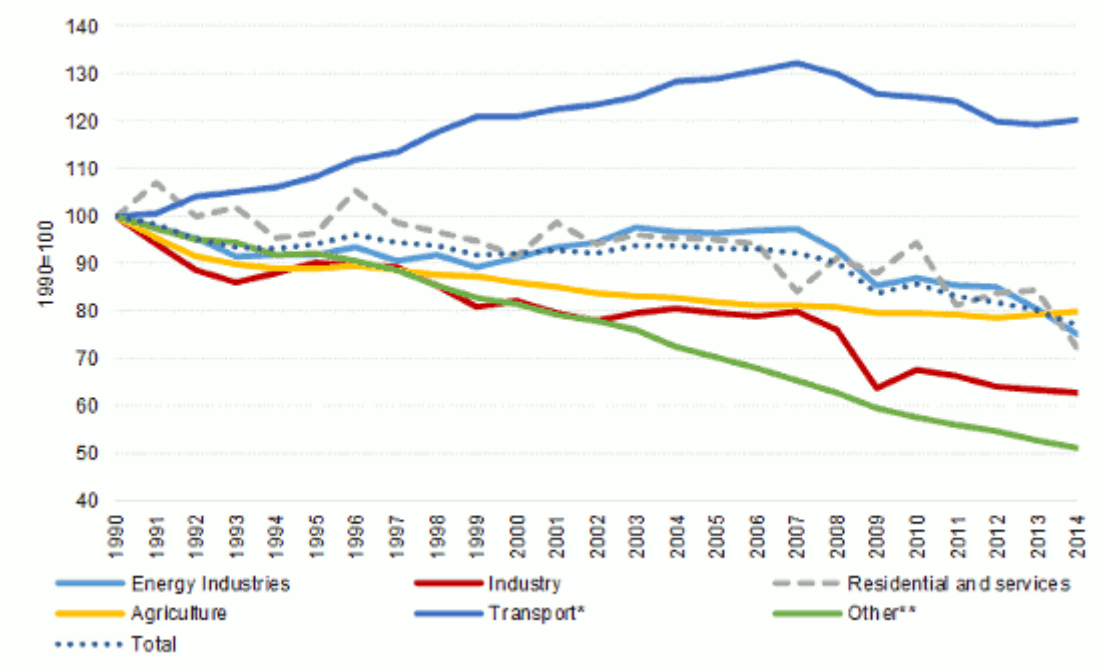


Figure 9: Evolution of the emissions per sector with reference from 1990. Source: [10]

The carbon dioxide is the major greenhouse gas and main contributor to the global warning. But transport vehicles do also emit other harmful greenhouse gases, notably methane and nitrous oxides among others. Considering all the emissions, the transport sector has not seen the same reduction as other sectors. In fact, the emissions started to decease in 2007 but they still remain above those from 1990 [10].

Considering the split between transport modes, railways are the only transport mode that have been consistently reducing the greenhouse emissions since 1990, with only a 34% of the emissions registered in 2018. Instead, aviation emissions have been increased by a 219 % and road by a 127% in 2018 by respect 1990.

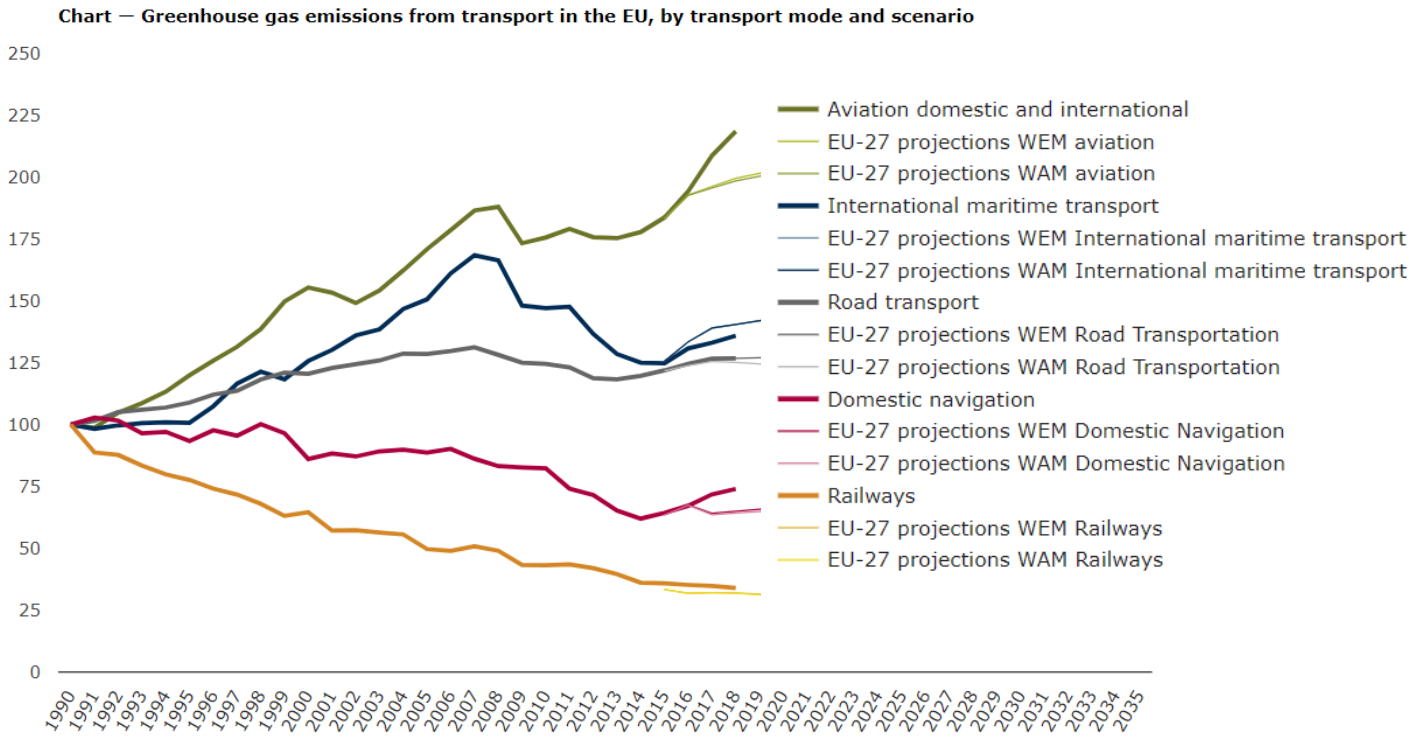


Figure 10: Change in emission levels from 1990 (index 1990 = 100) by transport mode. Source: [11]

In all, railways are the lowest transport mode by GHG in Europe with only the 0.6% of the total GHG emissions. Instead, civil aviation accounts for the 13,1% and road transport gathered the major emission of greenhouse gases with a 76% [10].

3.4 Energy efficiency

The U.S. Department of Energy (2020) [12] calculated the average energy consumption per passenger and kilometre of the main transport modes used in the country. As it can be shown in the table below, from the 6 transport modes analysed, trains are the most energetically efficient.

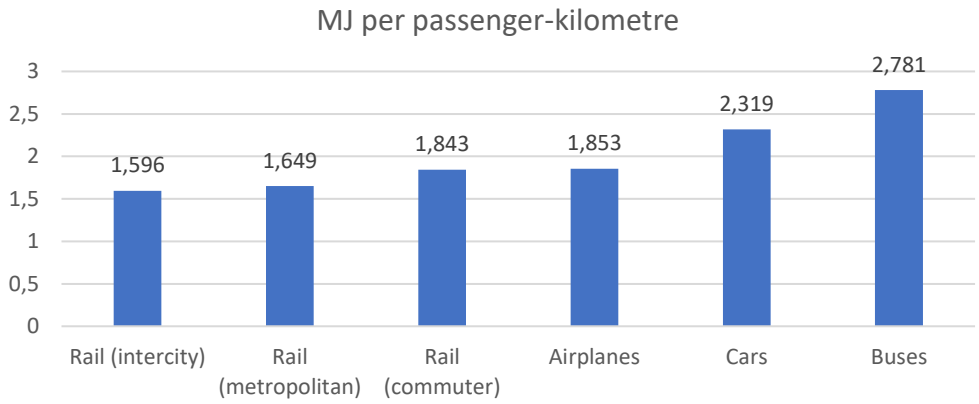


Figure 11: Comparison of the energy consumption per distance between transport modes. Source: [12]

Indeed, according to the portal ethify.org (2018) [13], the train is the motorized transport mode which offers a major energy efficiency, calculated as the distance travelled per energy with an average of 12,5 km/kWh, four times the efficiency of a car which offers around 3 km/kwh.

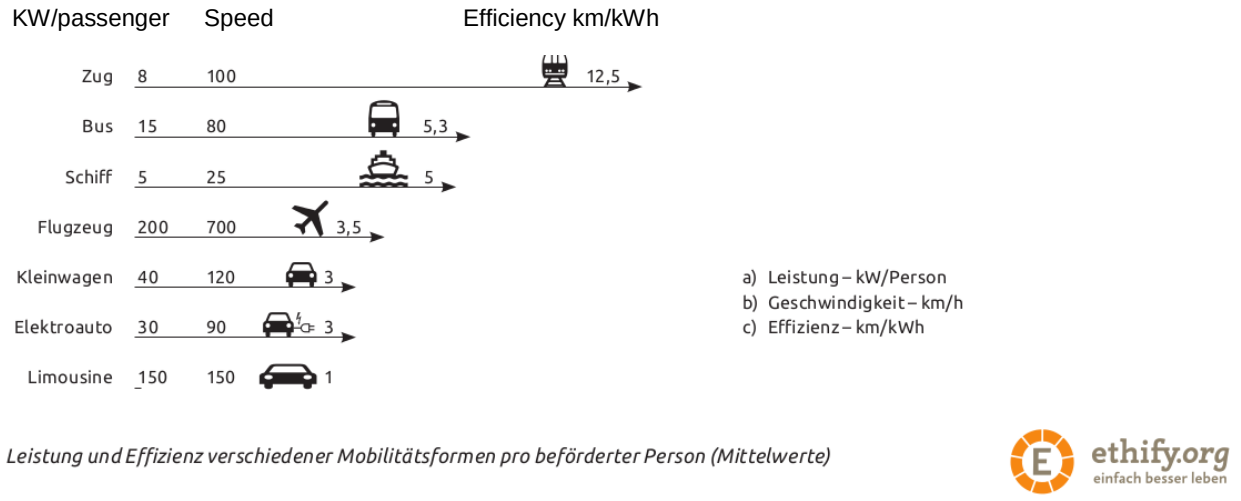


Figure 12: Power and efficiency of different transport modes. Source: [13]

This is aligned with the statistics of the International Energy Agency, which show that railways are the most energy efficient mode of transport. While trains are carrying the 8% of the world's passenger traffic and the 7% of global freight transport, they do only represent the 2% of total transport energy demand [1]. Indeed, in Europe the railways are the mass transport mode with a lowest energy demand, with only 1.6 % of the total energy.

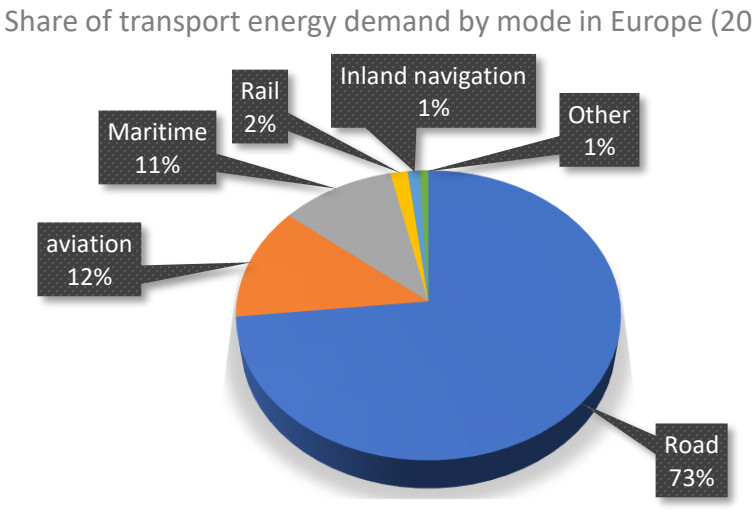


Figure 13: Share of transport energy demand by transport mode in Europe (%), 2014. Source: [10]

3.5 Safety

As a guided transport, trains are only limited to one dimensions of travel, which reduces by principle the uncertainty and risks from other transports. Additionally, the modern signalling systems such as the ERTMS (European Rail Traffic Management System) make the collision between trains very unlikely. The risk comparison in the European Union shows that the fatality risk for motorised bikes is the highest of all modes, and that road traffic has the highest fatality risk per passenger kilometre of all passenger transport modes. Instead, Rail and air travel are the safest modes per distance travelled, followed by bus [14].

Road (Total)	0.95
Motorcycle/moped	13.8
Foot	6.4
Cycle	5.4
Car	0.7
Bus and coach	0.07
Ferry	0.25
Air (civil aviation)	0.035
Rail	0.035

Table 1: Deaths per 100 million person kilometres

Road (Total)	28
Motorcycle/moped	440
Cycle	75
Foot	25
Car	25
Bus and coach	2
Air (civil aviation)	16
Ferry	8
Rail	2

Table 2: Deaths per 100 million person travel hours

Figure 14: death risk for the different travel modes in the EU (over distance and time) for the period 2001/2002. Source: [14]

The Department for Transport in the United Kingdom (2020) [15] reported that for an individual traveller per kilometre travelled, the car is 25 times less safe than rail, and travelling by motorcycle is 1,620 times less safe.

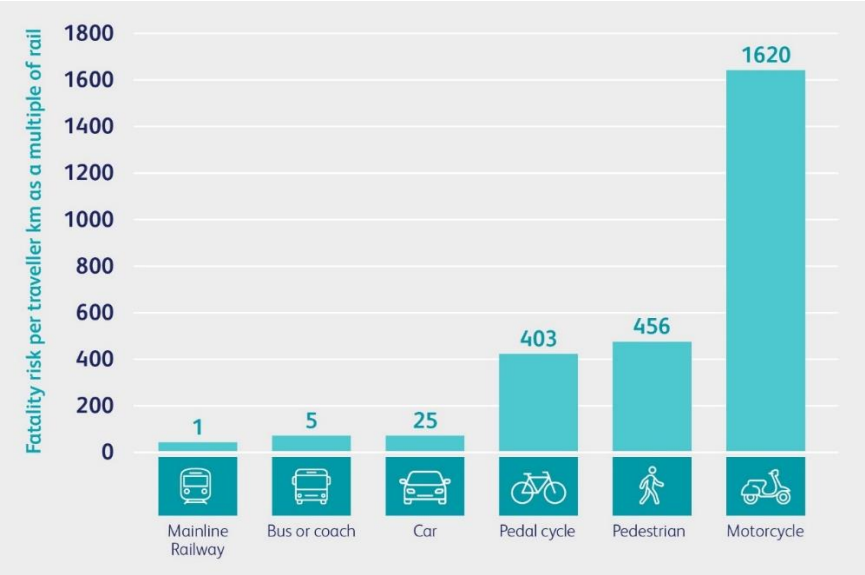


Figure 15: Traveller fatality risk for different transport modes relative to rail in the UK, 2018. Source: [15]

In the same way the federal Statistical Office in Switzerland (2020) [16] calculated the danger of fatal accidents in different transport, taking also the reference of the rail transport and comparing them with the person-km of other transport. In the Swiss study however, a period of 10 years was considered in order to minimise the influence of result of short-term fluctuations, which might give a more accurate perspective.

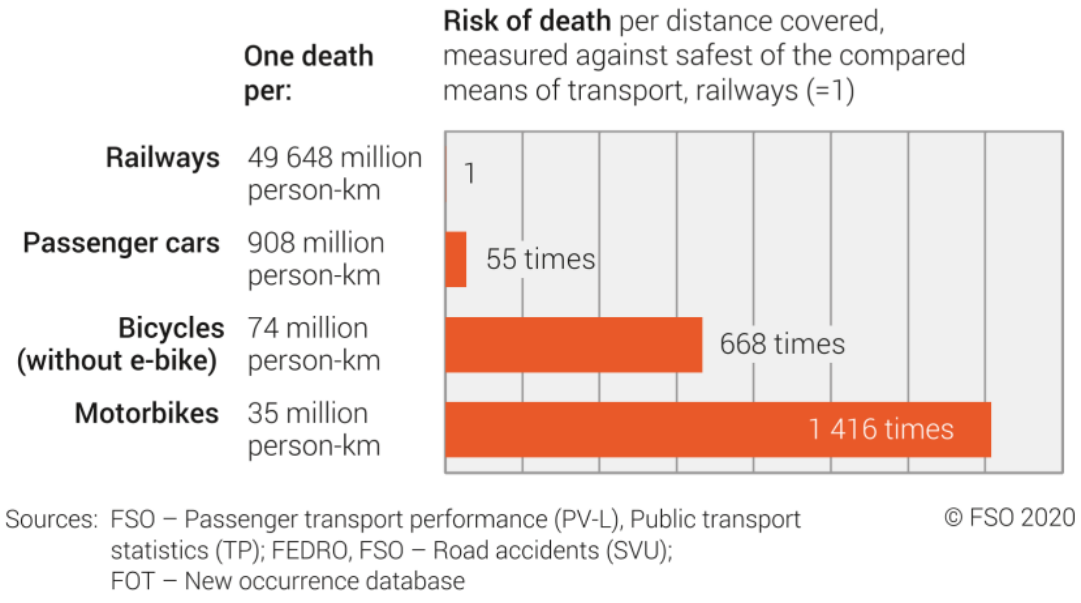


Figure 16: Risk comparison for different transport modes relative to rail in Switzerland, 2009-2018. Source: [16]

In the Swiss study the risk of death in passenger cars is 55 times more than traveling with rail, and this appears to be more than two times higher the risk observed for the cars in the UK. The risk of death when travelling by motorbikes is the highest of land transport modes and in Switzerland appears to be slightly slower than the UK.

3.6 Conclusions on the railways' advantages

As seen in this section the railways can be the most capacious and fastest transport mode, which are major competitive advantages against other systems.

They can also be highly sustainable and safe, which from a socio-environmental perspective are major reasons to incentive and support their usage.

The next section will investigate the quality factors of the railways that are most relevant for the passengers, which will be used later in the study to assess the performance of a system.

4. Drives, barriers and priorities of the users to the use of railways

This section will investigate what are the most relevant attributes of the railways creating attraction but also refusal of their use. For that a summary of the findings of the literature in the factors influencing the demand, the barriers to the usage, the priorities of the users and the strategies for attracting more passengers will be included.

4.1 Factors influencing the demand

Several studies examined the factors that influence rail passenger volume. For the creation of this section, a large revision of the specialized literature has been followed. Many authors articles and publications examined and studied the factors influencing . There are authors focusing their studies in the definition of factors, articles showing the surveys conducted to generate theories.

Thus, from all the reviewed literature, this is a general summary of the main findings that are of use for the goals of this thesis, which is to understand what are the priority factors of a railway system that move travellers to their use.

Sources have been found through specialized online research explorers such as researchgate.net, but also include many official publications and statistics of the European Union related with the different countries of the EU.

This approach will give the present study the right theoretical framework in which the assessment model that will be later develop is based. Thus this gives the guarantee that the fundamentals of this work are based on scientific findings from research studies.

There is a general agreement between the authors to classify the factors between internal and external, since the first can be changed when changing the performance of the railways, whilst the second are related with the conditions of the regions where the railways operate and much more difficult to change and thus independent from the conditions of the railways.

According to FitzRoy and Smith (1995) [17], the main rail indicator used to compare the demand for rail transport between countries is route density in both ratios rail km’s/country area and km’s/ inhabitants, which will be described later. This parameter is the essential condition to get connection and therefore directly linked to the use of the railways.

Furthermore, Pan et al. (2017) [18] grouped the factors influencing the demand into two types, the “internal factors”, which refer to the factors related to rail operations and “external factors”. In a similar perspective, Wanke et al. (2018) [19] pointed that the factors defining the use of railways can be divided

between endogenous, so having a cause that is inside the rail system itself, also identified as bounding factors, and exogenous, so those having causes that are outside the railway systems itself, also identified as contextual variables. In addition, Oliveira et al. (2019) [20], noted that apart from the factors related with the efficiency of rail transport, there are important aspects that are significant for the customers' experience that influence passenger demand. These three groups of factors are described below.

4.1.1 Internal factors

The internal factors are related to the operation of the railways. These factors define the quality of the service offered by the rail transport and have a major influence on the perception of the passengers.

Pan et al. (2017) [18] defined frequency, average speed and punctuality within the most important items defining the rail efficiency that also have a direct influence in the decision of customer to travel by trains instead of other modes.

- **Frequency:** time between same service, calculated in minutes or hours. High frequencies ensure users can accommodate their needs to the timetables of the train and make compatible the rail travel with the complementary intermodal transport, for example bus reaching station.
- **Speed:** it defines the time of travel, thus trans traveling in higher speeds can run longer distances in shorter times. In the survey done by Wang et al. (2017) [21], the results revealed that travel distance was the most significant variable influencing passenger modal choice. Thus, if trains can increase their speeds, time in travel a certain distance can be reduced and longer distances become more attractive for the users.
- **Punctuality:** operators consider delayed trains when these arrive with more than 5 minutes later than the planned arrival time. Even though in a regular use, a punctual delay is accepted and have no major influence on rail demand, consistent delays endanger seriously the attraction of passengers and thus this concept is fundamentally related to the reliability of the system.

Wanke et al. (2018) [19] added the following endogenous factors that even though may not be directly perceived by customers, have an essential impact on the quality of rail transport and consequently in the demand: double track ratio (railways with double track ratio ensure a high capacity and thus the frequencies and speeds as seen previously), as well as the electrified track ratio and the number of deaths and injuries per accident. Thus, the following factors are also relevant to determine the demand:

- **Safety:** railways are generally considered a safe transport system in the western world but might not be the case in other regions. Railways with very low accident rates will gain a positive

reputation among users. That's why the number of deaths per accident might be used as an effective indicator of the safety of the system.

- **Sustainability:** Contemporary users value sustainability of the transport and this play a role in their choice of transport mode. As pointed by Wanke, the electrified track ratio is a good measure of the sustainability of a railway system. Indeed, networks equipped with electrification are operated by electric trains that reduce substantially the pollution and enhance the efficiency compared to the non-electrified, which are operated by diesel trains normally polluting, inefficient and noisy.

4.1.2 External and exogenous factors

Pan et al (2017) [18] defined as external factors those associated with land use (characterized by density and built environment), transportation factors (parking facilities and costs, alternative and connecting bus lines…), and social-economic factors. Regarding the exogenous factors, Wanke et al. (2018) [19] pointed GDP per capita as the main factors, but also other influencing factors such as regulatory issues.

External factors are not part of the scope of this thesis. However, there are some of the factors defined by Pan that might be also under the responsibility of the railway administrators such as the parking facilities or bike parks in the stations, as well as the level of synchronisation of the rail timetables with the other public transport modes, and so these will be taken into account in this paper.

4.2 Barriers to the use of rail

Once the driving factors to the use of rail transport are defined, it is of the most interest to analyse the barriers, so the reasons why people refuse or tend to not use railways but other transport modes, private transport. Blainey and Hickston (2012) [22] analysed why customers prefer other means of transport over railways and grouped the reasons into three dimensions: hard, soft and complementary factors. These are described below.

4.2.1 Hard barriers

The hard barriers can be easily measured and affect in a similar way all passengers. The most important hard factors are travel time and travel costs.

- **Travel time:** users will not be motivated to use railways if the travel time to their destinations are substantially higher compared with other transport means. In fact, Gonzalez-Savignat [21] found that the total journey time was the most important determinant factor of market share. Thus, time travel of the railways must be competitive compared to other public transport modes in order to retain and attract new users from these modes (normally buses for middle distances and airplane

for long distance). Users will compare door-to-door time travel, and so speed of the trains as well as intermodal connectivity must be competitive and efficient as they have a huge impact on total travel time (CE Delft, 2018). Therefore, the present thesis will use the average speed of trains and door-to-door connectivity as main indicators to evaluate the travel time of the railways.

- **Travel cost:** users will not be motivated to use railways if the travel costs to their destinations are substantially higher compared with other transport means. As pointed by some authors [18], travel cost perception might differ heavily between users and thus what it might be a barrier for some users might it not be for others. Indeed, the study conducted by L. Eriksson (2011) proved that shorter time travels together with an increase of the frequencies, were main determinants for car users to switch to public transport when driving to work, as preferential factor than travel fares.

Both factors will be fundamental in the later development of the assessment model as indicators of performance of a railway system.

4.2.2 Soft barriers

The soft barriers are perceived differently by each traveller, and are based on the satisfaction derived to their perceptions offered by the rail operation and services. The following are the most common factors:

- **Station facilities:** difficulty to reach stations is within the major barriers for people on the use of railways. Thus, ensuring parking slots and connecting services is highly significant for that.
- **Comfort:** lack of free seats is normally a stressor for users. According the Deutsche Bahn [22], 96% of the travel time can be efficiently used by passengers, which is one of the major perceived benefits of using public transport. However, this is conditional to the comfort during the trip, above all to be able to travel seated. Thus, the availability of seats becomes essential.
- **Information provision:** railways without proper communication about the lines, connections and timetables will create stress to the users and loose potential new customers. Moreover, Oliveira et at (2019) [20] demonstrated that the availability of information is an essential factor defining the customer satisfaction during the rail travel. Delays and disruptions happen even in the most efficient systems. Thus, operators informing the passengers on-board lively about the situation can mitigate the dissatisfaction caused by the delays. In those cases, the anxiety due to lack of information during the incidences is replaced by serenity, and the users suffering disruption keep calm on-board.

- **Personnel on-board.** Trains without personnel on-board might give the feeling to the users they are travelling unattended, unaccompanied, and even that their personal security is not ensured. Although a good level of information and communication provision can also help fulfilling this (the screens might inform about final destination, next stop, timing and connections, and many modern railways include communication system for the passenger to the driver or central of operations in case of emergency), they cannot totally replace the effect of personal contact that the staff bring when they are on board.
- **Flexibility of prices in time and multiple-ticket options:** operators normally offer reduced fares when purchased within weeks in advance and card options with several tickets which suppose savings for the frequent user. This brings a priori to an increase of demand since users find solutions to get attractive prices to travel, but also a better cash-flow for the operator and capacity of planning the train occupation. However, as advised by Anciaes et at. (2019) [23] offer too many different types of tickets can also cause confusion which could make the user to get a negative perception of train travel and therefore bring a potentially reduce of demand.
- **On-board services:** according to Nordenholz et al. (2016) [22], strategies to improve the comfort on board providing entertainment, wireless and catering are powerful measure to shift users to rail.

In the next sections of the present study, these parameters will be used as indicators of the comfort and travel experience of the railway passengers.

4.2.3 Complementary factors

The complementary factors are related to the lifestyle and economic-cultural background of the people, and include habits, age and culture within the most important factors. Wang et al. (2017) [21] investigated the relation of these factors with the long-distance travel, summarized below:

- **Age:** travel behaviours differ deeply between age groups. Several studies show that for the elderly, safety and cost are the two most significant factors when choosing the travel mode. Older people care more about the travel cost than travel time.
- **Education and income level:** passengers with higher education and income level tend to travel more using the high speed rail and aviation. Instead, passengers with lower incomes tend to choose conventional train and bus.
- **Travel purpose:** whilst the principal reason for urban travel is work commuting, long-distance trips are normally motivated by leisure, going to holidays and business purposes, which causes different service demands. This will be of special attention in the later part of this study, since

the statistics used for the analysis will identify the users according to their travel purpose: communing, leisure activities, going to holidays or for business.

The EU (2019) [24] defines four major types of purposes for the railway travellers: commuters travelling to work, school or university; business trips; travellers going on holidays and travellers going to leisure activities. In 2018, the majority of the users in the EU affirmed to travel by train mostly for leisure activities (35%), followed by holidays (23%), commute (16%) and for business (9%).

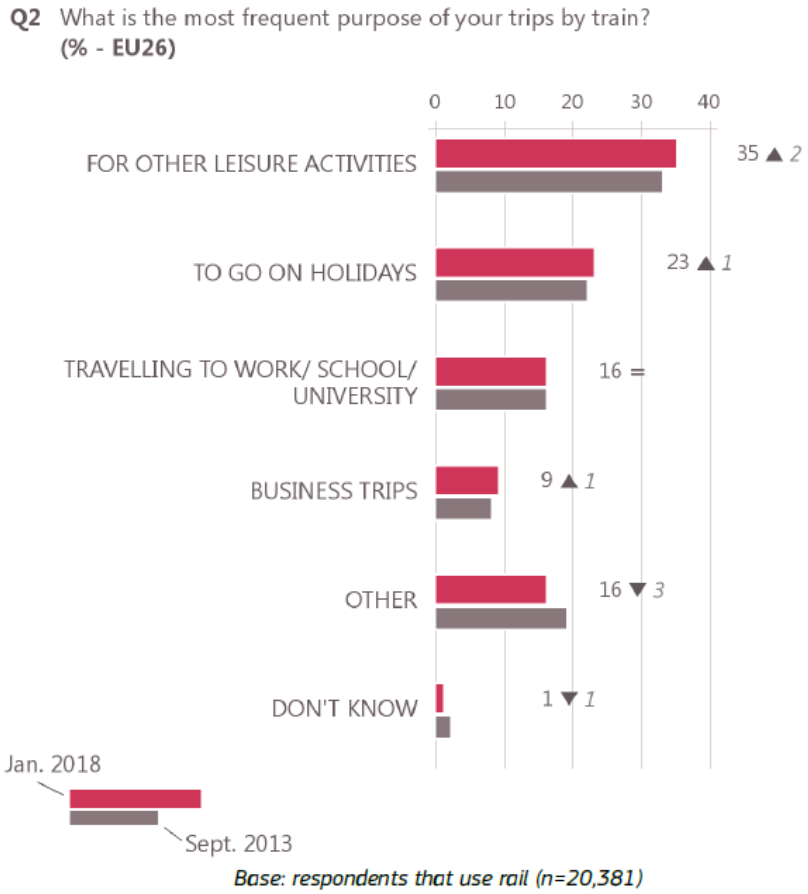


Figure 17: The four major purposes of travellers when using rail, 2018. Source: [24]

This is the average of the different countries in the European Community, and for each country the percentage of travel reasons are slightly different, although for 21 of the 27 countries analysed the major reason for travel is also for leisure, whiles in the others six countries (especially France, Italy and Poland) the main reason of the travel is for holiday. Thus, it's clear the tendency that in the European countries people use railways most often for leisure and holiday activities than for commuting and business activities.

These four travel purposes will be used later in the present study to analyse the different priorities of the different market segments to generate more accurate results.

4.3 Priorities of the rail users

The CE Delft (2018) [25] defined the quality attributes of public transport following the definition of the factors defined by Redman et. al. seen before. They considered “physical” and “perceived” attributes.

Physically, they defined 8 attributes including the previously seen travel time, punctuality (defined as reliability), frequency and price. But they also include accessibility (understood as the access of railways to people with any degree of reduced mobility); information related to timetables, routes and lines; the intramodality with other transport modes and connectivity to other rail lines and the status of the vehicles, not only aesthetically but specially the mechanically so they prevent from breakdowns.

Regarding the perceived attributes, these are more related with the soft factors such as the comfort of train travel seen before, and they also include safety, convenience and aesthetics.

Classification	Attribute	Definition
Physical	Travel time	The time spent for the entire door-to-door travel
	Reliability	How closely the actual service matches the route timetable
	Accessibility	The degree to which public transport is reasonably available to as many people as possible
	Frequency	How often the service operates during a given period
	Price	The monetary cost of travel
	Information provision	How much information is provided about routes and interchanges
	Ease of transfers/interchanges	How simple transport connections are, including time spent waiting
	Vehicle condition	The physical and mechanical condition of vehicles, including frequency of breakdowns
Perceived	Comfort	How comfortable the journey is regarding access to seat, noise levels, driver handling, air conditioning
	Safety	How safe from traffic accidents passengers feel during the journey as well as personal safety
	Convenience	How simple the transport service is to use and how well it adds to one’s ease of mobility
	Aesthetics	Appeal of vehicles, stations and waiting areas to users’ senses

Table 1: Physical and perceived attributes to the railways. Source: [25]

Additionally, they defined the importance each attribute might have depending on the type of user between business, commute and leisure traveller.

Table 5 - Main criteria influencing modal choice passenger rail transport

Criteria	Commuting	Business	Leisure
Travel time	+++	+++	++
Reliability	+++	+++	++
Comfort	++	++	+++
Accessibility	++	++	++
Price	++	+	++(+)
Frequency	++	++	+
Convenience	+	+	+
Safety	+	+	+
Environment	+	+	+

Table 2: Preferences of the users for the use of railways. Source: [25]

They define three levels of importance, from “+++”, meaning the highest correlation between the attribute and the modal choice of the users to travel with rail transport, to “++” and “+”, being the last one the lowest, so the attributes that contribute in less force to the choice of travellers for the use of railways.

As it can be seen, travel time and reliability are the most valued attributes for the commuter and business travellers. Frequency, comfort and accessibility follow in the influence to the demand.

The present thesis will use these attributes to set a collection of key performance indicators for the evaluation of the quality of a railway system in the perspective of how a system is good in attracting passengers.

5. Performance factors of a railway system

This section will define a set of parameters to evaluate a railway system from the perspective of the attractiveness to the users, so its capacity of catching new users and catching passengers form other transport modes. This will be the basis of the assessment model that will be built in the next section.

Before going into the definition of the assessment indicators, the section will introduce the concept of rail demand, as this is a useful indicator of the usage and thus an proper way to define the overall performance of a railway system.

5.1 Propensity to travel by rail

Almost 29% of the world's railway network is installed in Europe and is mainly dedicated to passenger transportation, whilst 30% is located in America and 26% in Asia and Oceania [26]. However, Asia is the region of the world gathering the most of the traffic (77% of the world passenger-km) with a smaller network than Europe and America. America only represents the 1% of the passenger-km which contrast with their extensive network. Thus, the length of the network in absolute terms is not indicative of a good status and usage of the railways. That's why in the present study the related parameters with the network will be considered in relative terms.

Table 6
Railway infrastructure and indicators.
Source: UIC (2015) and CIA (n.d.), completed by the authors. Year base: 2015.

Region/country	Extension (km)	%	Passengers.km (million)	%
Europe	258,270	29%	463,325	16%
Russia	85,262	9%	120,413	4%
Africa	55,600	6%	62,830	2%
Americas	269,155	30%	27,531	1%
Asia & Oceania	232,714	26%	2,278,880	77%
Total	901,001	100%	2,952,979	100%

Table 3: Railway indicators in the main regions of the world. Source: [26]

In fact, according to Marchetti and Wanke (2019) [26] the main indicator to compare the railway's performance is the propensity to travel by rail, calculated as the passenger rail-km travelled per capita. This is also identified as "intensity of use" by other authors.

As seen in the next chart, Switzerland is leading the ranking in Europe with 2420 p-km per habitant run in 2018, more than 2,6 times the average run in the EU27 of 909 p-km/hab. Austria, France and Sweden

follow with more than 1300 p-km/hab, whilst the Balkan and Baltic countries are at the bottom of the European ranking with less than 300 p-km/hab.

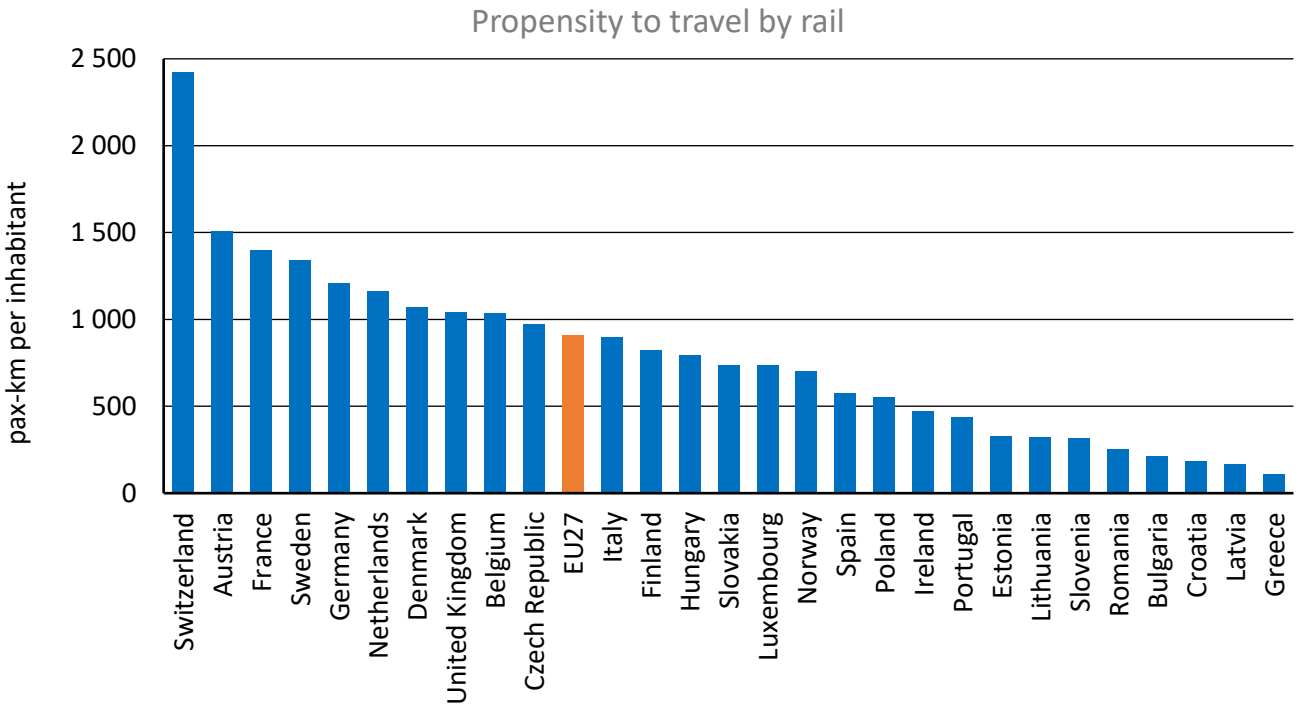


Figure 18: Propensity to travel by rail in Europe, 2018. Source: [27]

Although this is the most useful indicator to stablish the overall performance of a transport system and in a great extend it's the result of the different quality factors of the system, the propensity to travel by rail is not a quality factor for the target of this thesis, as it is not perceived as a value for the users. Therefore, even though the data is available for all countries, the parameter will not be included in the assessment model developed in the next section 6, but just as an indicator to gauge the results in section 7 and 8.

5.2 Indicators of the performance factors

As seen in the previous section, Redman et al. (2017) [21] proposed several attributes to define public travel quality, and divided them into "physical" and "perception". The physical attributes are the inherent features of the travel modes without involving passengers' opinions such as reliability, frequency, speed, accessibility and price. Instead, the perception attributes are measured by the feedback of passengers' satisfaction. Aligned with that, Eboli and Mazzulla (2012) [28] affirmed that the quality of transport services can be evaluated by subjective measures based on passengers' perceptions, whilst transport performance must be measured by comparison with fixed standards expressed as numerical values or

past performances. Thus, the set of performance indicators that will be defined here will be a mix of physical attributes and users perceptions.

5.2.1 Objective indicators

In this section the before mentioned “physical” measures of the performance of a railway system be presented. These will be the basis for the assessment model that will be built in further sections, as the parameters shown will be used as reference values. The collection of indicators is based on the attributes defined in the Table 1 seen in the previous section, and built with the available data that is can be comparable for all countries of the EU. Therefore, only research studies including all the countries of the EU are used and for that source are mainly the official statistics of the EU.

The objective indicators are grouped in clusters with similar nature and level importance to the users. An overview of the indicators is show here:

Cluster	Performance indicator
Extension of the network	Route density per km (km of rail route / country area)
	Route density per capita (km / inhabitant)
Quality of operation	Average speed of trains
	Transport performance
	Punctuality (% of trains with delay <5min)
	Reliability (% of cancelled trains)
	Fares
Safety	Fatalities per length
	Fatalities per traffic
Sustainability	Electrified ratio (% of electrified lines)

Table 4: Objective indicators overview

All them will be defined in the next subsections.

5.2.1.1 Indicators about the extension of the network

These indicators inform about how long are the railway lines and how many destinations can the trains reach. Major levels of these mean that users can reach many destinations along the country. The two indicators used are relative to the area and the population.

- **Network density (per country area)**

The density of railway network is calculated here as railway extension relative to surface area (line-km per thousand km^2).

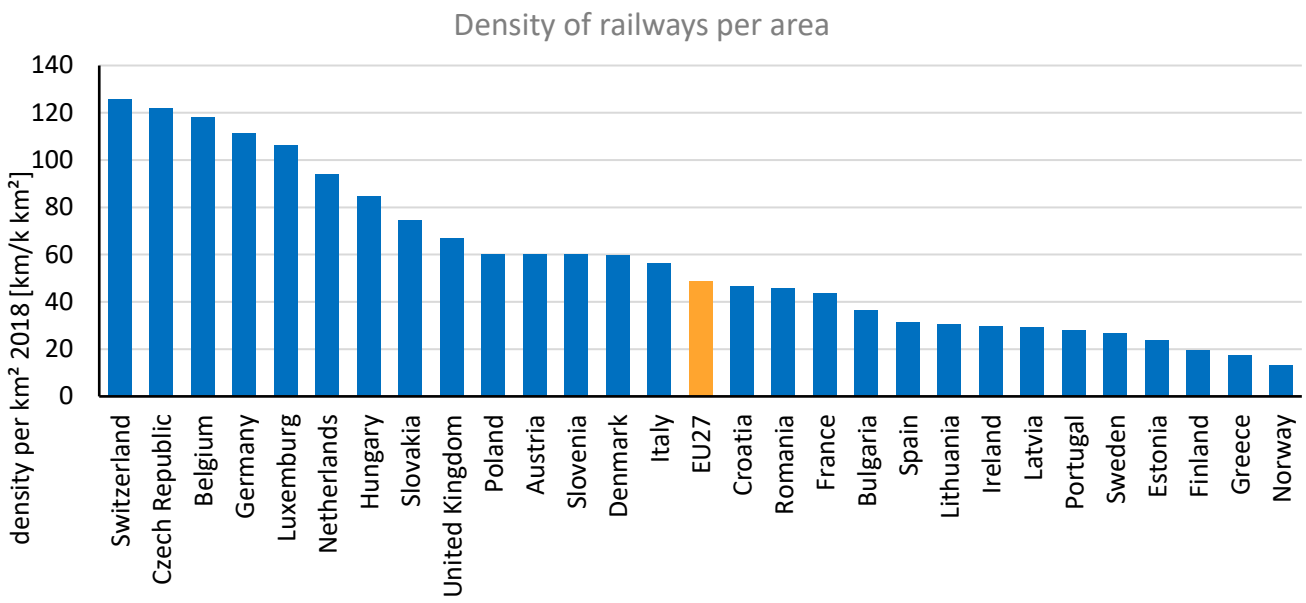


Figure 19: Density of the railway networks per surface area in Europe. Source: [27]

Considering the density relative to surface area, Switzerland has the most dense railway in Europe. There is a huge disparity of values.

- **Network density (per population)**

The density of railway network here is calculated as railway extension relative to population (line-km per million people).

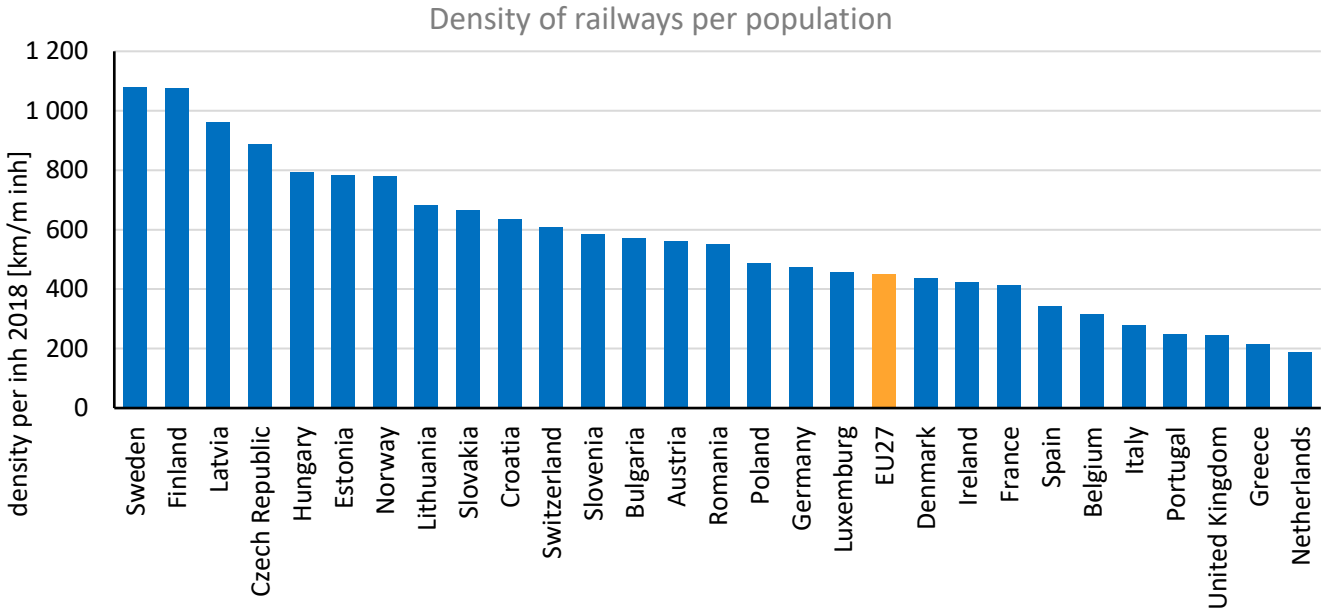


Figure 20: Density of the railway networks per population in Europe. Source: [27]

Considering the density relative to population, the less densely populated countries are leading the ranking, with Sweden and Finland at the top, since they need longer lines to connect the spread people. There is a big disparity of values between the values of the leading countries and the less performing.

5.2.1.2 Indicators about the quality of operation

These indicators evaluate the quality factors that affect directly the users during the rail travel and that coincide with the internal factors of the rail services already seen in the previous section 4.1.1: travel time, punctuality, reliability and frequency. The sources are statistics of the European Commission. At first the indicators defining the average speeds of the railways will be introduced, then the concept of transport performance defined.

- **Average speed of trains**

Higher speeds bring to a reduction of time travel which is one of the main hard factor drives for passenger to choose using railways. This indicators is given by regional and long distance trains.

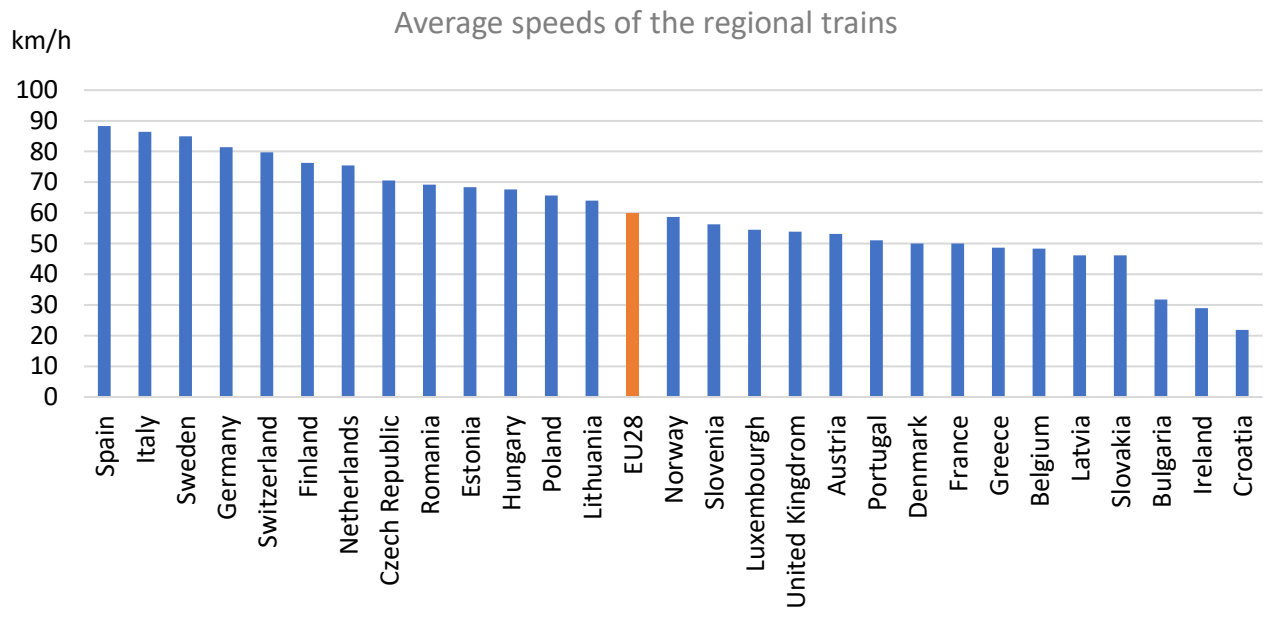


Figure 21: Average speeds of regional services, 2016. Source: [29]

Spain and Italy register the fastest speeds of the regional trains with almost 90km/h. This contrasts with regional railways in Ireland and Croatia, with speeds below 30 km/h.

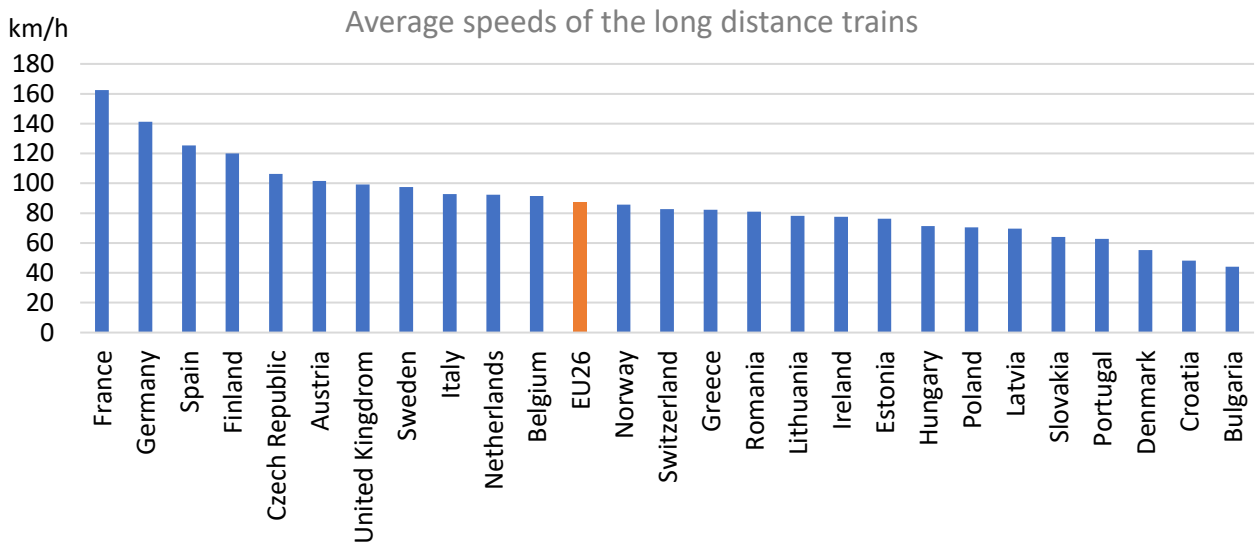


Figure 22: Average speeds of long distance services, 2016. Source: [29]

For the long distance trains, the three countries with largest high speed networks in Europe France, Germany and Spain, register the major average speeds.

- **Transport performance**

Poleman et al (2020) [30], defines the indicator “transport performance” as the ratio between the population reachable in a maximum of 1,5h travel time by the total population within 120 km radius. They calculated this for the combination of walk with rail, and bike with rail transport. They calculated two type of travel time, the optimal time which assumes the users arrives just on time to the train station, and the average time which takes into account the waiting time.

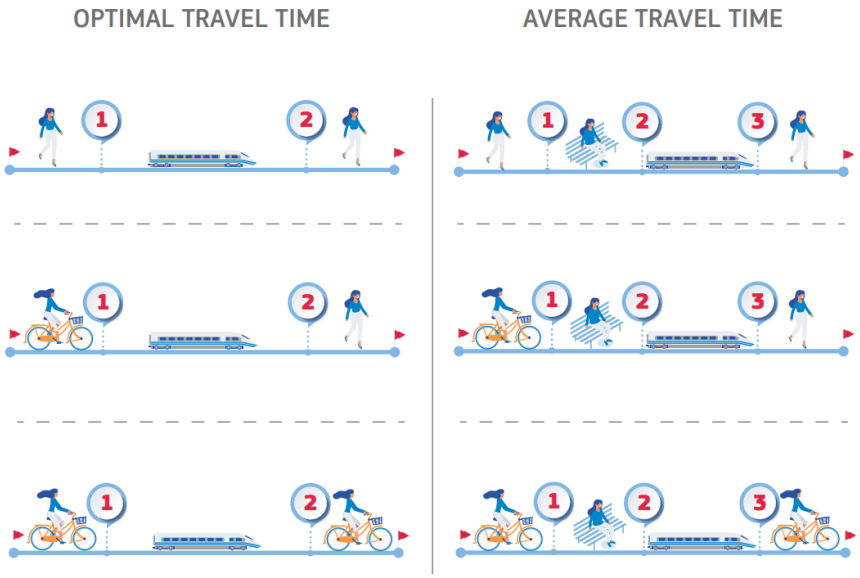


Figure 23: Difference between optimal and average travel time. Source: [30]

The results show that Denmark, Switzerland and Austria are the countries with higher transport performance, so a major portion of population can be reached within 1,5h of travel time. It also shows that when combining the travelling by bike, rail and bike, the performance increases substantially.

For the present study, the average time will be considered as this is more realistic, as well as the combination walking with rail, as this is representative of the majority of the users. The next figure show the transport performance in average time for the countries of the EU.

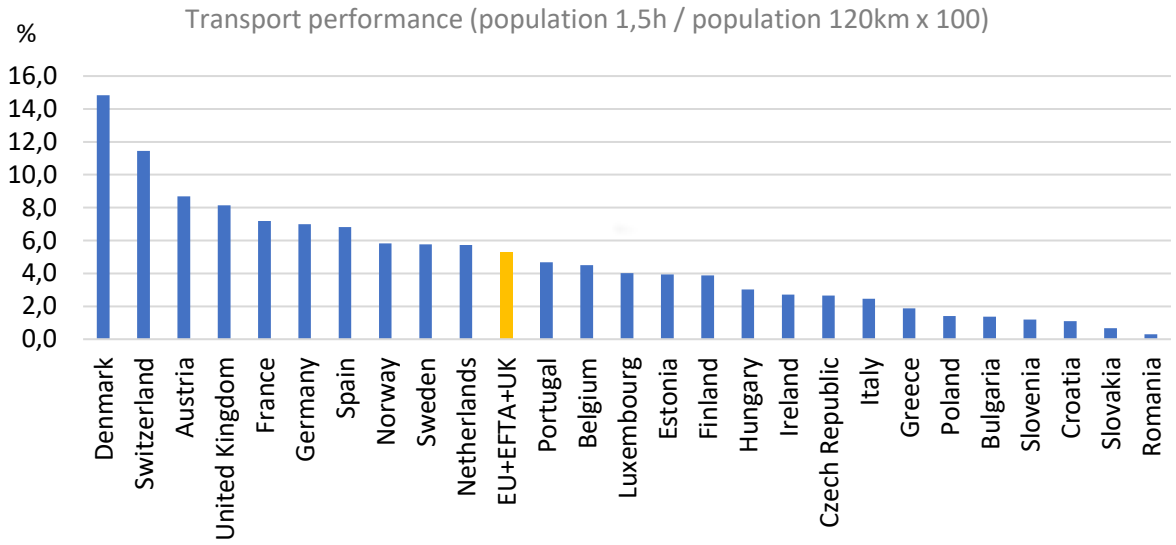


Figure 24: Population reachable in 1,5h travel time (walk + rail + walk), average time. Source: [30]

- **Punctuality ratio**

The punctuality of railways is one of the most valued factor by the passengers as seen in section 4.1.1. The EU defines punctuality when trains arrive in their destination with a maximum of 5 minutes delay by regards of the planed timetable. Switzerland, which applies a narrower definition of punctuality of a maximum delay of 2 minutes and 59 seconds, reported a 88% of punctuality in its long distance services in 2019.

Considering the 5 min punctuality concept, in Europe the most punctual systems in 2018 where Lithuania and Latvia of more than 96% of punctuality. The Baltic countries have networks with low traffic volumes, and consequently also less rail disturbances, which helps ensuring the punctuality of the railways. Instead, busier networks of France and Germany are below the average punctuality of the EU with a respective rate of 76% and 71% of punctually. Considering only the busy systems in terms of traffic, Netherlands reported the highest punctuality with 92% and Italy the worst with 53%.

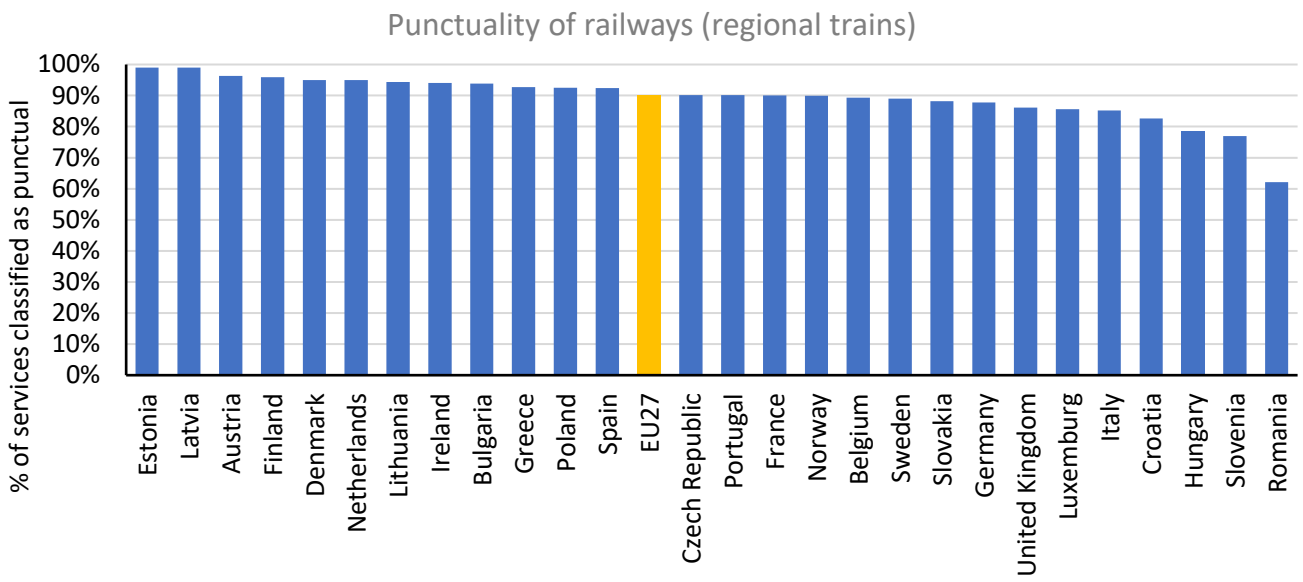


Figure 25: Percentage of regional rail services classified as punctual in Europe, 2018. Source: [27]

The punctuality is calculated for the regional and the long distance trains.

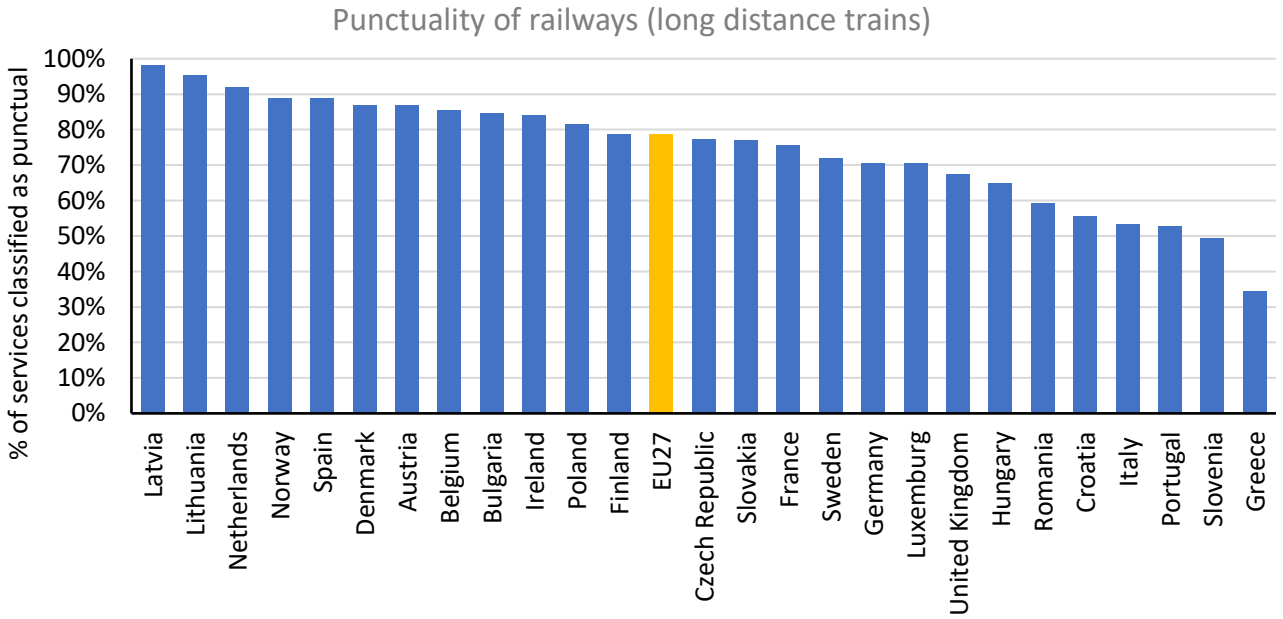


Figure 26: Percentage of long distance rail services classified as punctual in Europe, 2018. Source: [27]

- **Reliability ratio**

The reliability is calculated as the percentage of services cancelled. Data is available for regional and long distance services. For the regional trains, Norway registered the highest portion of cancelled services with a 4,3% in 2018, while the European average was about 0,18%.

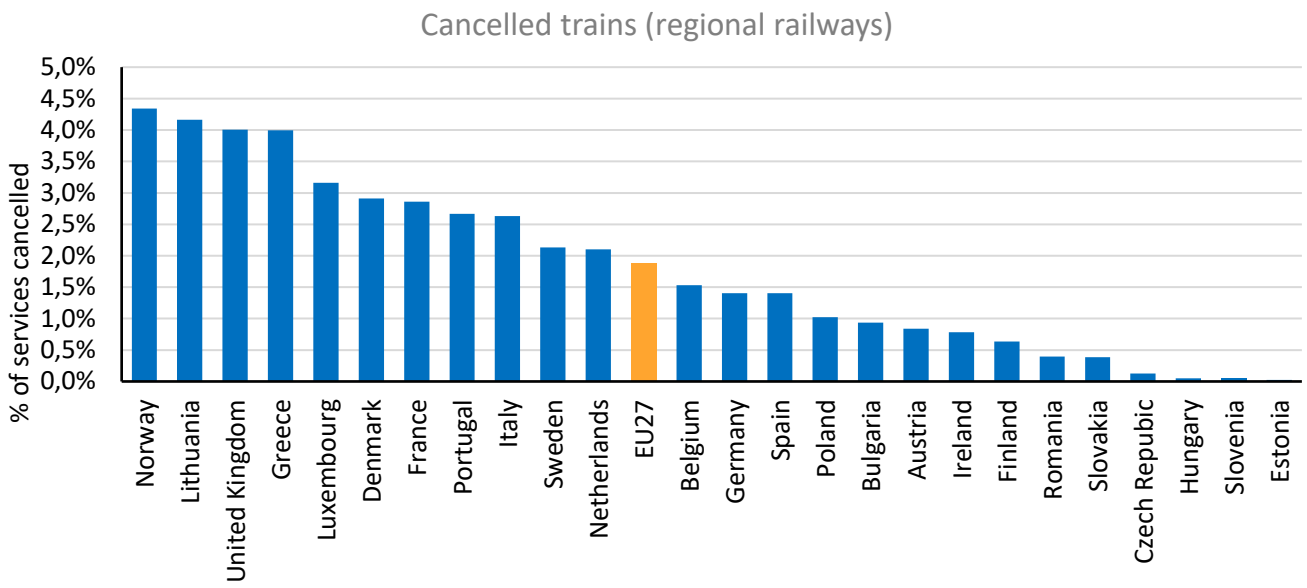


Figure 27: Reliability of regional services in Europe as percentage of trains cancelled, 2018. Source: [27]

For the long distance trains, Greece registered the highest portion of cancelled services with a 5,2% in 2018, while the European average was about 1,3%. In a majority of countries, the long distance trains are more reliable than the regional.

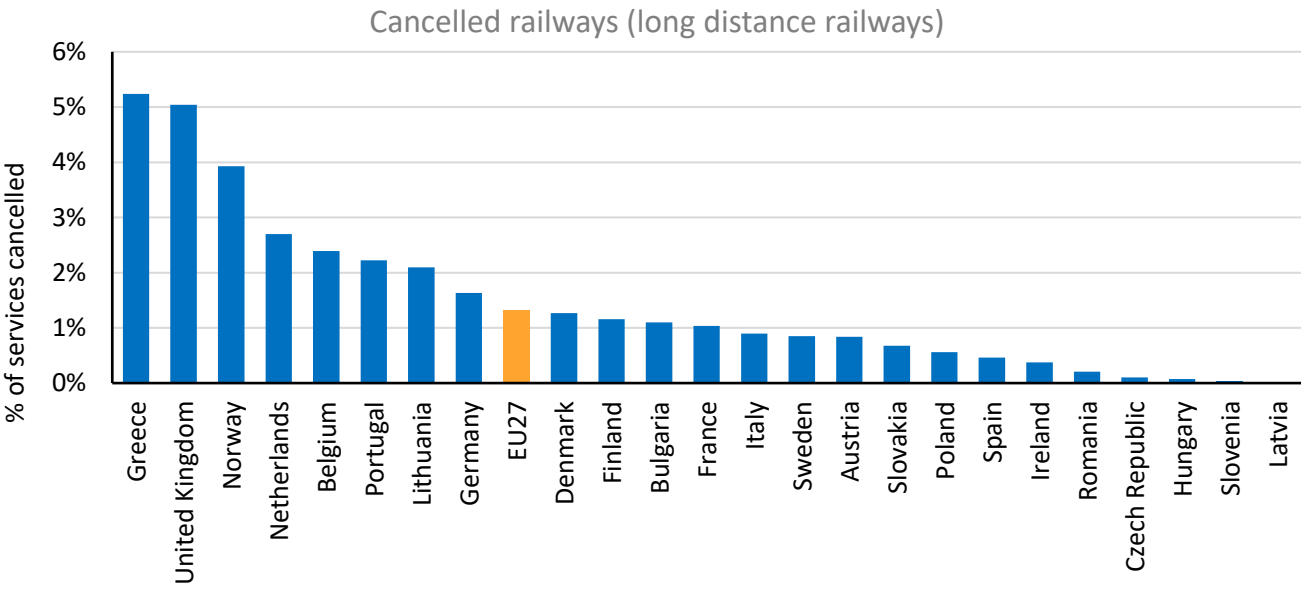


Figure 28: Reliability of long distance services in Europe as percentage of trains cancelled, 2018. Source: [27]

In this indicator the less performing systems are scoring the highest values, therefore in the next section 6 in which all reference values of the indicators will be collected, the values of this indicator will be inversed (see section 6.2.2.1).

- **Frequency**

The frequencies are calculated as the running trains per direction per hour in a considered railway line or section. Frequencies below 1, so less than a train per direction per hour, are normally considered to be non-competitive compared to road transport, and at least connections with enough demand should offer trains every hour. Frequencies around 2, so trains every half an hour, increase the passenger attractiveness substantially without the need of dedicated lines. Frequencies of around 3, so trains every 20 minutes, are found to high demand corridors and require greater capacity lines (normally equipped with double track, advanced signalling systems, etc). High frequencies of 4 or more, so trains every 15 minutes or less, are normally reserved to rapid and commuter systems.

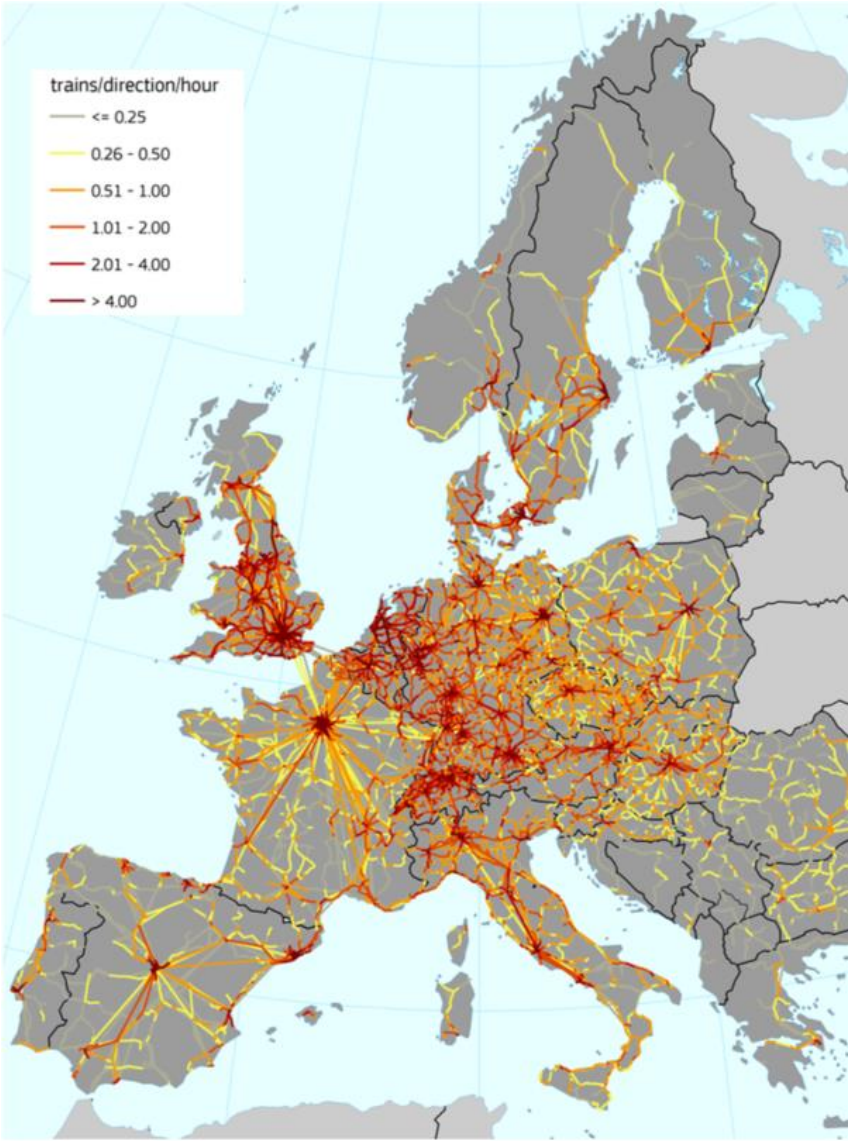


Figure 29: Frequencies of rail direct connections, 2019. Source: [27]

The highest frequencies in Europe are found in the UK and Germanic countries, with many long distance connections served with frequencies of 2 trains per hour and more. The Nordic countries are mostly served with frequencies of around 1 train per hour. The Latin countries, expect the hubs of most populous urban areas served with high frequencies, have comparatively reduced train frequencies.

Even though this summary of the situation in Europe, the source does not give numerical data for the frequencies on the countries. Thus in the present research project there will not be any objective parameter related with the frequency of railways.

- **Rail fares**

The rail fares are the prices of the tickets for travelling by train and for the present indicator are calculated as a ratio of € per km. In 2016 the European Commission [29] did a comparison of the rail fares between the European countries. All fares were shown in Purchasing power parity (PPP) adjusted euros to reflect differences in purchasing power in the different European countries, meaning that the fares shown reflect the cost for the national user relative to their standard basket of goods. The comparisons will be used here for the two types of trains, regional and long distance.

The rail fares in regional trains are shown in the next figure :

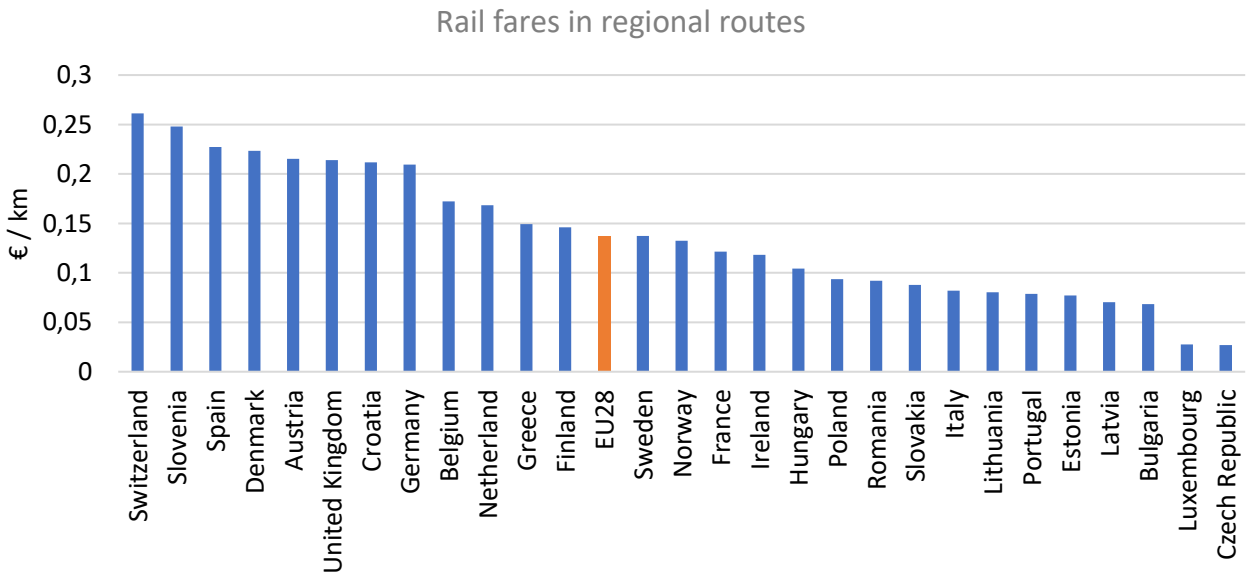


Figure 30: Rail fares in €/km of regional routes (PPP adjusted), 2016. Own creation based on [29]

The most expensive fares for the regional trains are in the UK, with almost 0,6€/km. Germany, Austria, Spain and Norway have the highest fares in continental Europe, between 0,2 and 0,3 €/km. The rail fares in long-distance trains are shown in the next figure:

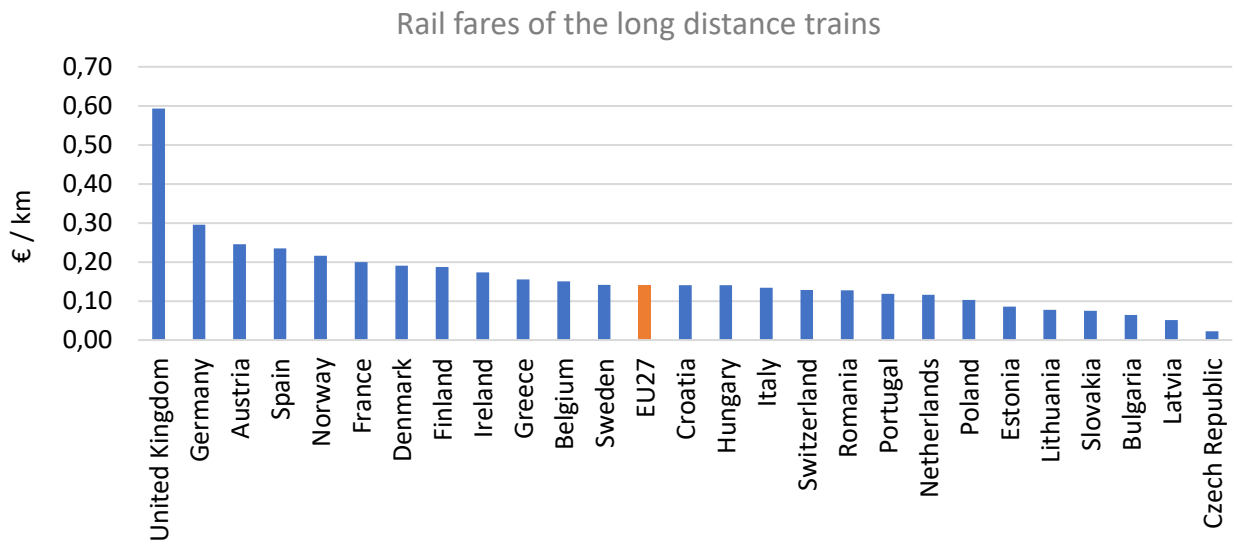


Figure 31: Rail fares in €/km of long distance routes, 2016. Own creation based on [29]

The United Kingdom present the highest prices on the day of travel, almost doubling the fare per km in Germany, the second most expensive country in Europe.

5.2.1.3 Indicators about the safety

Customers are very sensible on the safety of a transport system. The usual perception of railways is to be one of the safest transportation means. However, rail accidents do happen and specially the fatal rail accidents are ostentatious and dramatic so they tend to create huge impact in the mass media, which may create alarm within the users. According to the Eurostat [31], only 5% of the railway accidents are due to train collision although they account for the 80% of the total fatalities.

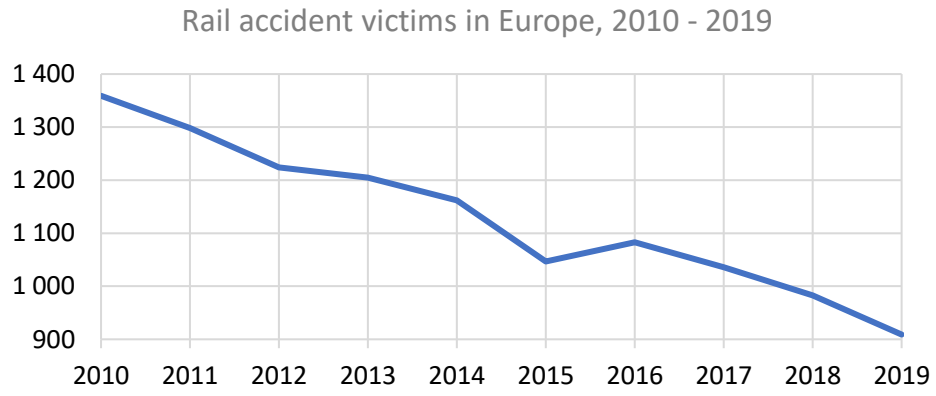


Figure 32: Evolution of rail accidents victims in Europe, 2010 – 2019. Source: [31]

Failures on the signalling system, human error and derailment provoked by excessive speed or inappropriate conditions of the track (mostly due to lack of maintenance) are within the main causes of

the rail accidents. Thus, the advanced railway systems invest heavily in reducing the risks of fatal accidents as these have a huge impact in the user's perception and consequently in the passengers choice of transport mode as seen in section 4.1.1.

The safety of a railway system is calculated considering the casualties observed in a temporal frame. In Europe, death have been decrease during the last 10 years, which shows the increase of the safest of the several network systems of the continent, mainly thanks to the measures taken by the EU and the different countries to enhance the safety of the rolling stock, the signalling system and the traffic management. The indicator used in the present thesis to evaluate the safety of the system will be the rail accident ratio exposed below.

- **Rail accident ratio**

Busier and longer systems may have higher accidents, thus the authors suggest two types of indicators to define the safety of a railway system based on the number of accident ratio [31]. On one hand the proportion of fatal accidents per railway length, which give the average of victims per kilometre of rail route and on the other hand the share of fatal accidents per traffic, which shows the victims per passenger-km. Taking into account the accidents this may vary substantially within two consecutive years, so the ratio considered in the present study uses the accumulated victims in the railways for the last 10 years.

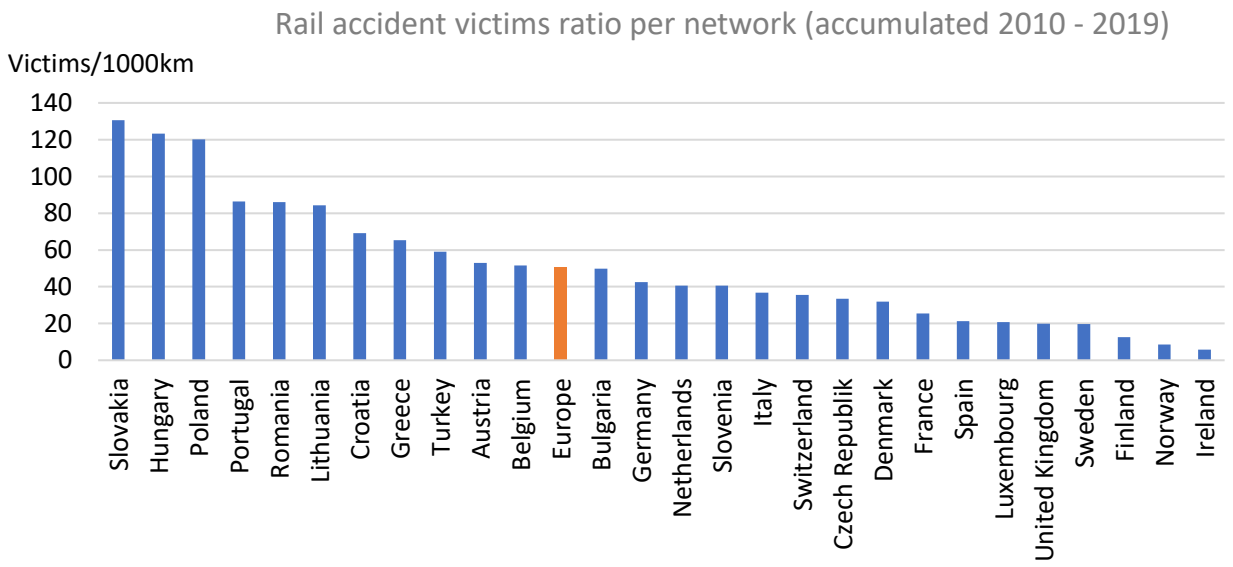


Figure 33: Rail accidents ratio per network, accumulated victims 2010 – 2019 in Europe. Own creation based on [31]

In Europe, the safest railway systems considering the number of victims per networks lengths are the Irish and Nordic railways, mostly the Norwegian and Finnish. Instead, the railways in Eastern Europe registered the major accumulated victims per rail kilometre, specially Poland, Hungary and Slovakia.

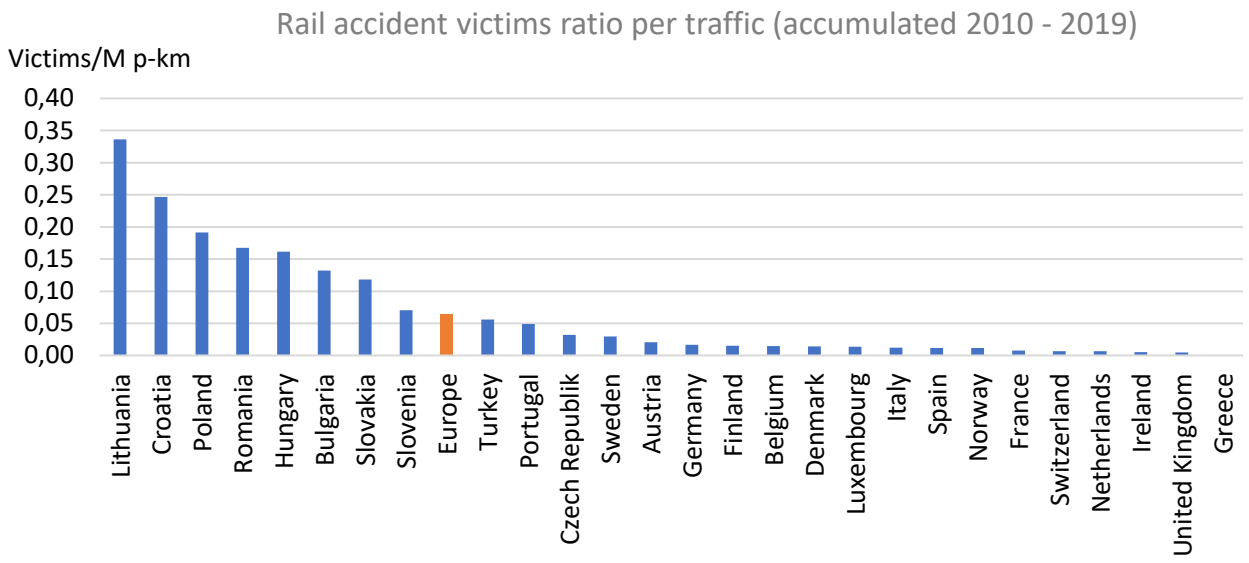


Figure 34: Rail accidents ratio per traffic, accumulated victims 2010 – 2019 in Europe. Own creation based on [31]

Considering the victims per traffic, the ranking vary slightly but the trend follow similar patrons. The British and French railways are within the safest systems especially considering the huge volumes. Instead, the Eastern countries stand out again for their higher number of victims per passenger km. Croatia and Lithuania registered the highest ratio of victims per rail traffic during the last 10 years.

5.2.1.4 Indicators about the sustainability

As seen in the section 3.3, modern railways are one of the most sustainable of the motorized transport modes. In the electrified lines, trains take current from an overhead line along their way, so no combustion engines are involved and so during the operation of the trains these don't generate emissions. This also implies a smother, noiseless and smokeless operation with enhances the comfort of the users.

Nowadays many people are aware and worried about global warming and climate change. For that users see railways as a very sustainable choice when deciding how to travel. Nonetheless, as seen before railways are not *per-se* sustainable. There are many non-electrified lines operated by diesel trains that are highly polluting. Additionally, considering the increased efforts from the car industry to move towards the electrification of the automobiles, the future of the transportation will change deeply and private transport, but also buses and other newly electrified transport systems, will become a competitor on the sustainable fight against railways. As a result transport users will becoming more demanding to the environmental impact of the system they use and more conscious on the degree that railways have a clean path.

Thus, in the present study the parameter electrified track ratio will be used to evaluate the level of electrification of the railways as indicator of the sustainability of the operation of the trains.

- **Electrified track ratio**

The electrified ratio is the proportion of rail lines equipped with electricity supply by the total network. According to the International Energy Agency, the regions with the highest share of electric train activity are Europe, Japan and Russia, while North and South America still rely heavily on diesel.

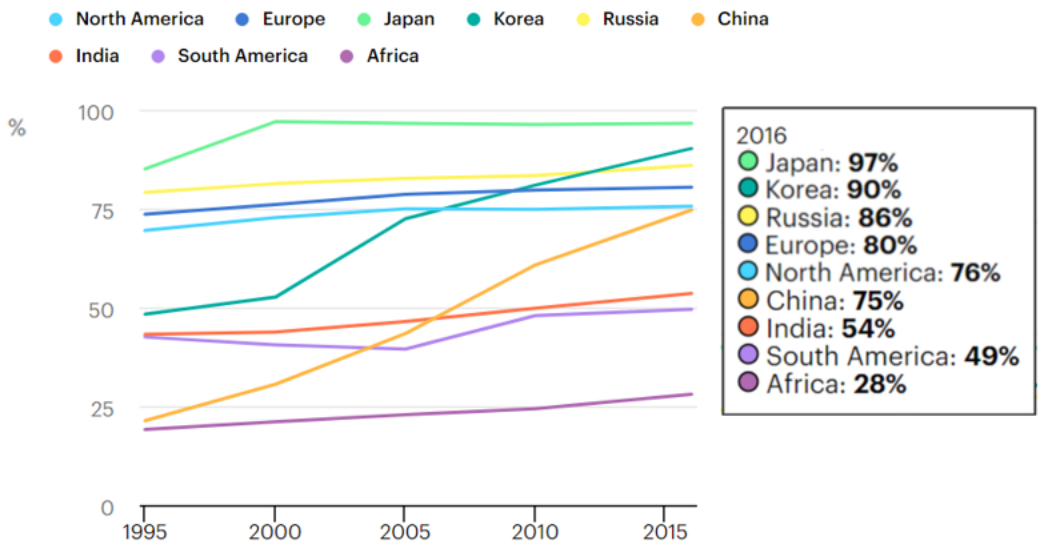


Figure 35: Share of activity on electric trains for selected countries and regions (%), 1995-2016. Source: [1]

In Europe, Switzerland is the country with highest electrification rate. Almost all its rail network is electrified, except for the few tracks on which steam locomotives operate for tourism purposes only.

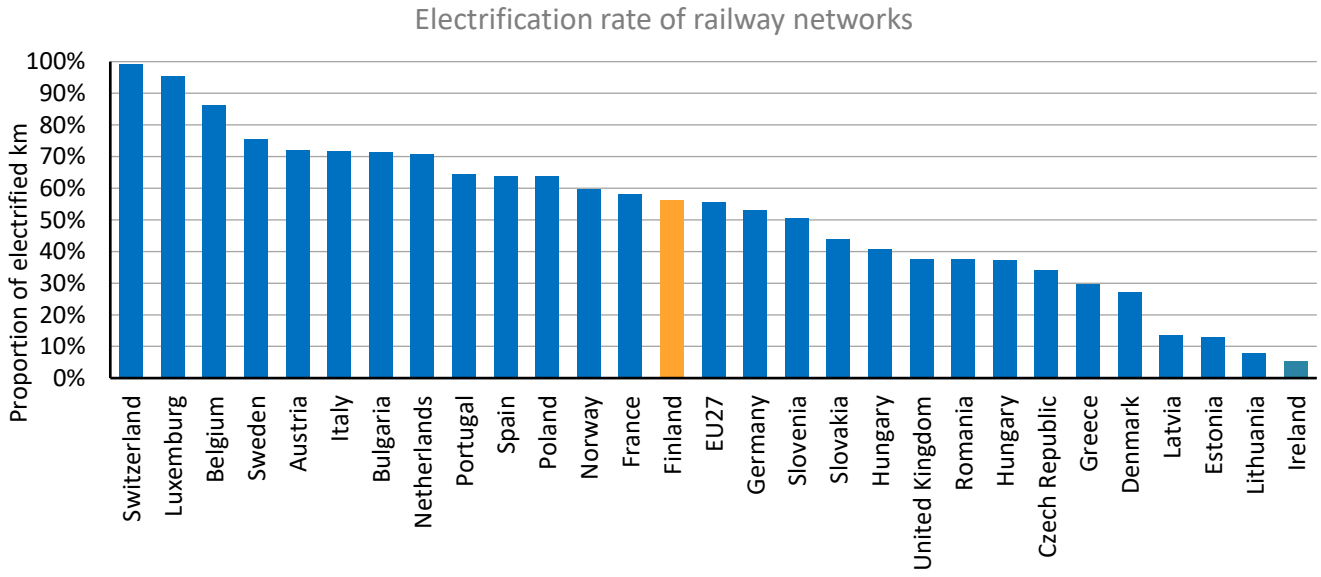


Figure 36: Electrified ratio in the railway networks of the EU. Source: [27]

In the EU Luxembourg is leading the ranking of electrified network with a 95%, as seen in this figure. It stands out the case of the United Kingdom, the third largest network in Europe, with only 38% of the lines electrified, so the most of the British railways operated by diesel trains.

5.2.2 Subjective indicators

In this section the subjective parameters obtained by customer satisfaction survey will be presented. These are related with the factors defining the demand introduced in section 4.1, but also the soft barriers described in 4.2.2. There are two sources for the data, the official Eurobarometer for the satisfaction of the passengers with railways in the EU conducted on 2018 and the survey from 2011. In the latest version of the Eurobarometer, some questions with relevant data for the present study were removed, reason why the previous version has been also used in this paper. Both surveys are part of the official statistics of the EU [24] [32].

In a similar way that the previous objective indicators, the subjective will be grouped in attribute clusters.

Cluster	Performance indicator
Connectivity	Commercial speed satisfaction
	Punctuality and reliability customer satisfaction
	Satisfaction with frequency
	Connection with rail services
	Intermodality: Connection with other modes
	Parking facilities for cars and bikes
Comfort and aesthetics	Comfort of seating areas
	Availability of seats
	Cleanliness and good maintenance of stations
	Cleanliness and good maintenance of trains
Information	Information about train timetables and platforms
	Information during the journey
	Assistance / personnel on board
Marketing and sales	Ease of buying tickets
	availability of through-tickets (for different sections or lines)
	availability of tickets for several modes (bus, tram, metro…)
	Handling complaints
Accessibility	Accessibility of stations for disabilities
	Assistance by staff for persons with disabilities
	Accessibility of trains for disabilities
Security	Security in stations
	Security on-board

Table 5: Subjective indicators overview

Each indicator will be described and the reference values within the European countries compared.

5.2.2.1 Indicators about the connectivity

These group of perception indicators are related with the satisfaction of the users with the main object of the railways, so to ensure fast, reliable, frequent and efficient connection. Thus, satisfaction with speed, punctuality, frequency and connecting services (with other modes and with other railway lines) will be included.

- **Commercial speed satisfaction**

As seen before in section 4.1.1 short travel times are within the most important factors acting as a drive to the use of railways. As objective parameters, two indicators were defined in 5.2.1.2. As subjective, the satisfaction with commercial speeds of trains is used as shown here:

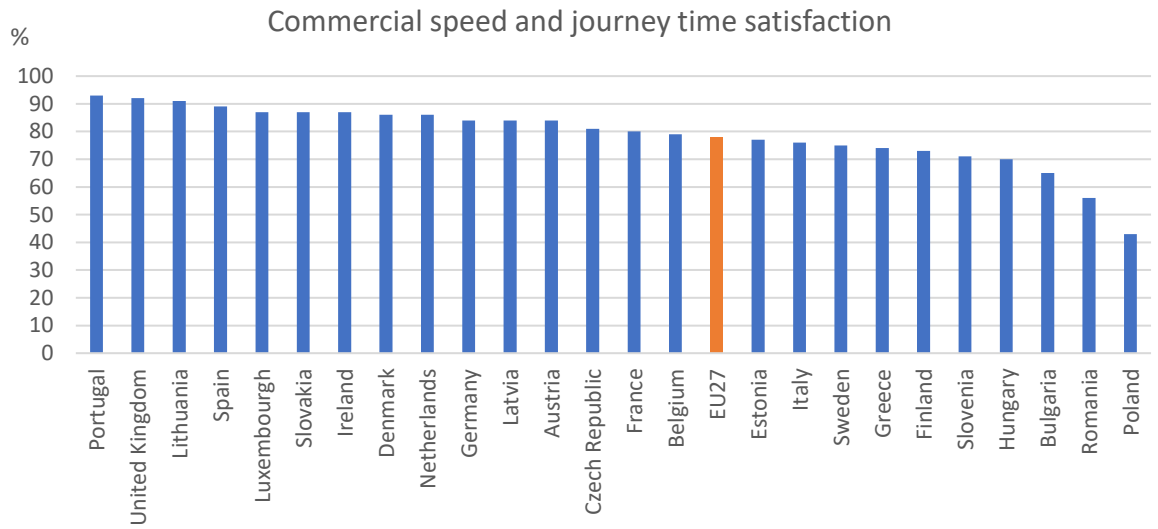


Figure 37: Percentage of satisfied population with commercial speed of railways in Europe. Source: [32]

The majority of the countries approve in terms of speed satisfaction and except for the case of Romania and Poland. There is little disparity of the results.

- **Punctuality and reliability customer satisfaction**

Additionally to the objective parameters of punctuality and reliability ratios defined in the previous section 5.2.1.2, the subjective perception of punctuality and reliability will be also considered. The results of the satisfaction survey on the punctuality of railways in the EU are shown here:

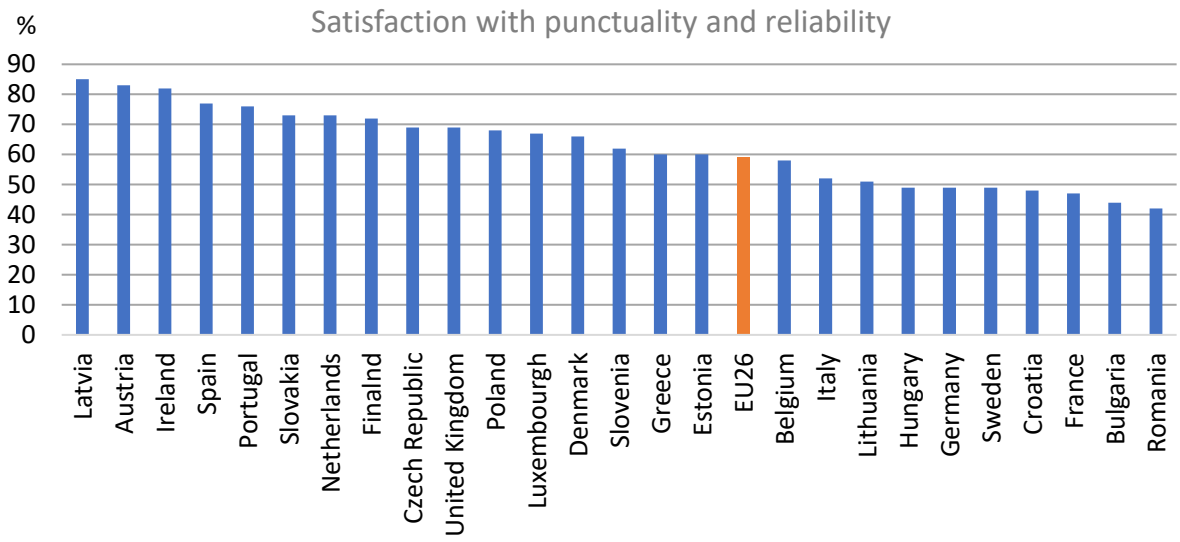


Figure 38: Customer satisfaction with the punctuality and reliability of trains in the EU, 2018. Source: [24]

Latvia is the country with the most satisfied users with the punctuality and reliability of their trains, followed by Austria and Ireland. Instead, less than 50% of the respondents in Germany and France, the two countries with highest traffic in Europe, are satisfied with this aspect and are below the EU average. The case of France is especially severe as there are more dissatisfied than satisfied.

- **Customer satisfaction with frequency**

As seen before, due to the lack of data there won't be any objective parameter defining the frequency of railways. That's the reasons why the level of the satisfaction with frequency becomes more relevant since it will be the only indicator accounting for this concept.

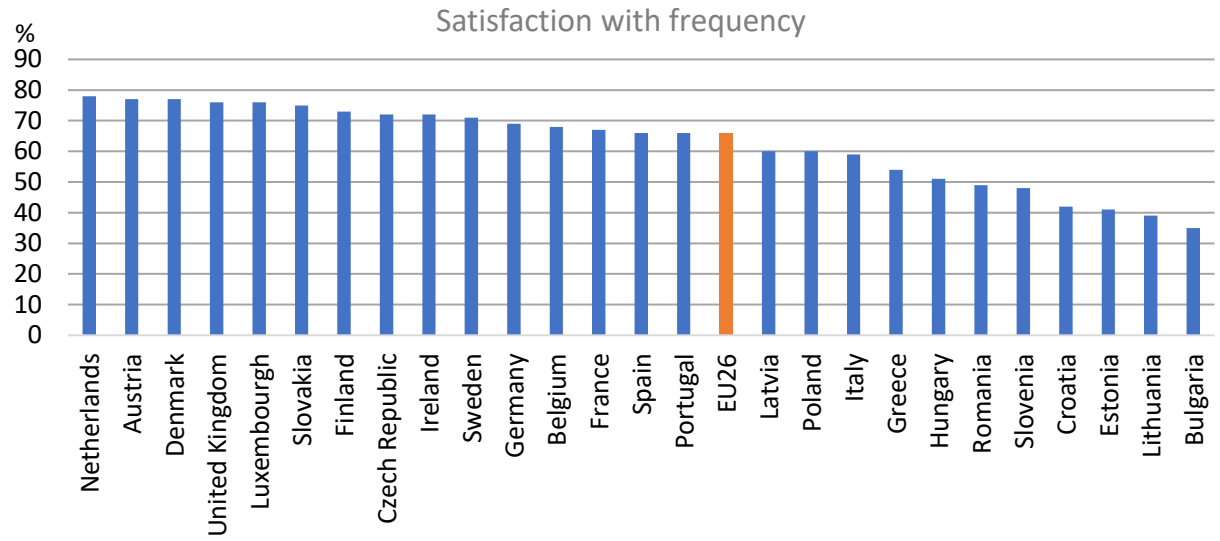


Figure 39: Percentage of satisfied population with average speed of the railways. Source: [32]

Luxembourg is the country with major satisfied users with regards to the frequency of its railways. All western countries approve on this parameter, whilst many of the eastern countries are in the bottom of the ranking with a majority of dissatisfied users.

- **Connecting services**

This indicator defines the level of satisfaction of the users with the efficiency of the transfers between different railway lines.

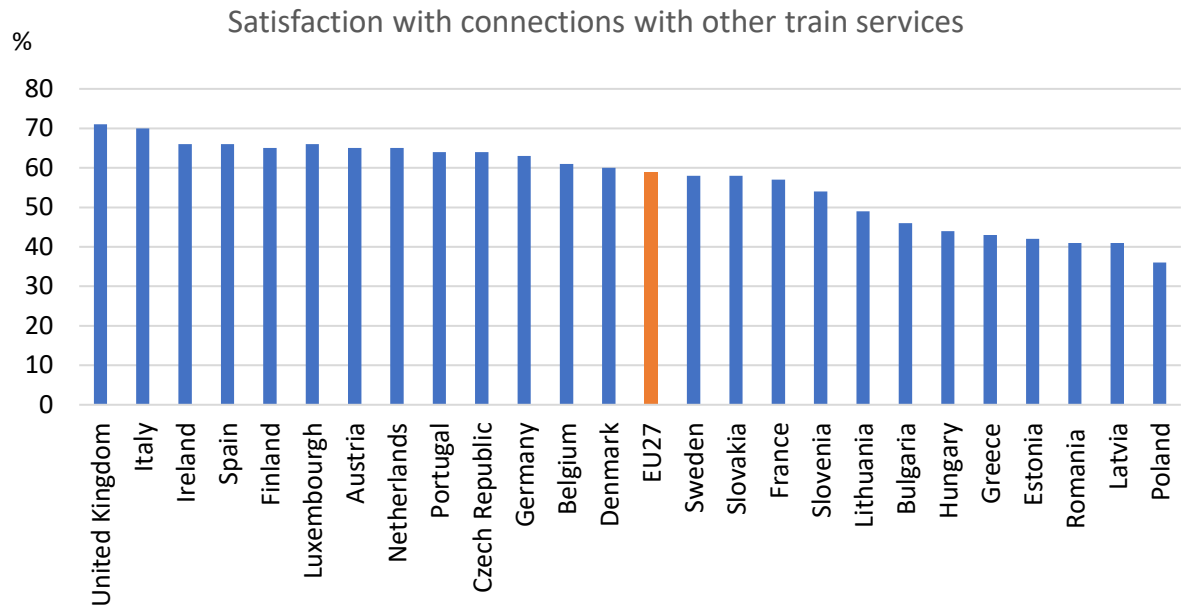


Figure 40: Percentage of satisfied population with connection with other train services in Europe. Source: [32]

United Kindgom leads the ranking with 71% of the satisfied users. All western countries approve on this parameter whilst many eastern countries the level of satisfaction is below 50% suggesting the users don't find transfer between rail services efficient.

- **Connection with other modes**

This indicator defines the level of efficiency of synchronization between railway services and other transport modes such as buses, metros and tramway.

All countries approve on the level of satisfaction. Western countries rank better than eastern, as well as the Baltic countries that also show satisfaction levels above the average in the EU.

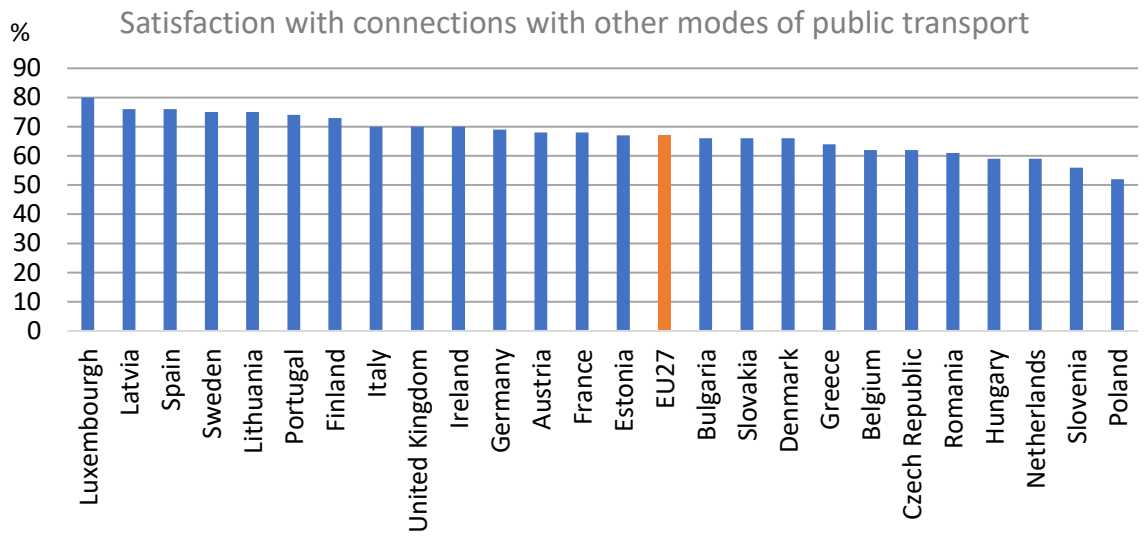


Figure 41: Percentage of satisfied population with connections with other modes of public transport. Source: [32]

Netherlands show relatively poor levels of satisfaction which contrast with other positive perception, most probably due to the higher expectation of the users in the country.

- **Parking facilities**

Finally, the availability of parking slots for cars and bikes next to the stations also ensures the connectivity of the users.

Figure 42: Customer satisfaction with the parking facilities in the EU, 2018. Source: [24]

Only 7 countries in the EU showed a majority of satisfaction regarding the parking facilities next to the rail stations, with the Netherlands as the country with most of the users being satisfied. Spain, Sweden and Italy are below the EU average and have many dissatisfied respondents, especially the Italians.

5.2.2.2 Comfort and aesthetics

This group is defined by several attributes related with the soft factors seen in section 4.2.2, the comfort and availability of seat and the cleanliness and good maintenance of trains and stations. All them are subjective parameters given by the survey of satisfaction to rail users.

- **Comfort of seating areas**

This takes into account the perception of comfort about the seats inside the rail carriages.

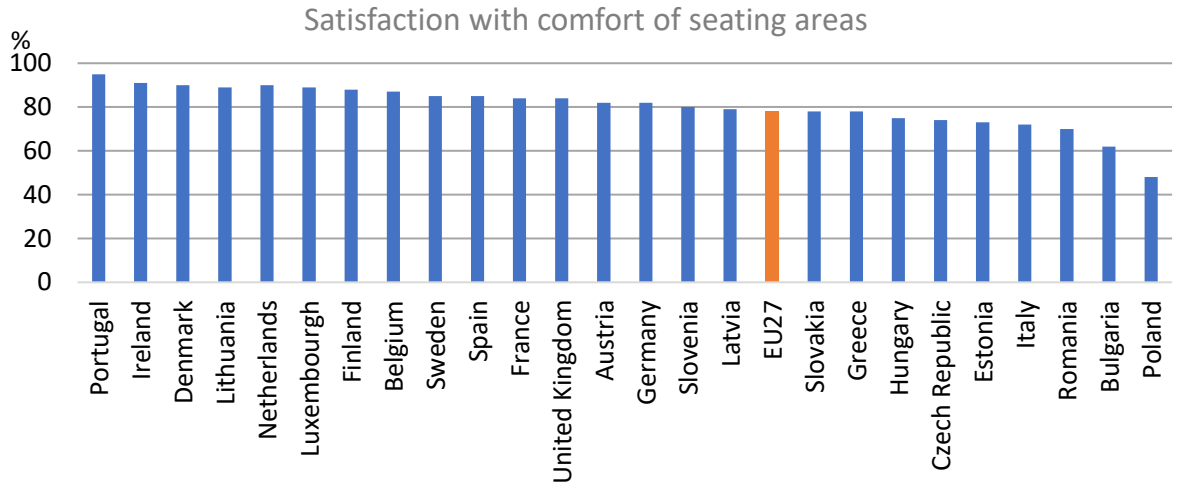


Figure 43: Customer satisfaction with the comfort of seats on trains in the EU, 2018. Source: [24]

Portugal is the country where users are more satisfied with the comfort of the seats followed b Ireland and Denmark. Instead, In Poland less than 50% of the users found the seats of their trains comfortable.

- **Availability of seats**

This indicators is the satisfaction of the users with the capacity to find free seats during their journeys in the railways.

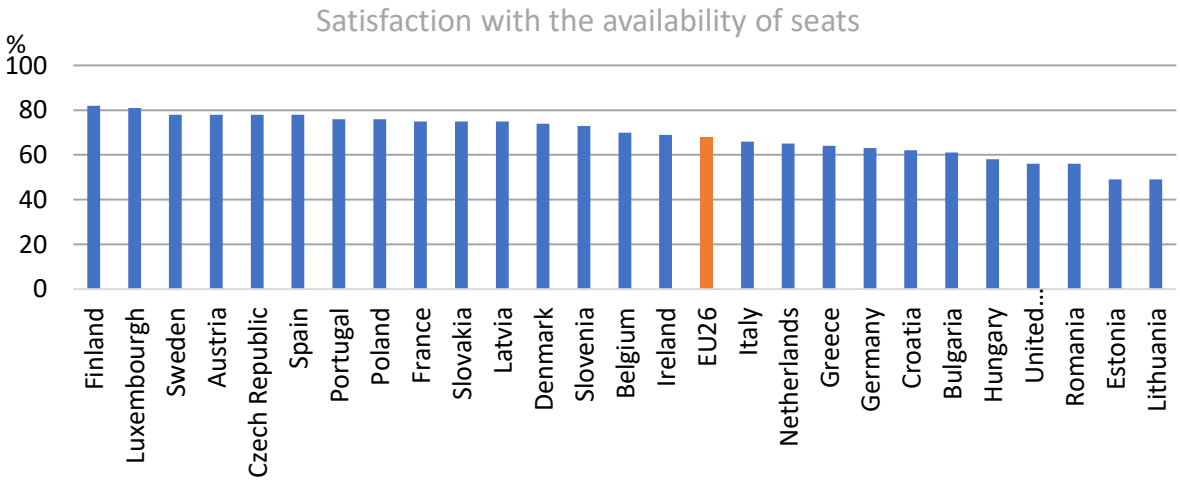


Figure 44: Customer satisfaction with the availability of seats on trains in the EU, 2018. Source: [24]

A relative majority of respondents in all countries is satisfied with the availability of seats, even though in Germany and specially the United Kingdom a considerable portion of respondents are dissatisfied.

- **Cleanliness and good maintenance of stations**

Clearly the stations that are clean and correctly maintained will have an attractive effect to the users.

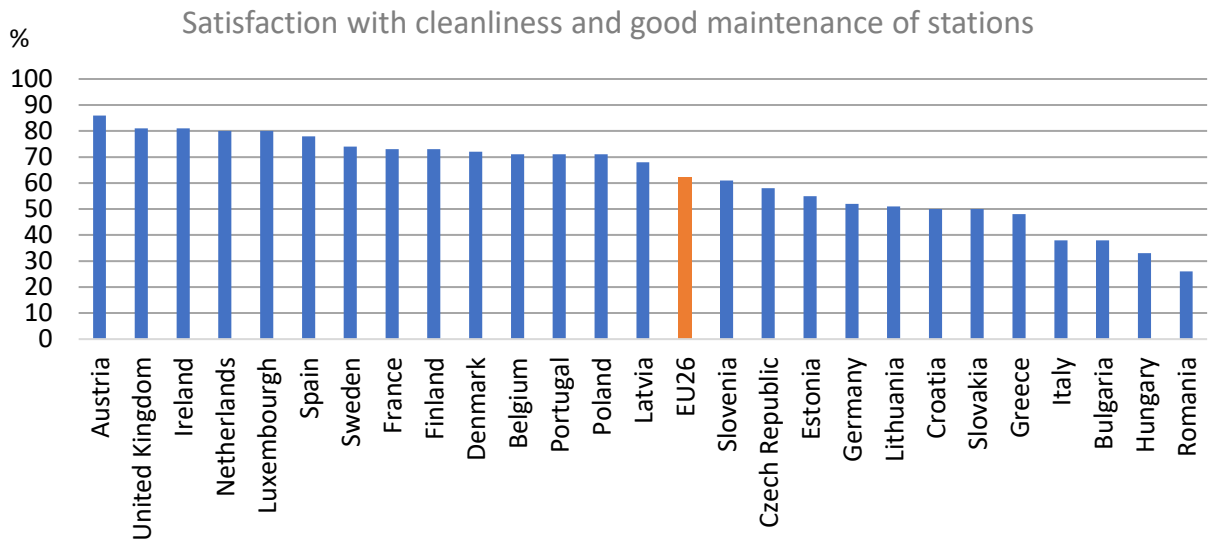


Figure 45: Customer satisfaction on cleanliness and maintenance of stations in the EU, 2018. Source: [24]

In the most of the countries in the EU users are satisfied with the cleanliness and maintenance of the stations, especially in Austria. Germany is below the average and the case of Italy is particularly outstanding, where the majority of the users are dissatisfied.

- **Cleanliness and good maintenance of trains (including train toilets)**

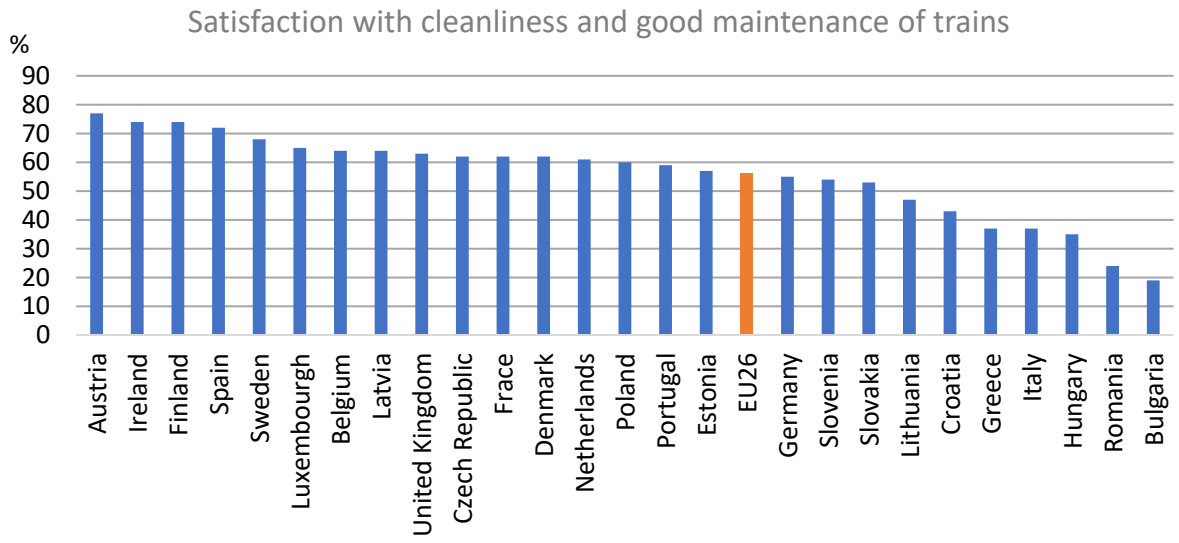


Figure 46: Customer satisfaction with the cleanliness and maintenance of trains in the EU, 2018. Source: [24]

Even more important for the attraction to the users is the cleanliness of the trains since normally is where passengers spend most of the time during the travel. This indicators also includes the good functioning of the toilets, which might be very valued for many users, especially in long distance trips.

The perception of cleanliness and maintenance of the trains also show a big disparity as for the previous aspect. Austria is leading the satisfaction ranking, whilst Italy stands out with very few satisfied and a majority of dissatisfied users, same as Greece, Romania and Bulgaria, which are in the bottom.

5.2.2.3 Information provision

Several authors pointed the importance of the information for the users. These group of indicators include the satisfaction with all information channels that users get: before the trip, on station and during the trip.

- **Information about timetables and platforms**

In all but one country, the majority of respondents are satisfied with the information about train timetables and platforms being Slovakia with major satisfied respondents.

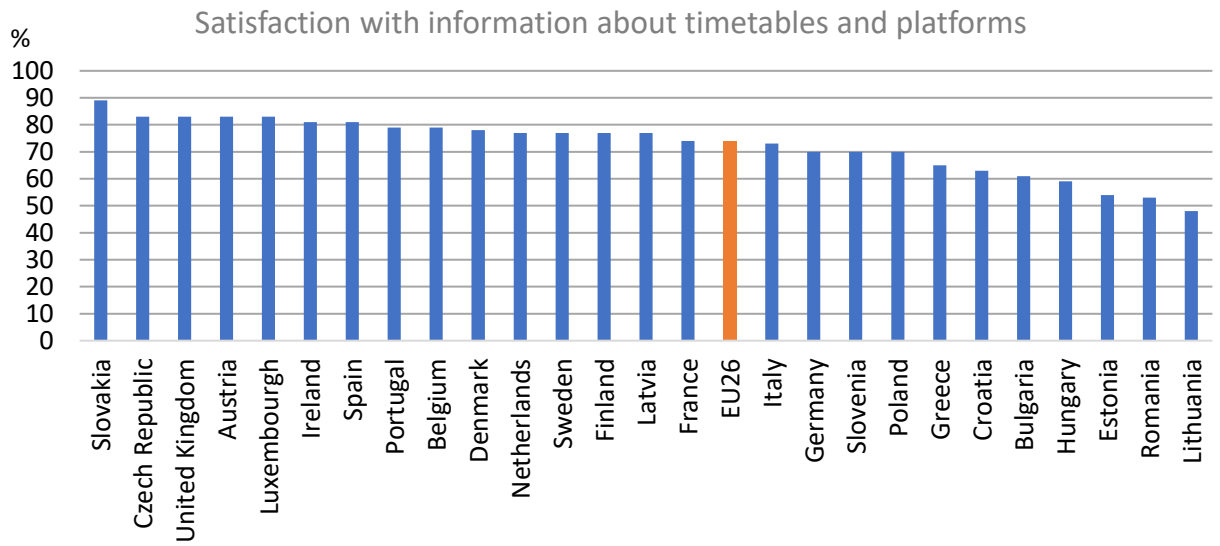


Figure 47: Customer satisfaction with information about timetables and platforms in the EU, 2018. Source: [24]

In general central and western European countries have more satisfied users. Italy and Germany are however below the EU average. Lithuania is the only country with less than 50% of the satisfied users.

- **Information during journey (particularly in case of delay)**

The Irish and British and Finnish respondents are the most satisfied with the information of their railway during the journey especially in case of delay. Countries with huge passenger volume such as Italy are

below the European average and Germany and France do not reach the 50% of the satisfied respondents. Bulgaria and Romania scores the lowest satisfaction and there are more dissatisfied.

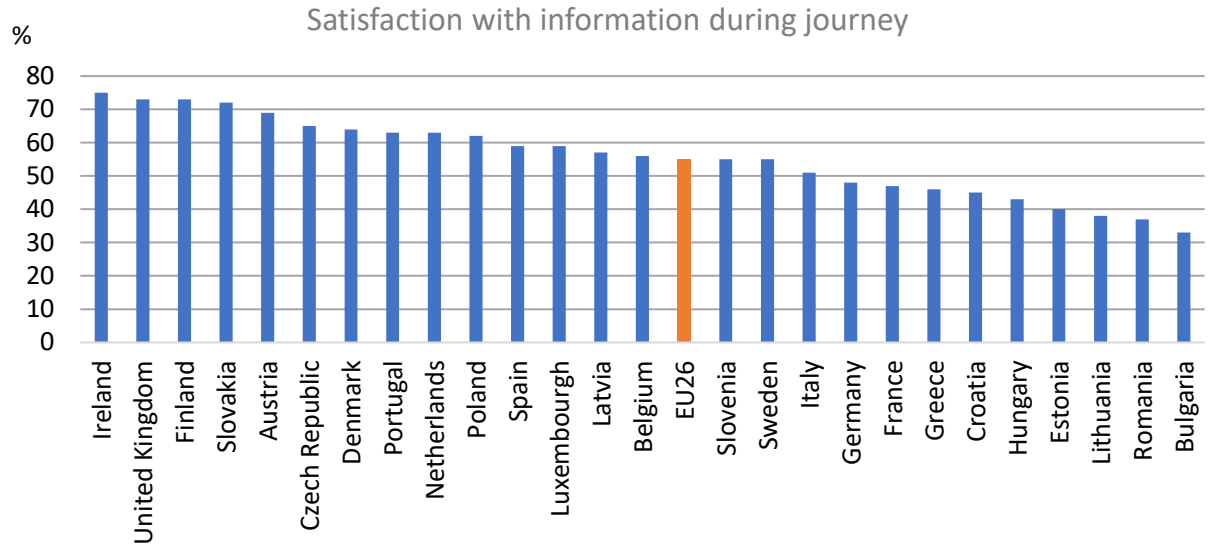


Figure 48: Customer satisfaction with the information during the rail journey in the EU, 2018. Source: [24]

- **Assistance on trains**

There is a big disparity of the perception of the availability of assistance on board the trains. Austria leads the ranking of satisfaction with a clear majority of respondents satisfied. France and the Netherlands are below the European average and in Italy less than 50% of the users are satisfied. The Balkans and Baltic register the less satisfied respondents.

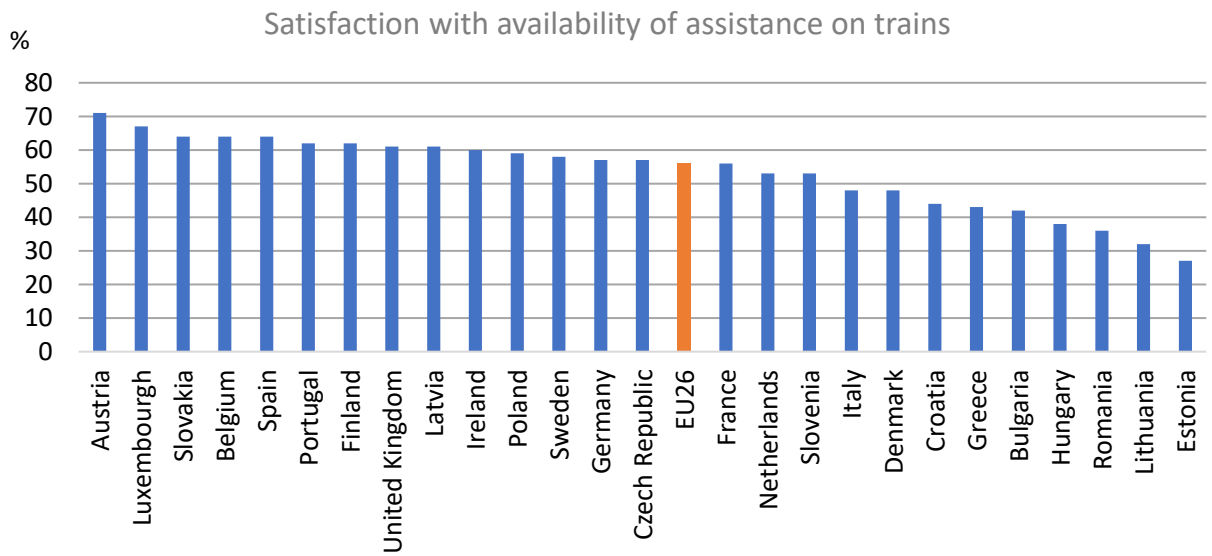


Figure 49: Customer satisfaction with the assistance on-board in the EU, 2018. Source: [24]

5.2.2.4 Accessibility for persons with reduced mobility

Three attributes conform the accessibility for persons with reduced mobility (PRM): the accessibility in trains and stations and the availability of staff with specific skills to assist the PRM's.

- **Accessibility of stations or platforms**

This is the satisfaction of the users with the features of stations to allow access of PRM, including lifts, ramps and other systems to reduce mobility barriers.

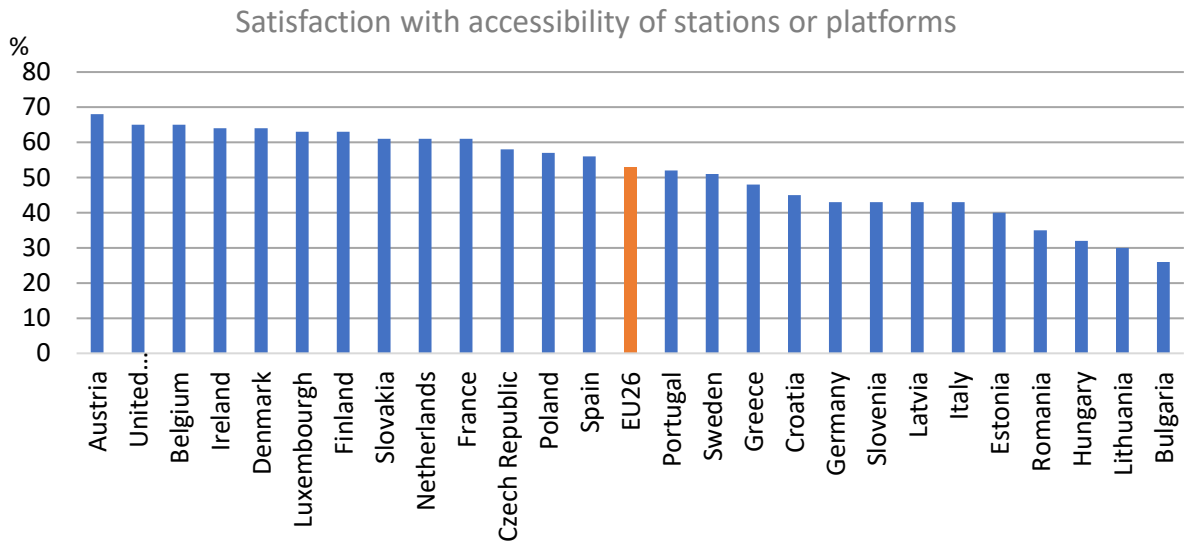


Figure 50: Customer satisfaction with the accessibility of stations in the EU, 2018. Source: [24]

- **Assistance by staff for persons with disabilities**

This is the satisfaction of the users with the availability of staff in stations and trains equipped with the necessary skills for the assistance to PRMs.

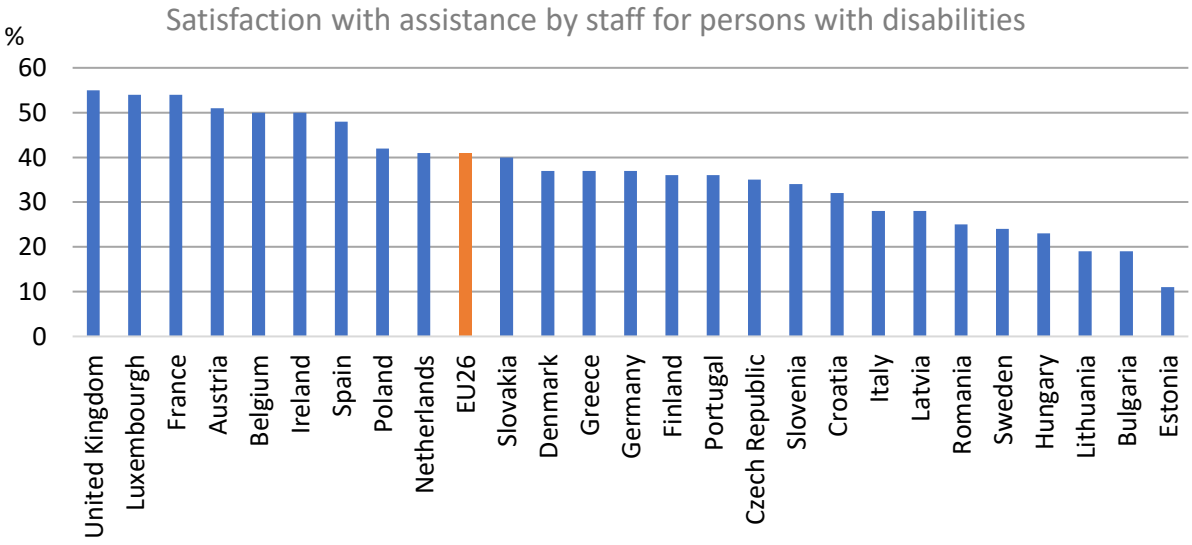


Figure 51: Customer satisfaction with the assistance for persons with disabilities in the EU, 2018. Source: [24]

- **Accessibility of train carriages**

This is the satisfaction of the users with the features of trains to allow access of PRM, including sliding steps, low floor carriages, toilets adapted for PRMs etc.

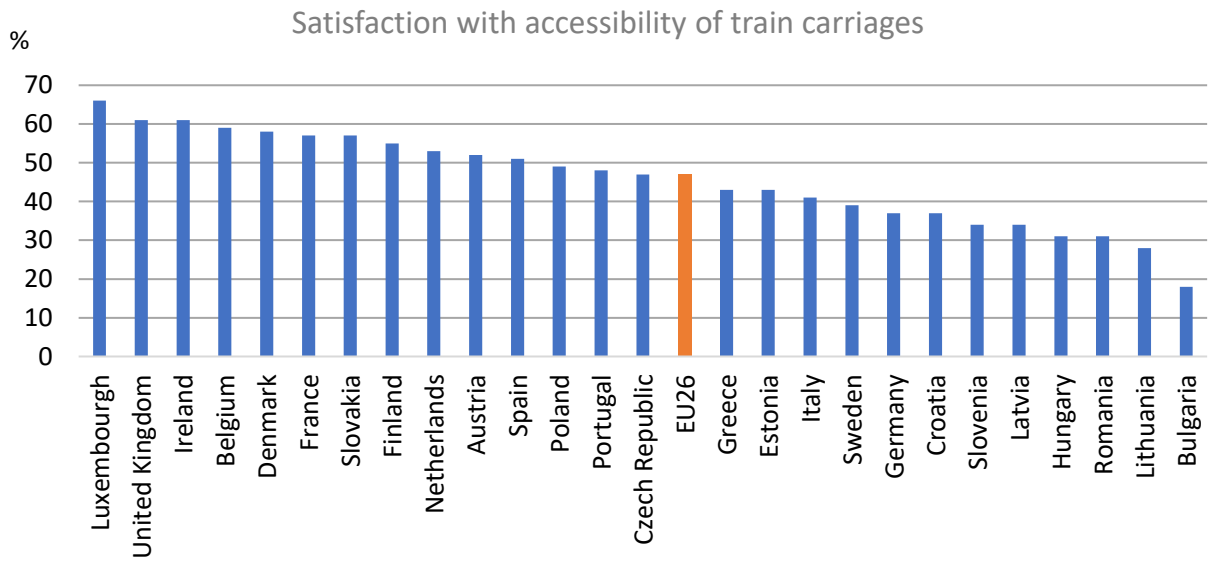


Figure 52: Customer satisfaction with the accessibility of trains for persons with reduced mobility. Source: [24]

5.2.2.5 Marketing and sales

There are several indicators for the prices, tickets and after-sales. First, the prices of the tickets which are objective parameters, second the satisfaction with getting tickets, with flexibility of the tickets and with handling a complaint.

- **Ease of buying tickets**

In all European countries the majority of respondents are satisfied with process of buying tickets. Slovakia is leading the ranking, while countries with intensive use of rail such as Germany and Netherlands score lower on this aspect.

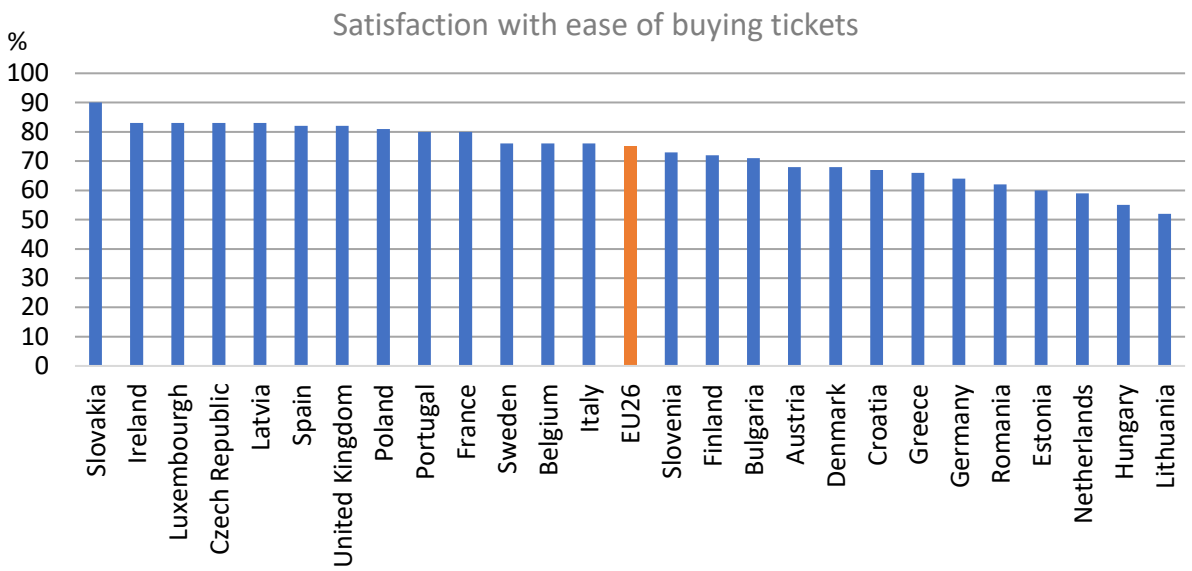


Figure 53: Customer satisfaction with the ease of buying tickets in the EU, 2018. Source: [24]

- **Availability of tickets for journeys using several modes of transport**

The users of many countries are satisfied with the availability of tickets for a journey using several modes, for example tram, metro, bus or local trains. Luxembourg is the leader of the ranking with 80% of the respondents being satisfied. Hungary, Bulgaria, Estonia and Lithuania are in the bottom even though large proportion say the question is not applicable.

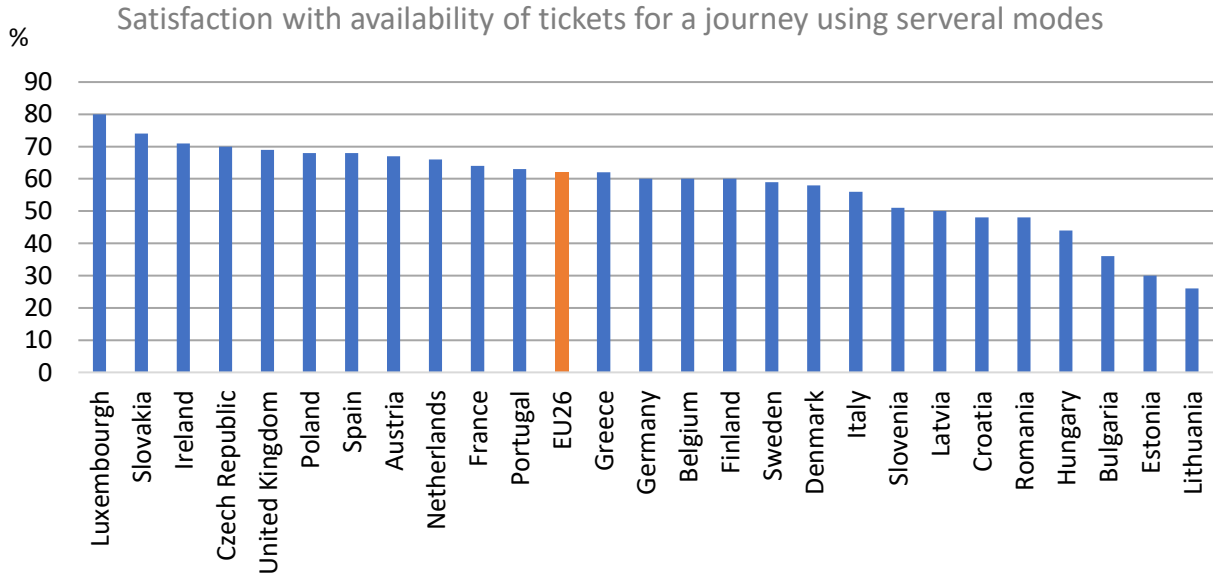


Figure 54: Customer satisfaction with the tickets for journey using several modes in the EU. Source: [24]

- **Handling a complaint**

Only three countries show a majority of satisfaction regarding the process of handling a complaint: Luxembourg, Spain and Ireland, in all the rest satisfied respondents are below 50%. Germany and the Netherlands are below the European average, with only 34% and 31% of satisfaction, and in Italy there are more dissatisfied users. Lithuania and Estonia register the lowest satisfaction portion in Europe.

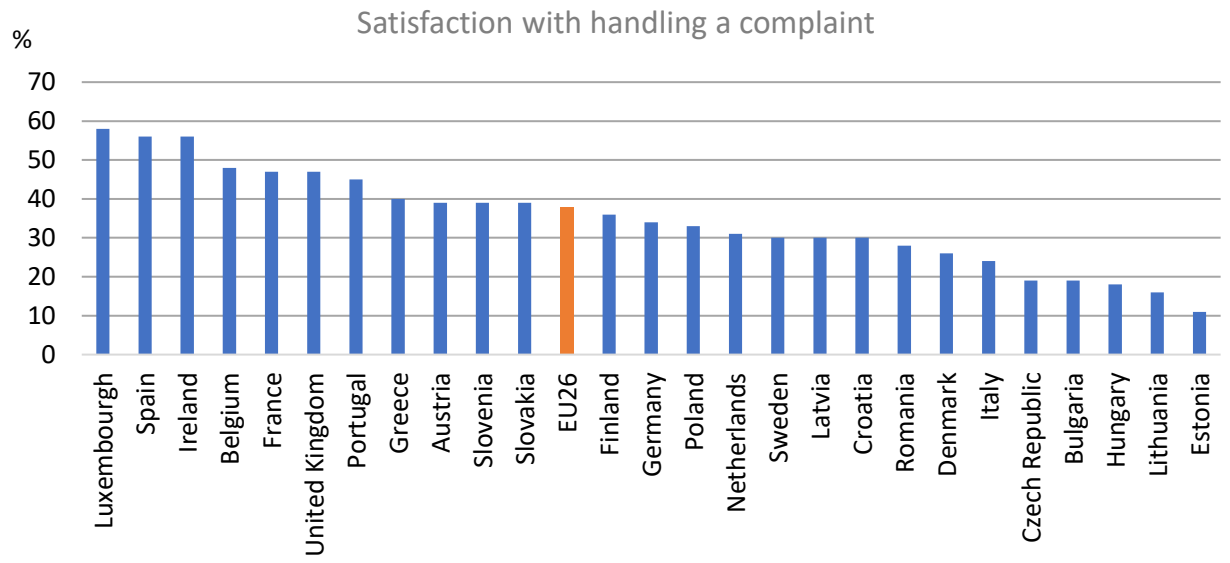


Figure 55: Customer satisfaction of handling a complaint in the EU, 2018. Source: [24]

It must be noted that there are very high levels of 'not applicable' and 'don't know' responses in a number of countries.

5.2.2.6 Security perception

Finally, there are two indicators showing the different levels of satisfaction of the users with their personal security in stations and trains against crime and delinquency.

- **Security in stations**

In Finland respondents show the major satisfaction with security in stations. All countries in Europe show more than 50% of the users satisfied with this concept.

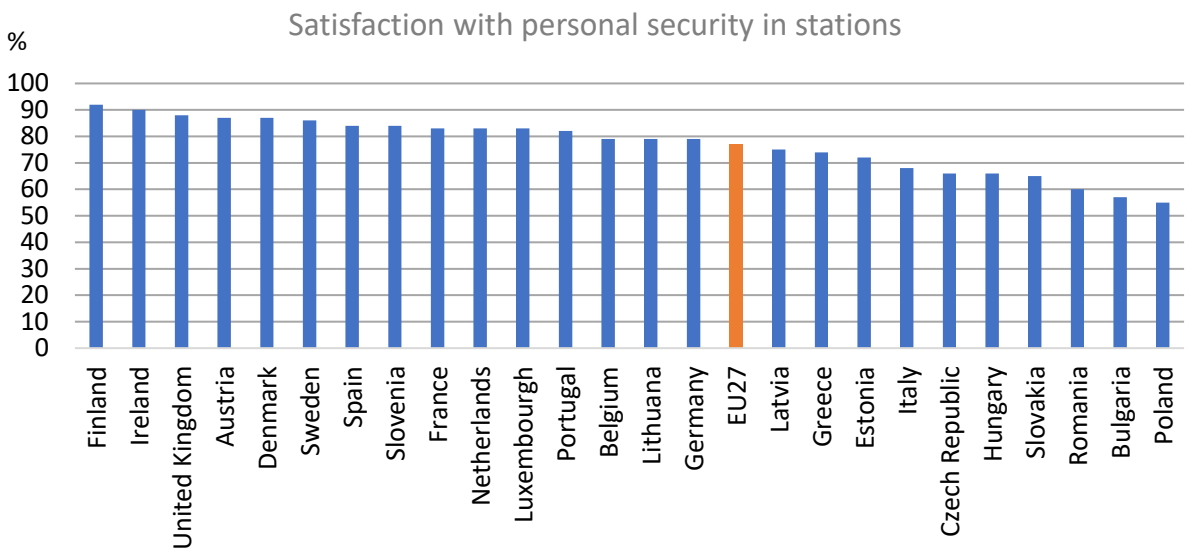


Figure 56: Percentage of satisfied population with security in stations. Source: [32]

- **Security on board**

Regarding the security on board, Finland also shows the major satisfaction of the users:

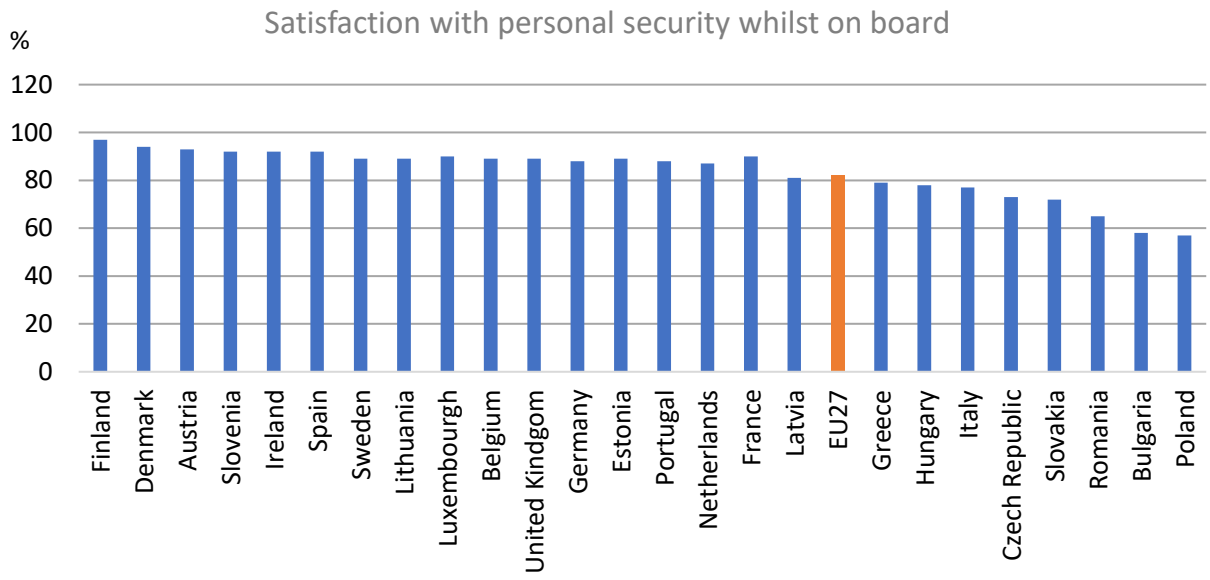


Figure 57: Percentage of satisfied population with security on board of the railways. Source: [32]

5.3 Combination of KPI within performance categories

Once all the performance indicators are defined, these will be grouped into categories in a similar way than the research studies of the CE Delft seen in Table 1. For that the 32 indicators will be classified into the following 10 categories:

1. **Network reach:** it measures the extension of the network relative to the area and population.
2. **Travel time:** takes into account commercial speeds, satisfaction with speeds and transport performance.
3. **Punctuality and reliability:** mixes measure of the objective rates of punctuality and reliability as well as the satisfaction with them.
4. **Frequency:** as said before, since there is no KPI for the objective values of frequencies, this takes into account only satisfaction of the users with frequency.
5. **Convenience:** this is analysed considering only subjective attributes, the satisfaction with the connection with other lines, the connections with other modes of transport and parking slots.
6. **Comfort and travel experience:** it takes into account all factors that contribute to the feelings of the passengers and their perception of comfort before an during the trip. This includes information, availability of seats and appearance of stations and trains.
7. **Prices, marketing and sales:** mixed measure of the rail fares and the perception of how easy users get tickets and make complains.
8. **Accessibility:** it considers three subjective parameters defining the level of accessibility for persons with reduced mobility.
9. **Safety and security:** it measures the objective safety of the system and the perception of security.
10. **Sustainability:** considering the electrification rate of the lines it is a measure of the sustainability of the network.

All the quality indicators that will be used in the present research study are summarized in the next table and will be defined in the next subsections.

Category	#	KPI	Units
1. Network reach	1	Route density per km (km of rail route / country area)	km /k km2
	2	Route density per capita (km / inhabitant)	Km/ m. inh
2. Travel time	3	Average speed of trains	km/h
	4	Transport performance	%
	5	Commercial speed satisfaction	%
3. Punctuality and reliability	6	Punctuality (% of trains with delay <5min)	%
	7	Reliability (% of cancelled trains)	%
	8	Punctuality and reliability customer satisfaction	%
4. Frequency	9	Satisfaction with frequency	%
5. Convenience	10	Connection with rail services	%
	11	Intermodality: Connection with other modes	%
	12	Parking facilities for cars and bikes	%
	13	Comfort of seating areas	%

6. Comfort and travel experience	14	Availability of seats	%
	15	Cleanliness and good maintenance of stations	%
	16	Cleanliness and good maintenance of trains	%
	17	Information about train timetables and platforms	%
	18	Information during the journey	%
	19	Assistance / personnel on board	%
7. Prices, marketing and sales	20	Rail fares	€ / km
	21	Ease of buying tickets	%
	22	availability of through-tickets (for different sections or lines)	%
	23	availability of tickets for several modes (bus, tram, metro…)	%
	24	Handling complaints	%
8. Accessibility	25	Accessibility of stations for disabilities	%
	26	Assistance by staff for persons with disabilities	%
	27	Accessibility of trains for disabilities	%
9. Safety	28	Fatalities per length	Victims / 1000 km
	29	Fatalities per traffic	Victims / M pass. x km
	30	Security in stations	%
	31	Security on-board	%
10. Sustainability	32	Electrified ratio (% of electrified lines)	%

Table 6: Key performance indicators and performance categories. Own creation.

There are indicators that are more relevant for the attraction of passengers, so that their effect is higher as potential motivator for the usage of railway, or for a barrier. Thus, in the next section 6 internal correlations will be defined to stablish which are the importance of each parameters. These indicators will be used in the next sections to develop an assessment method for a railway system.

6. Performance evaluation of a rail network

In this section an evaluation framework of the performance of a railway system will be developed. This will serve as an analysis tool of the level of attractiveness to users of each attribute of the railway.

The inputs to the model will be the key performance indicators defined in the previous section. The outcomes will be numeric values indicative of which factors require the major improvements.

At first the existing Index RPI will be presented as this is the basis and inspiration of the model here developed. Then the model will be described and finally the further actions presented. Whilst this point describes the construction of the model, the next sections will include the validation with the case study of the Spanish railways in order to verify the effectiveness of the tool. At the final sections, the model will be applied with further cases in order to exemplify the functionality and utility of the model.

6.1 European Railway Performance Index

The European Railway Performance Index "RPI" developed by the Boston Consulting Group [33] measures the performance of railway system in three dimensions: intensity of use, quality of service and safety rating. This Index serve as inspiration for the construction of the framework of the thesis.

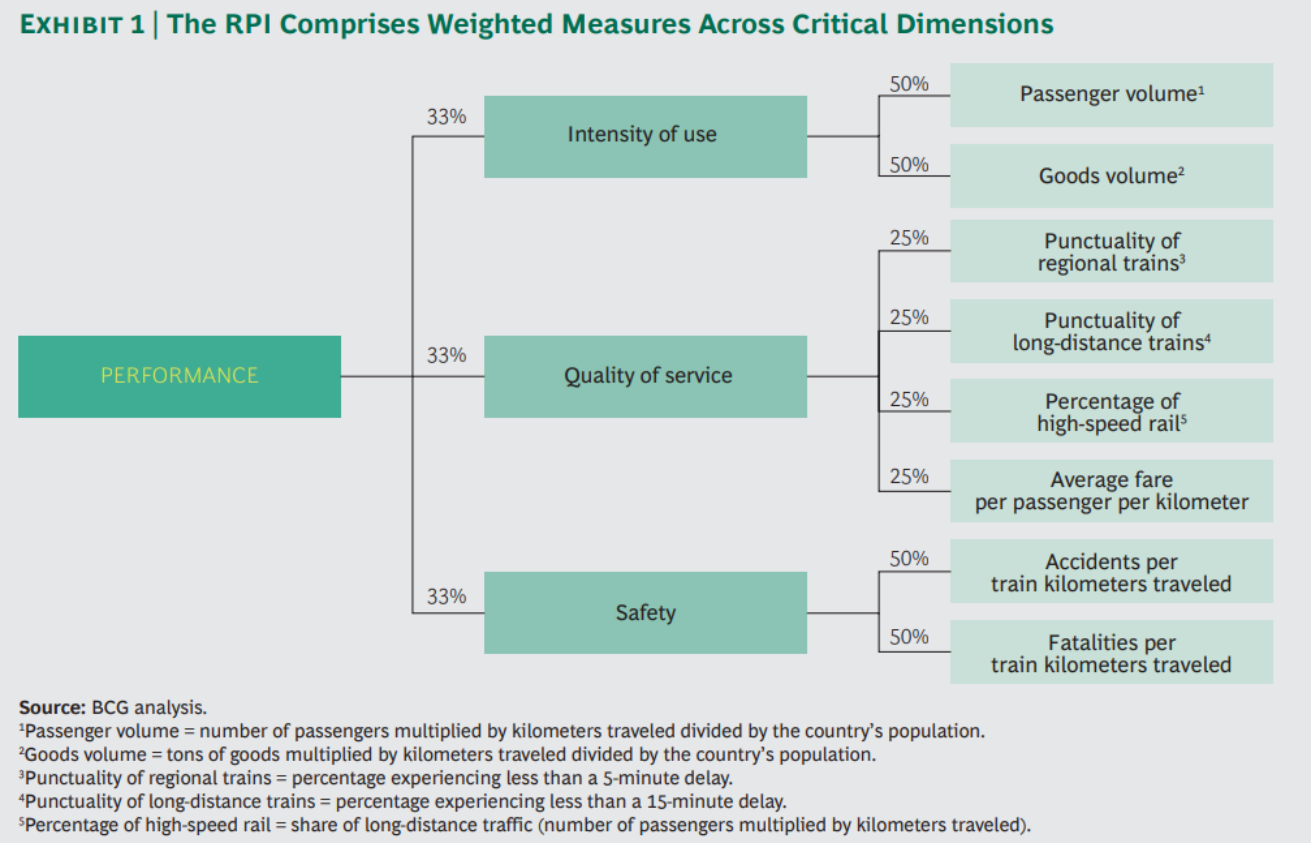


Figure 58: Weighted measures used to calculate the European Rail Performance. Source: [33]

In the 2017 edition of the "RPI" index, Switzerland was ranked first among national European rail systems for its intensity of use, quality of service and strong safety rating. The results show that all western countries, except Portugal and Ireland, are ranked much higher than the eastern European countries, whose are all classified in the cluster "tier 3" except the Czech Republic.

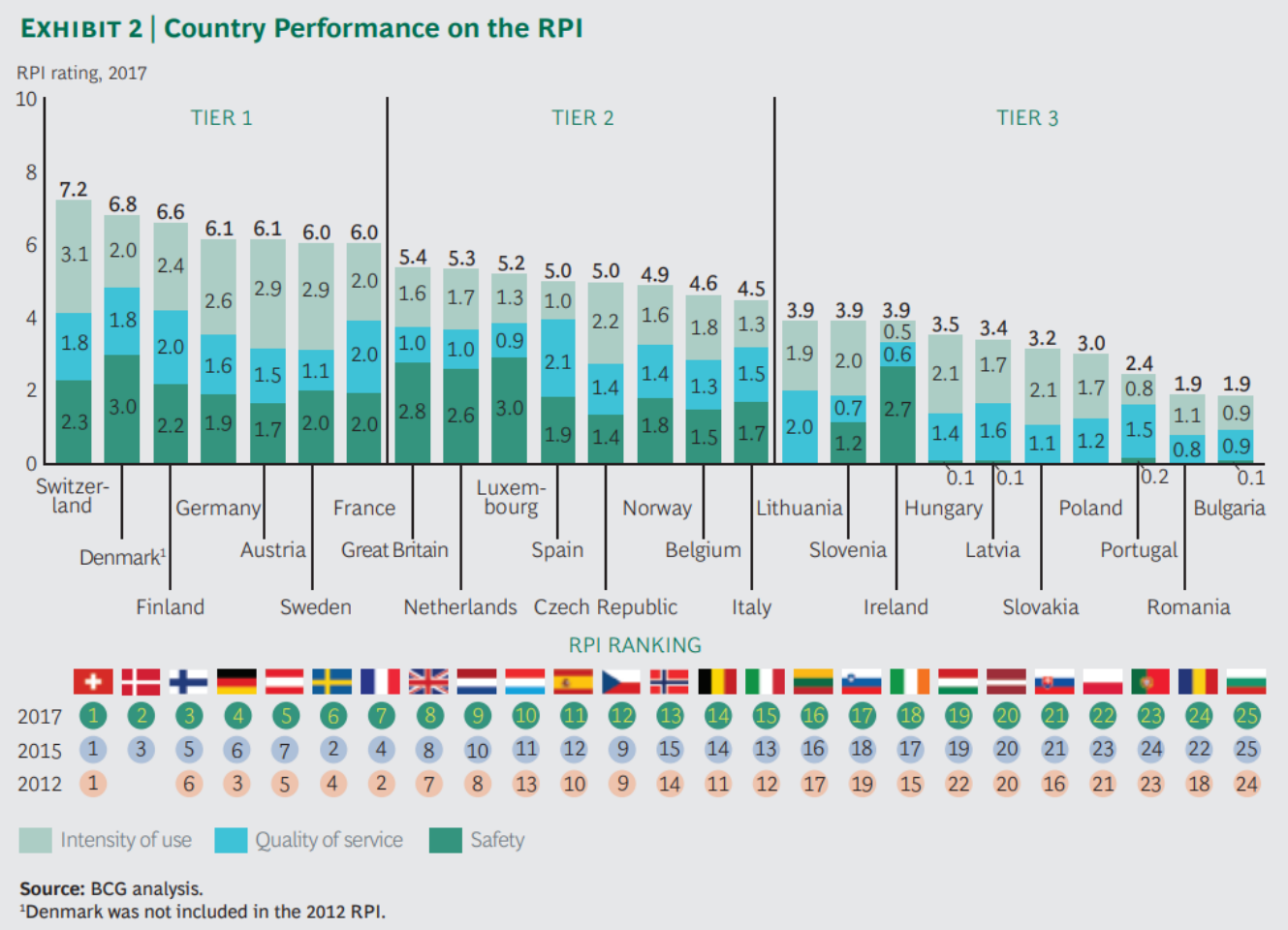


Figure 59: Ranking of the performances of the European rail systems. Source: [33]

Even though this ranking served as inspiration for the present thesis, the are some elements that will need to be and make this index not able to be used for the purpose of this thesis:

- At first, the concept "intensity of use" of the RPI takes into account both passenger and goods volume. Since the aim of this paper is to study the passenger use of railways, the model to be developed should not consider to transportation of goods.
- The performance factors to be considered in the thesis should be oriented to the attractiveness of users and thus related to passenger demand. Thus the indicator intensity of use shouldn't be part of the model as this is not relevant to define the quality of the system perceived be the users.

- The three components are weighted equally (33%), meaning all them ave the same importance for the final ranking of the performance. Also, the different factors constituting each component are weighting equally as well, meaning they have the same importance for the performance component. However, as seen in section 4.3, the performance factors are not equally relevant for the users. Thus, a system of importance and priorities will be developed.
- Some relevant factors relevant for the demand as seen in section 4.1 and 4.2 are missing, such as the frequency and the soft factors. Considering the travel time, this is only represented by the high speed. These will need to be incorporated in the model to be developed.
- Finally, this index does not takes into account the extension of the network. Thus, countries with short railways and with lack of connection will not be reflected in the ranking. For that reasons, the model to be developed will include the indicators “network reach” which takes into account the density of railways per area and population.

All these points will be included in the model to be developed in the present paper. The aim will be to consider all possible factors so to maximize the inputs for the evaluation of a railway system taking into account the relative impact of these factors to the demand and attractiveness of users. Thus, the model described in the next point will follow the idea of the RPI but using an extended collection of KPI’s as defined in the previous Table 6, and a different system of weighting.

6.2 Development of the assessment model

The aim is to get a model in which the KPI inputs are introduced to get numeric outputs to be interpreted as an evaluation of the level of performance of the different factors of the railway system.

As seen in section 4.3, some of the quality parameters have a major impact in the attraction of new users. Thus the model takes into account internal weighting to reflect what are the parameters more relevant as well as the priorities of the users. For that the model will analyse the priorities of four types of travellers: commuters, business, holidays and leisure travellers. Similarly, it will analyse the particularities of the users of two different type of railways, the regional and long distance trains.

In the next subsection all the details of the model will be described. At first an overview of the assessment process will be presented. Then the reference values to be used in each case will be given. Afterwards, the beforementioned weighting system considering the importance of the factors and the priorities of the users will be described. Finally, the calculation method of the rankings and the final outputs together with the interpretation of results will be exposed.

6.2.1 Assessment process

This assessment process will give the priorities of the actions to be implemented in a railway system considering the type of travellers (between commuters, business, leisure and holiday) and railways (regional and long distance). The assessment process has six steps:

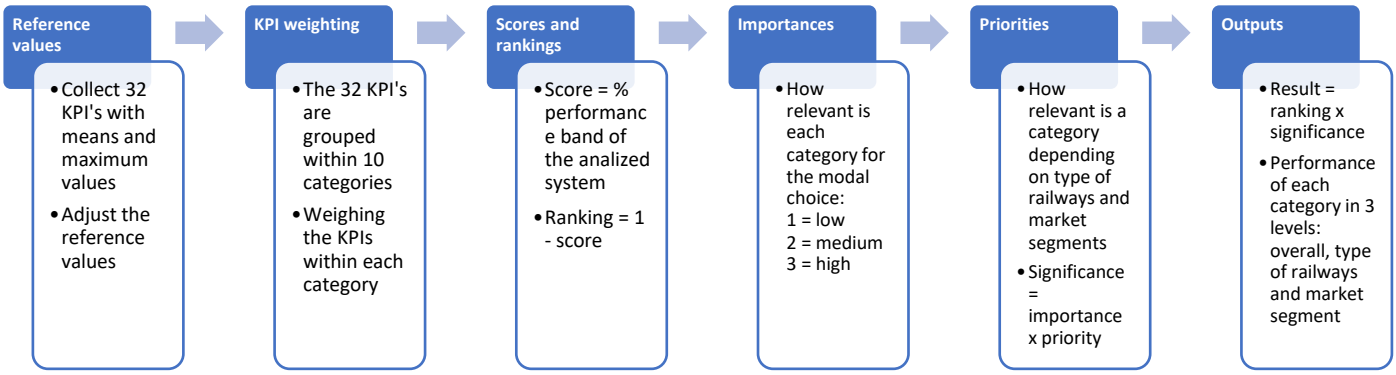


Figure 60: The six steps of the assessment process

A summary of each step is described below:

- At first, the reference values are created. These will be the maximum and arithmetic mean of the KPI's defined in previous section 5.3.
- Since the KPI's are grouped in 10 categories, each parameter constituting a category will be weighted considering its importance to the final value.
- In the third step, the scores are calculated. These are the ponderation of each KPI of the assessed system relative to the reference values considered. Then these are transformed into rankings for the better analysis of the results.
- The importance are defined as how relevant is each of the 10 categories for the passenger demand.
- The model includes the assessment depending on the type of railways and travel purpose. Thus, apart from importances, priorities are also considered. These are defined as how relevant is each category for the type of railways and purposes. Significances are the produce of the previously defined importance x priorities.
- Finally, the outcomes are the numeric values obtained as the product of the rankings per significances, and the results are interpreted in overall, for each type of railways and for each market segment.

All details of each step are defined in the next subsections.

6.2.2 Reference values

The source for the reference values used in this research will be the objective parameters defined in section 5.2.1 and the subjective defined in 5.2.2. For that, the maximum value and the arithmetic mean of each of the parameters will be taken as a reference.

The maximum show the potentially reachable value, and the arithmetic gives the minimum that the system might reach. All values between maximum and mean will be defined as the performance band as it will be described later.

As already said in the previous sections, the framework for this assessment is based in the European standards, as data comes from the official EU sources. However, for the calculation of the maximum and mean values countries with very low usage are not considered. For that, data from 20 countries (Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and United Kingdom) will be used as reference for the analysis. Data from Norway and Switzerland are only partially available and thus for some of the parameters, the reference values will be taken considering 18 countries.

6.2.2.1 Interpretation and adjustment of reference values

The most of the reference values are interpreted in a way that the maximum value signifies the better performance. However, there are four indicators defined with the in the inverse logic, so a bigger value implies lower performance. Therefore in order to be able to use the indicators in the assessment model they must be mathematically inversed. The indicators that require this process are described below:

- **Reliability (%):** the indicator used to define the reliability is the % of cancelled trains. The countries ranking the major values are therefore those having a higher ratio of cancelled trains and thus a lower reliability. The value used for the assessment will be the inverse: $1 - reliability$
- **Rail fares (€/km):** from the user's perspective, the better ranked systems are those with lower prices, thus the parameter to be considered in the model is also the inversed: $1 / fares$
- **Fatalities per length (victims/km):** one of the indicators used to define the safety of the railways gives the number of fatalities per network length. Since the safest systems will have lowest ratios of fatalities per length, this indicator will be inversed as well: $1 / fatalities\ per\ length$
- **Fatalities per traffic (victims/pas-km):** likewise the previous, this indicator needs to be introduced in the model inversed: $1 / fatalities\ per\ traffic$

6.2.2.2 Reference values used in the model

In the following two tables, the values to be used as reference for the later calculation will be given. They come from the different indicators exposed in the section 5, and as introduced in the previous subsection, the maximum values and the arithmetic means are used.

- **Reference values for regional and long distance trains**

The values of the 32 parameters taken from the 20 or 18 reference countries are listed below:

Performance category	#	KPI (units)	Regional trains		Long distance	
			Max.	Mean	Max.	Mean
1. Network reach	1	Route density (km /k km^2)	126	66,7	126	66,7
	2	Route density per capita (Km/ m. inh)	1078	537,7	1078	537,7
2. Travel time	3	Average speed of trains (km/h)	88,2	63,6	162,5	94,76
	4	Transport performance (%)	14,8	5,6	14,8	5,6
	5	Commercial speed satisfaction (%)	90	79	90	79
3. Punctuality and reliability	6	Punctuality (%)	96	90	92	77
	7	Reliability (%)	99,95	98,16	99,93	98,54
	8	Punctuality and reliability satisfaction (%)	86	71	86	71
4. Frequency	9	Satisfaction with frequency (%)	88	75	88	75
5. Convenience	10	Connection with rail services (%)	70	61	70	61
	11	Intermodality: Connection other modes (%)	80	67	80	67
	12	Parking facilities for cars and bikes (%)	66	49	66	49
6. Comfort and travel experience	13	Comfort of seating areas (%)	95	82	95	82
	14	Availability of seats (%)	87	78	87	78
	15	Cleanliness and maintenance station (%)	90	73	90	73
	16	Cleanliness and maintenance trains (%)	80	66	80	66
	17	Information timetables & platforms (%)	91	85	91	85
	18	Information during the journey (%)	80	66	80	66
	19	Assistance / personnel on board (%)	75	63	75	63
7. Prices, marketing and sales	20	Prices (1 / € / km)	0,97	0,82	0,98	0,82
	21	Ease of buying tickets (%)	91	82	91	82
	22	availability of through-tickets (%)	84	72	84	72
	23	tickets for several modes (%)	86	69	86	69
	24	Handling complaints (%)	61	40	61	40
8. Accessibility	25	Accessibility of stations for PRM (%)	83	73	83	73
	26	Assistance by staff for PRM (%)	78	69	78	69
	27	Accessibility of trains for PRM (%)	73	68	73	68
9. Safety and security	28	Fatalities per length (1 / (Victims / 1000 km))	0,17	0,04	0,17	0,04
	29	Fatalities per traffic (1 / Victims / M pas. x km)	0,99	0,96	0,99	0,96
	30	Security in stations (%)	91	79	91	79
	31	Security on-board (%)	98	85	98	85
10. Sustainability	32	Electrified ratio (%)	0,99	0,61	0,99	0,61

Table 7: Performance indicators for regional and long distance trains

These values will be used in all assessments of the railways systems when evaluating the different type of railways in the present thesis.

- **Reference values considering market segments**

The values of the 32 parameters taken from the 20 or 18 reference countries are listed below:

Category	#	KPI	Units	Commuters		Business		Holidays		Leisure	
				Max.	Mean EU-18	Max.	Mean EU-18	Max.	Mean EU-18	Max.	Mean EU-18
1. Network reach	1	Density per km	km /k km2	126	66,7	126	66,7	126	66,7	126	66,7
	2	Density per capita	Km/ m. inh	1078	537,7	1078	537,7	1078	537,7	1078	537,7
2. Travel time	3	Average speed	km/h	88,2	63,6	162,5	94,76	162,5	94,76	88,2	63,6
	4	Transport performance	%	14,8	5,6	14,8	5,6	14,8	5,6	14,8	5,6
	5	Speed satisfaction	%	90	79	90	79	90	79	90	79
3. Punctuality and reliability	6	Punctuality	%	96	90	92	77	92	77	96	90
	7	Reliability	%	99,95	98,16	99,93	98,54	99,93	98,54	99,95	98,16
	8	Punctuality satisfaction	%	75	54	93	59	88	65	88	68
4. Frequency	9	Satisfaction frequency	%	88	70	84	69	80	71	89	75
5. Convenience	10	Connection rail services	%	70	61	70	61	70	61	70	61
	11	Intermodality	%	80	67	80	67	80	67	80	67
	12	Parking facilities	%	70	51	66	41	60	45	67	48
6. Comfort and travel experience	13	Comfort of seats	%	95	82	95	82	95	82	95	82
	14	Availability of seats	%	81	67	86	71	89	78	90	74
	15	Cleanliness stations	%	93	67	87	64	84	65	89	70
	16	Cleanliness of trains	%	76	61	71	56	83	59	83	61
	17	Information stations	%	89	81	89	83	90	80	92	84
	18	Information journey	%	75	57	82	60	84	59	80	63
	19	Assistance on board	%	69	62	75	62	79	62	76	60
7. Prices, tickets and sales	20	Prices	1 / € / km	0,97	0,82	0,98	0,82	0,98	0,82	0,97	0,82
	21	Ease of buying tickets	%	89	83	89	86	92	82	93	82
	22	Through-tickets	%	84	75	78	67	85	73	83	71
	23	Tickets several modes	%	89	76	82	62	86	68	87	68
	24	Handling complaints	%	56	44	57	34	63	42	58	41
8. Accessibility	25	Access. stations PRM	%	81	70	78	64	80	67	88	67
	26	Assistance staff for PRM	%	71	69	90	62	75	66	81	65
	27	Accessibility trains PRM	%	72	65	69	57	62,1	62	78	63
9. Safety and security	28	Fatalities per length	1 / victim / 1000 km	0,17	0,04	0,17	0,04	0,17	0,04	0,17	0,04
	29	Fatalities per traffic	1 / vict. / M pas km	0,99	0,96	0,99	0,96	0,99	0,96	0,99	0,96
	30	Security in stations	%	91	79	91	79	91	79	91	79
	31	Security on-board	%	98	85	98	85	98	85	98	85
10. Sustainability	32	Electrified ratio	%	0,99	0,61	0,99	0,61	0,99	0,61	0,99	0,61

Table 8: Performance indicators for the different traveller market segments

These values will be used in all assessments of the railways systems when evaluating the different market segments in the present thesis.

6.2.3 Weighing of the KPI's into their performance categories

For those performance categories having more than one indicator, a ponderance weighting will be stablished to define how relevant is each KPI for the final evaluation of the performance category.

As each category is normally defined by different factors, an internal weighting coefficient has been stablished for each of them, defining the importance of each parameter in the final value of each category.

There will be cases that all KPIs are equally relevant, thus the weighting is the same for all. In other cases however, some KPIs will be more relevant and thus they will be highly pondered than others. The justification of the weighting for each performance category is described below:

- Regarding the network reach, both indicators are to be considered equally relevant.
- Regarding the travel time, transport performance is the parameter that respond better to the concept analysed, thus it has been weighed to a 50%, so half of the value of the category. Commercial speed satisfaction and average speed of trains then take the rest of the 25% of the share each. In this case the objective indicator of average speeds is not fully responding to the travel time since it might be biased by high speed lines which prevents the low speeds trains to show.
- For the punctuality and reliability, the objective data should have more weight since the perception of the punctuality can be very different depending on cultures. Thus, a 60% of the category will be taken from the objective parameters, and since both are considered to be equally important, each will count for the 30% of the category value. The rest 40% will count for the customer satisfaction parameter.
- Frequency is only made of one indicator, thus the 100% comes from the satisfaction KPI.
- For the category convenience, considering that the majority of the rail users will get stations using public transport instead of private, and that many of them will need to change lines to get their destinations, the KPI's "connection with rail services satisfaction" and "connection with other transport modes satisfaction" will be relatively weighted double than the KPI "parking slot satisfaction".
- Regarding comfort, 6 out of 7 KPI's will be weighted equally at 15% except cleanliness of stations that will be weighted slightly lower since this is considered less relevant for the demand than the others. For regional and long distance trains, users will spend much more time in travelling than waiting in the stations, thus the parameters of the travel experience will be more relevant for them.

- The five KPI's of the marketing and sales category are weighted since there are no evidences of which are the most relevant factors.

The justification of the weighting of the last three categories is described in the next page. The weighting of each KPI relative to the performance category can be found in the next table:

Category	#	KPI	KPI weighting
1. Network reach	1	Route density per km (km of rail route / country area)	50%
	2	Route density per capita (km / inhabitant)	50%
2. Travel time	3	Average speed of trains	25%
	4	Transport performance	50%
	5	Commercial speed satisfaction	25%
3. Punctuality and reliability	6	Punctuality (% of trains with delay <5min)	30%
	7	Reliability (% of cancelled trains)	30%
	8	Punctuality and reliability customer satisfaction	40%
4. Frequency	9	Satisfaction with frequency	100%
5. Convenience	10	Connection with rail services	40%
	11	Intermodality: Connection with other modes	40%
	12	Parking facilities for cars and bikes	20%
6. Comfort and travel experience	13	Comfort of seating areas	15%
	14	Availability of seats	15%
	15	Cleanliness and good maintenance of stations	10%
	16	Cleanliness and good maintenance of trains	15%
	17	Information about train timetables and platforms	15%
	18	Information during the journey	15%
	19	Assistance / personnel on board	15%
7. Prices, tickets and sales	20	Fares	20%
	21	Ease of buying tickets	20%
	22	availability of through-tickets (for different sections or lines)	20%
	23	availability of tickets for several modes (bus, tram, metro…)	20%
	24	Handling complaints	20%
8. Accessibility	25	Accessibility of stations for disabilities	35%
	26	Assistance by staff for persons with disabilities	30%
	27	Accessibility of trains for disabilities	35%
9. Safety and security	28	Fatalities per length	20%
	29	Fatalities per traffic	20%
	30	Security in stations	30%
	31	Security on-board	30%
10. Sustainability	32	Electrified ratio (% of electrified lines)	100%

Table 9: Weighting between the quality factors of same performance category

- The items accessibility to stations and to rail carriages will be pondered slightly higher since they are the least necessary factors to ensure the accessibility for persons with reduced mobility to the railways. Assistance by staff for PRM's is very valued for the users with reduced mobility but less decisive in their access to the railways.
- The perception of security is relatively more valued for the users than the perception of safety. In other words, users will mostly refuse travelling if they feel the stations and carriages are not secure in terms of delinquency. Thus the two objective KPI's defining the safety will weight overall 40% and the two subjective KPI's defining the security will weight overall 60% of the category.
- Finally, since there is only one item defining the sustainability, the KPI electrification rate will get the 100% of the weighting of this category.

6.2.4 Calculation of the scores and rankings

For the valuation of each parameter, a relative "performance band" is stablished. This is defined as twice the deviation between the maximum value and the arithmetic mean of the reference values, and calculated in percentile. This is obtained by simple cross-multiplication of ratios. The target is that in the later assessment, all parameters can be compared.

The reference values will be taken from the performance indicators seen in the previous section 5. According to the formulae proposed below, the score of a parameter falling just in the arithmetic mean would be 0.5, and the score of the maximum value would be 1. Some parameters falling below the minimum of the band would score negative. For the later interpretation of the results, all scores will be transformed into rankings. Thus, the ranking will be considered as *ranking = 1 – score*. This will give a scale for the later interpretation of the values in which the biggest values are the most priority for the actions to be implemented.

$$ranking = 1 - score = 1 - \frac{\overbrace{x - \left(\mu - (max - \mu)\right)}^{score\ of\ the\ parameter\ from\ the\ minimum\ value\ of\ the\ band}}{\underbrace{2(max - \mu)}_{length\ of\ the\ performance\ band}} = 1 - \frac{x - (2\mu - max)}{2(max - \mu)}$$

In which,

- max is the maximum reference value
- μ is the arithmetic mean of the reference values
- x is the value of the parameter of the railway system to be assessed

After the transformation from scores into rankings, the parameters falling between the maximum and the mean value have the lowest scores. Parameters falling in the second half of the performance band, so below the mean, have relative higher rankings. And finally, negative ranks (so those parameters falling below the whole length of the performance band) have the highest rankings.

6.2.5 Importance, priority and significance

According to the academic studies seen in section 4.3, it can be stablished what are the most relevant factors for the attraction of passengers to public transport. For that, each performance category will get a coefficient relative to the final relevance on the usage. Thus, this is the step in which the importance of each criteria for the rail demand are introduced to the model.

Furthermore, apart from the relative importance of the 10 performance categories, the assessment model also takes into account the priorities of the different type of users considered. Thus, the relative priorities of each group of users between commuters, business, holiday and leisure travellers, as well as for regional and long distance trains travellers are considered.

For that in this section three new concepts are defined:

- **Importance:** how relevant is each performance category for the modal choice of railways between low, medium and high, in a scale from 1 to 3.
- **Priority:** how relevant is a category depending on type of railways and market segments between low, medium and high in a scale from 1 to 2.
- **Significance:** the pondered product of the previous concepts for each KPI.

The values of importances, priorities and significances will be calculated in the next tables. These are based on the academic studies that analysed the importance of each factor to the users as shown in section 4.3.

6.2.5.1 Importances of the categories

These are defined in the academical works seen in the previous section 4.3 and represent the influence of the demand of each factor. The level of importance is numerically set according to the following :

- High relevance = 3
- Medium relevance = 2
- Low relevance = 1

The attributed importances are shown in the next table:

Performance category	Importance for the demand	Importance value (1 – 3)
1. Network reach	High	3
2. Travel time	High	3
3. Punctuality and reliability	High	3
4. Frequency	High	3
5. Convenience	Medium	2
6. Comfort	Medium	2
7. Prices and tickets	Medium	2
8. Accessibility	Low	1
9. Safety and security	Low	1
10. Sustainability	Low	1

Table 10: Users' importance of each performance category

6.2.5.2 Priorities and significances for the type of railways

The users of the two considered regional and long distance railways might have different preferences. The concept of priorities has been defined to reflect these preferences and is based on the research studies of the CE Delft [25] exposed in section 4.3. For each performance category, a level of priority has been assigned between low and high, depending on how relevant is the factor for the user of this type of railways. Then, a numerical value related to the priority level is given according to the following:

- High relevance = 2
- Medium relevance = 1,5
- Low relevance = 1

The priorities considered for each market segment are shown in the next table:

	Regional	Long distance
1. Network reach	High	Medium
2. Travel time	High	High
3. Punctuality and reliability	High	Medium
4. Frequency	High	Medium
5. Convenience	High	Medium
6. Comfort	Low	High
7. Prices and tickets	Medium	High
8. Accessibility	Low	Medium
9. Safety and security	Medium	Medium
10. Sustainability	Low	Low

Table 11: Priorities of the performance categories for each type or railways

6.2.5.1 Significances for the type of railways

As seen before the significance is calculated as the product of the importance per priorities.

Performance category	Importance	Services' priority (1 – 2)		Importance x priority	
		Regional	Long distance	Regional	Long distance
1. Network reach	3	2	1,5	6	4,5
2. Travel time	3	2	2	6	6
3. Punctuality and reliability	3	2	1,5	6	4,5
4. Frequency	3	2	1,5	6	4,5
5. Convenience	2	2	1,5	4	3
6. Comfort	2	1	2	2	4
7. Prices and tickets	2	1,5	2	3	4
8. Accessibility	1	1	1,5	1	1,5
9. Safety and security	1	1,5	1,5	1,5	1,5
10. Sustainability	1	1	1	1	1
TOTAL	21	16	16	36,5	34,5

Table 12: Significance' calculation of the performance categories for each type or railways

Finally, the significances for each performance category and type of railways are obtained as a pondered coefficient, so the product of the *importance x priority* divided by the total. These are given below:

Performance category	Significance for regional trains	Significance for long distance trains
1. Network reach	0,16	0,13
2. Travel time	0,16	0,17
3. Punctuality and reliability	0,16	0,13
4. Frequency	0,16	0,13
5. Convenience	0,11	0,09
6. Comfort	0,05	0,12
7. Prices and tickets	0,08	0,12
8. Accessibility	0,03	0,04
9. Safety and security	0,04	0,04
10. Sustainability	0,03	0,03
TOTAL	1,00	1,00

Table 13: Pondered significances of the two type of railways

These values will be used in the next section 7 for the assessment of the Spanish railways for the validation of the model, as well as in section 8 for the application of the model to the railways in Austria.

6.2.5.2 Priorities of the market segments

Additionally, each type of traveller or market segment will also have different priorities, for example commuters will value more the frequency of railways than holiday travellers. Same as for the type of railways, each level have been assigned a numerical value of :

- High relevance = 2
- Medium relevance = 1,5
- Low relevance = 1

The priorities considered for each market segment are shown in the next table. They are based on the literature observations shown in Table 2.

Performance category	Commuters	Business	Holidays	Leisure
1. Network reach	Medium	Medium	High	High
2. Travel time	High	High	Medium	Medium
3. Punctuality and reliability	High	High	Medium	Medium
4. Frequency	High	Medium	Low	Medium
5. Convenience	Medium	Medium	Medium	High
6. Comfort	Low	High	High	Medium
7. Prices and tickets	Medium	Low	High	High
8. Accessibility	Medium	Medium	Medium	Medium
9. Safety and security	Medium	High	High	Low
10. Sustainability	Medium	Low	Low	Medium

Table 14: Market segment priorities. Own creation based on [25]

The level of priorities given are justified below:

- Network reach is highly important for holiday and leisure travellers as they might go to less urban areas, normally connected with rail. Instead commuters and business travellers might travel to more industrialized and urban areas that may already have more available connections.
- Travel time is mostly important for commuters and business travellers as they see the trip as an obligation. Instead leisure travellers can enjoy the trip and are less demanding to fast connections. This is the same for punctuality and reliability, as the consequences of a delay for commuters and business mean delays in their work duties, whilst leisure travellers might be more flexible in the arrival times.
- Frequency is of one of the highest priorities for commuters as they can adapt the rail travel times with their working hours. Likewise business travellers will also value frequencies that adapt to their

business meetings although might not be as much. Instead, leisure travellers might find that factor less relevant.

- Comfort for commuters is less important than business and leisure travellers, as their target is to arrive on the destination quickly and efficiently. The business travellers might use the trip for their working purposes and will be more demanding on comfort. Leisure and specially holiday travellers, as the trip is part of the enjoy will also look for more comfort.
- Convenience is priority for commuters as they look for regular and fast connections to their work. Business and leisure travellers are more occasional travellers thus they may accept less convenient railways, for example lack of direct connections or synchronisation with other transport modes.
- Price is especially important for commuters, but also for leisure travellers. It's normally less important for business travellers since the price of the travel is usually paid by their employers.
- Accessibility is considered to be equally important for all groups of travellers.
- Safety will be important for business and leisure travellers as they might prefer safety connections for their enterprises.
- Sustainability might be important for regular users, so especially for commuters that can decide to travel with railways due to environmental reasons, but less for business and leisure occasional travellers, looking for the convenience of their connections.

The numerical values of the priorities as well as the product *importance* x *priority* are show below:

Category	Importance	Segment priority				Importance x priority			
		Commuters	Business	Holidays	Leisure	Commuters	Business	Holiday	Leisure
1. Network reach	3	1,5	1,5	2	2	4,5	4,5	6	6
2. Travel time	3	2	2	1,5	1,5	6	6	4,5	4,5
3. Punctuality and reliability	3	2	2	1,5	1,5	6	6	4,5	4,5
4. Frequency	3	2	1,5	1	1,5	6	4,5	3	4,5
5. Convenience	2	1,5	1,5	1,5	2	3	3	3	4
6. Comfort	2	1	2	2	1,5	2	4	4	3
7. Prices & tickets	2	1,5	1	2	2	3	2	4	4
8. Accessibility	1	2	1,5	1,5	1,5	1,5	1,5	1,5	1,5
9. Safety & security	1	1	2	2	1	1,5	2	2	1
10. Sustainability	1	1,5	1	1	1,5	1,5	1	1	1,5
TOTAL	21	16	16	16	16	35	34,5	33,5	34,5

Table 15: Importances and priorities for each market segment

Finally, the pondered significances of each category and market segment are obtained as the product of the importance per priorities divided by the total sum of the products:

	Commuters	Business	Holiday	Leisure
1. Network reach	0,13	0,13	0,18	0,17
2. Travel time	0,17	0,17	0,13	0,13
3. Punctuality and reliability	0,17	0,17	0,13	0,13
4. Frequency	0,17	0,13	0,09	0,13
5. Convenience	0,09	0,09	0,09	0,12
6. Comfort	0,06	0,12	0,12	0,09
7. Prices, tickets and sales	0,09	0,06	0,12	0,12
8. Accessibility	0,04	0,04	0,04	0,04
9. Safety and security	0,04	0,06	0,06	0,03
10. Sustainability	0,04	0,03	0,03	0,04
TOTAL	1,00	1,00	1,00	1,00

Table 16: Pondered significances for each market segment

In the same way as for the type of railway, these values will be used in the next section 7 for the assessment of the Spanish railways for the validation of the model.

6.2.6 Outcomes of the model

Once the rankings and priorities of each category are obtained, the final results are calculated as the product of the rankings (related with the performance) and the significances (related with the relevance to the usage):

$$final\ results = ranking\ x\ significances$$

the output gives a classification of the performance categories according to the scores obtained. As pointed before, the categories standing the first, so scoring the higher, are those with lower performance according to the type of railways and travellers considered.

The results can be identified as follows:

- More than 0,12: high lack of performance
- Between 0,10 and 0,12: medium to high lack of performance
- Between 0,07 and 0,09: medium lack of performance
- Between 0,04 and 0,06: medium to low lack of performance
- Below 0,04: low lack of performance

Additionally and for the ease of the comparison and results interpretation, each value is classified within five colour scales as shown here:

Result: level of lacking performance				
Low	Low to medium	Medium	Medium to high	High priority
≤ 0,03	0,04 – 0,06	0,07 – 0,09	0,10 – 0,12	≥ 0,13

Table 17: Colouring scales to identify the lack of performance of each category

In conclusion, the results show the lack of performance of each category. These inform about the level of priority improvement that each performance category should undertake. In other words, what would be the most important areas of improvement to get an increase of the passenger usage.

6.3 Further actions: development of strategies for attracting users

Although it will not be included in the present thesis, the next step once the priority group of measures is defined would be the creation of specific actions to improve the performance of the selected parameter in order to increase customer attraction. There is a significant amount of literature about proposals, studies and projects of improving the performance of the railways. Redman et al., (2013) [37] selected 74 of those studies and assessed which performance criteria were targeted for improvement to attract car users.

	Targeted quality attribute						
Improvement strategy	Reliability	Frequency	Price	Speed	Access	Comfort	Convenience
Network upgrades		2		2			
Extended service		6			5		
Rail lines replacing bus	9			10			
Underground improvements	3			3			
Integrated public transport systems (quality bus partnership)	7	2	7	8	7	9	9
Price mechanism (discounts, free tickets, integrated ticketing)			14		1		5
Bus rapid transit (BRT)	15	13		16	1	15	8
Improved information							2
Reduced distance between PT nodes					2	2	
Total	34	23	21	39	16	26	24

Table 18: Improvement strategies for attracting car users to public transport seen in literature. Source: [25]

Together with the output of the assessment models, this would serve as the starting point for a new research. Once the priority factors to be improved are identified with the developed model, the next phase of research would be based on the development of specific strategies for the increase of the usage of passenger railways. This is not part of the scope of the present thesis but the paper is intended to act as a motivational force for further investigation on this field and encourage further scholars to continue the work.

7. Validation of the model: case study of railways in Spain

In this section the framework model for the evaluation of a railway system previously defined will be applied to the case of the Spanish railways. The aim is to validate the model proposed, confronting the results with the observations and feedback given by the users' interviews.

The first part of the section will describe the interviews, the analysis method and the results collected. Afterwards, the assessment tool defined in section 6 will be applied to the case of the Spanish railways. Finally, the outcomes of the both procedures will be compared and discussed.

7.1 Interviews to Spanish travellers

The present study includes a collection of interviews to 12 travellers of the Spanish railways. The aim of these interviews is to understand what are the main requests of the users and more specifically what do they feel is not performing well and so what would need to be improved in the railways in Spain. The structure, analysis method and results of the interviews are described in the next points.

The main target of the interviews is to understand the reasons that make people in Spain to not use the railways as much as in other countries. By speaking with the daily users of the railways, but also to people that can't or don't want to travel with railways, it will be able to apprehend their reasons for using and for not using them. Specifically, the interviews ask for how they value the performance of the system. Additionally, some of the respondents are technical experts of the Spanish railways who can give much information and details which could be impossible to get in a standard customer satisfaction survey. The interviews will make the users reflect about their experience and knowledge, and will catch all the details and nuances of their perceptions and ideas, in order to determine what are the perfectible factors of the Spanish railways.

7.1.1 Design of the interviews

The definition of the categories and questions is inspired in several studies and academic papers such as Nathanail (2007) [35], who studied the quality of the Greek Railways; the research from Eboli and Mazzulla (2012) [36], who analysed the services offered by rail operators in the Northern Italy; as well as the Eurobarometer 463 already mentioned in the previous section 5 for the definition of the subjective indicators (2019) [24], which performed surveys asking users of all European countries to stablish a comparison on the customer satisfaction between the different railways.

The interviews are structured in three main sections:

1) **User profile:** the aim is to determine the user transport needs, the purpose of his/her travel and most frequent mode of transport. To understand how and how often the user moves. The data to control is average distance travel, distinguishing between weekdays, weekends and holidays. All used transport modes and changes are noted.

2) **Questions about motivation and priorities:** these questions inquire on the drives and main concerns of the interviews for the use of railways. Special attention to the positive and negative feelings they get when traveling by train, and special focus on the key decision criteria to travel or not by train.

3) **Questions about the quality and performance of the railways in Spain:** these questions are oriented to make the interviews reflect about his/her experiences when travelling with railways in Spain. The questions are designed according to the performance categories that will be used in the later study.
   - Connectivity, operation and transport convenience: determine the user's perception about the quality of service (speed, frequency, punctuality) as well the network. These are of the most valued factors by the regular users, especially in their daily working travel needs. The spectrum of the interviewees does only include working people, thus the importance of these factors are high for all users.
   - Comfort, accessibility and travel experience: determine the perception of the interviewees by the rest of services and features linked to the rail travel that may have an important impact in the user's satisfaction, and thus influence their decision of travelling by rail: train comfort, safety, cleanliness, information, attendance, price and facilities.
   - Prices, tickets and after-sales: determine the perception of the users regarding the fairness of prices and the easiness of getting tickets, their flexibility for using different lines and types of transport etc.
   - Safety: determine whether safety and security issues of the Spanish railway are perceived as blocking points

Finally, the interview moves to a general reflection of the user to conclude their opinions:

- Final evaluation of the railways in Spain: get the final valuation of the user in the transport of the country and further ideas that may enrich the interview, as well as to uncover hidden information from conversations across several users to reveal new insights.
- Additional questions for the experts: The last questions of the interview are reserved to the experts, considering them the professionals with an advanced knowledge of the railways.

Once the structure of the interview is set, all questions are defined. The interviews are made of a total of 40 questions, even though the last 5 are only asked to the experts.

The template of the interview in English and in the original Spanish and Catalan languages can be found in the appendix 1.

7.1.2 Interviews' procedure

Due to the Covid-19 pandemic, face-to-face interviews were dismissed and all them have been done using conference calls. The interviews have been performed in the native language of the interviewed users, either Catalan or Spanish. The target for that was to facilitate the interviewee to express their ideas and feelings naturally. For the sake of the project, these have been afterwards translated to English. Having the role of the interviewer, I tried to not interfere with the respondent opinions, so to stay neutral, but to motivate the interviewee to give all the information and feedback as possible. All interviewees showed great interest and wish to express their opinion. The average time to complete each interview was between 1 hour and 2 hour 30 min. The transcription of all the interviews translated in English can be found in the appendix 1 of the study.

7.1.3 Interviewee criteria and social spectrum

Twelve interviews have been conducted. The interviews were done to users with daily needs of travel but very different type of mobility and knowledge of the transport systems. The aim is to reflect the diversity of the society.

The spectrum of the interviewees is precisely selected, looking for people that not only have regular travel needs, but also that they are somehow sensible to the situation of the rail transport. Thus, different motives have been defined to select the interviewers:

- People with special geographic location
- People with regular use of rail transport
- People with regular use of private transport
- People with special knowledge of the railways

As the target is to be able to identify particular aspects of the users that affect the usage of railways in Spain, the interviewees must have great experience in the mobility of Spain. Not all users have strictly Spanish origins but all them lived the most of their lives in Spain. On the other hand, it was of special interest to interview users that can reflect experiences abroad. Thus, considering the location of the interviewed people, two groups have been identified:

- People living since long time in Spain, either with Spanish origin or not
- People living abroad that lived largely and experienced intensively the mobility in Spain

The target of this is to use the experiences the people that practiced the transportation in other countries to enrich the study. The second group of interviews will be done to people living in Switzerland, France, the United States, the United Kingdom and Germany, where railways play a special role in the social mobility.

7.1.4 Interviews analysis method

The interviews will be analysed using the thematic analysis method, popularized by Braun and Clarke (2006) in their article "Using thematic analysis in psychology" [37]. The thematic analysis is a useful method of qualitative data analysis to identify patterns through qualitative data, thus it is widely used to analyse interviews. The analysis process is based on coding the data, so a systematic organization and identification of the meaningful parts of the interviewees' answers which are related to the research question.

The analysis is made of four steps.

1. Transcription of the answers. As the present interviews are already pre-structured, the interviews get already transcribed in the categories that will be used in the following phase.
2. Analysis of the answers for each of the categories defined, looking for patterns, common perceptions between different respondents and identifying relevant or critical points, and removing all irrelevant answers.
3. Transversal analysis across the different categories, linking concepts in order to condense data into new themes.
4. Final analysis of the themes to get the relevant information related with the research question.

The different phases are described in the next subsections. Due to the long extension of the two first sections these have been moved to the annexes. In the following subsections, these are described and finally the third and last step of the process with the relevant outcomes of the analysis for the present study is included.

7.1.4.1 Transcription of the answers (Phase 0)

At first, the transcription and translation to English of the 12 interviews can be found in the annexes.

7.1.4.2 Analysis of the results for each group of questions (Phase 1)

As presented before, the interviews were clearly pre-structured in different category groups. The first phase of the analysis in this study is based on identifying patterns and highly critical points within the different respondents for each question group. In this phase, all irrelevant information have been omitted.

The three sections of the interview have been separately analysed:

- Interviewee profile
- Motivations and priorities
- Railways in Spain

The development of this phase is included in the annexes.

7.1.4.3 Cross analysis of the findings and combination into themes (Phase 2)

The third phase of the analysis is to define the themes that are meaningful to the research question of the study. These themes have been structured as follows:

	Question group	*Answers' analysis*
Interviewees profile	**Living place and origins**	
	Occupation	
	Weekly use of railways	
Rail transport motives	**Drives**	
	Barriers	
	Priorities	
Quality and performance of the railways	**Network reach**	
	Operation	
	Convenience	
	Comfort	
	Prices and tickets	
	Safety	
Final evaluation of the railways in Spain	**Spanish railways valuation**	
	What needs to improve?	
Additional questions for the experts	**Reasons for the low usage**	
	Proposed measures	

Table 19: Cross analysis of the interviewees answers model (phase 2)

The complete analysis can be found in the annexe.

7.1.4.4 Comprehensive analysis of the interviews (Phase 3)

As a result, pointed facts about the rail transport in Spain. Since these come from an inductive reasoning, they also come with an uncertainty and total truth can't be ensured.

Question group	*Answers' analysis*
What is perceived good?	- High speed services are valued good, even though people are not proud of them, they are perceived as a waste of money.
What limits the quality of the transport?	- network not enough extended and therefore lack of connections - dedicated high speed stations outside cities without bus connections - too large time travel of regional and middle distance trains - reduced frequencies of the middle distance trains
what limits the customer satisfaction?	- Security in stations and specially on-board (lack of guards) - comfort but for regional and conventional middle distance trains - cleanness of the regional stations and the graffiti of the trains - informative app/web (network, connection and timetables) that includes all services and public transport modes - Lack of information in case of delay or incidence
What are the strategies to increase situation?	- Extend network and reduce time travel - improve frequencies of commuters and middle-distance trains - Ensure connections to High Speed stations - Optimize correspondences

Table 20: Comprehensive analyse of the interviewees answers

7.2 Analysis of the rail usage: propensity to rail

Spain is the fifth country in Europe in number of traffic passenger-km. However considering the traffic per capita, Spain falls into a the countries with lowest passenger-km per inhabitant :

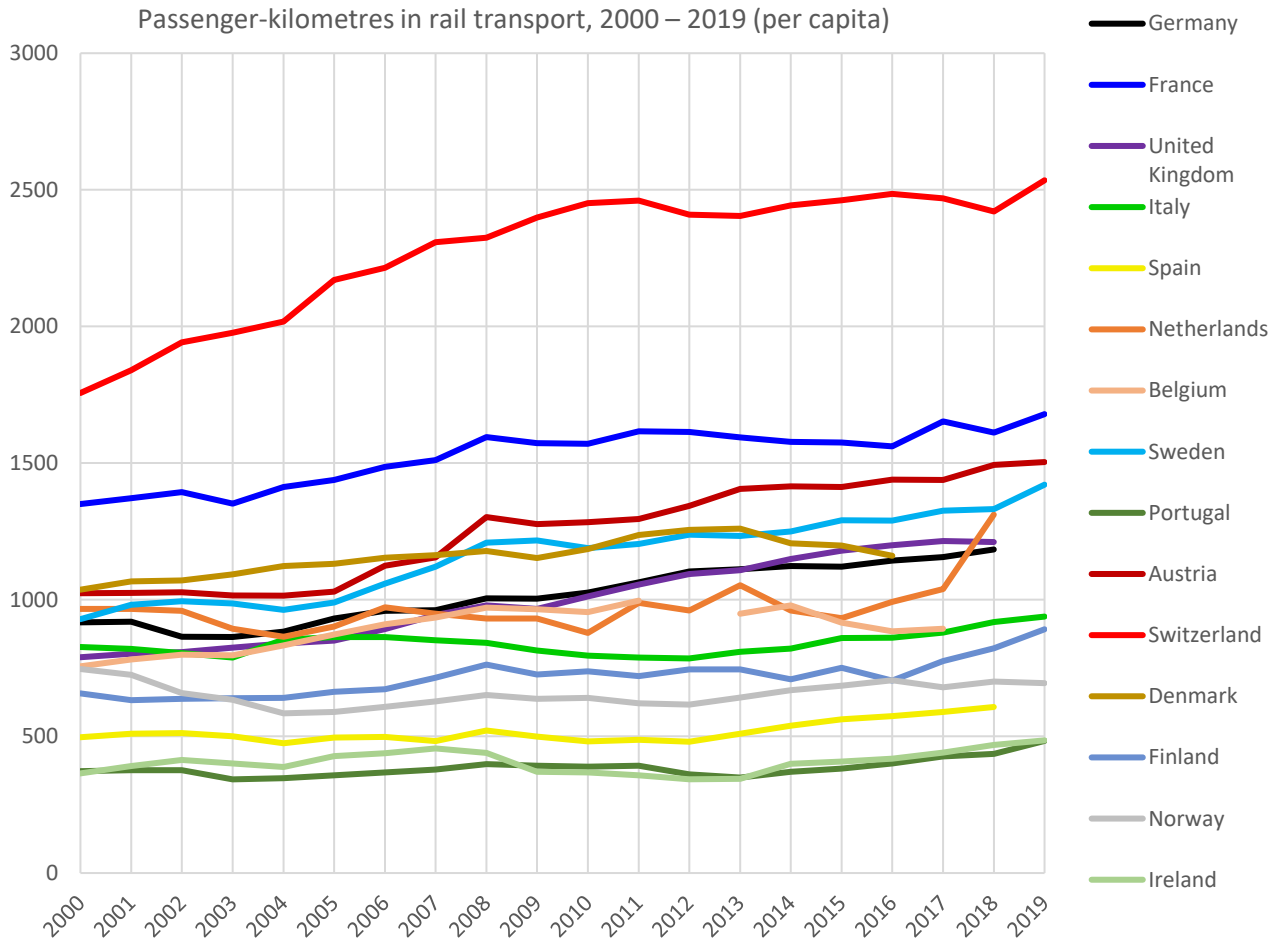


Figure 61: Rail transport usage per capita of the western European countries. Own creation based on [38]

Examining the evolution of passengers moved using railways for the last 20 years in the most populated countries in western Europe, we see that the situation in Spain improved slightly after 2013, so after the major opening of the new high speed lines.

However, the graphic also shows that despite the opening of high speed lines during the last decades, Spain remains within the countries of lower passenger usage of rail transport in western Europe, only above Ireland and Portugal. This might suggest that there might be further actions that the Spanish railways should undertake to increase the potential use of its railway to a major number of users.

7.3 Assessment of the performance of the Spanish railways

In this point, the assessment model developed in 6.2 will be applied to case of Spain. Following the process described, at first the reference values of each factor are collected and weighted to conform he performance categories. Secondly, the rankings indicating the performance of the factors are calculated,

as well as the significances, indicating the relevance of each factor for the users. Finally, the standing of the categories can be determined, showing the different levels of lack of performance. Thereafter, the results will be compared to outcomes of the interview

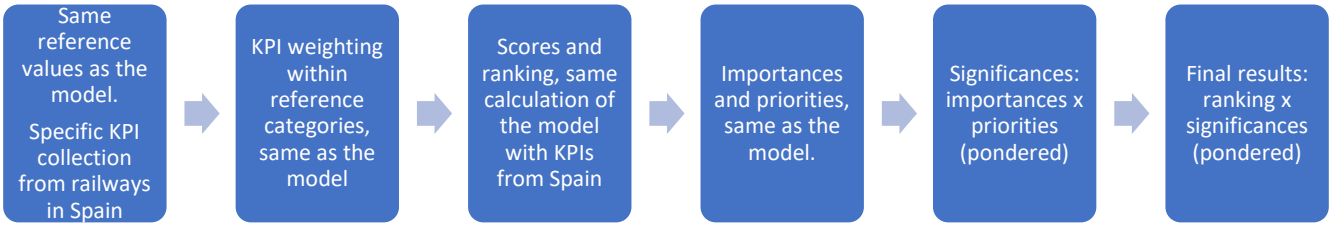


Figure 62: The six steps of the assessment model of the railways in Spain

7.3.1 Reference values KPI's and performance categories

The assessment model to the Spanish railways will evaluate to the two type of railways regional and long distance. For them, the maximum and arithmetic mean of the reference values will be the same as given in the Table 7. The assessment model will also investigate the impact on the different market segments: commuter, business, holiday and leisure travellers. For them the reference values will be the same as given in Table 8. The values of the KPI's of the Spanish railways are shown in the next tables.

- **KPI's of the Spanish railways for the type of railways**

Category	#	KPI	Units	Regional trains in Spain	Long distance trains in Spain
1. Network reach	1	Route density per km	km /k km^2	31,6	31,60
	2	Route density per capita	Km/ m. inh	341,0	341,0
2. Travel time	3	Average speed of trains	km/h	88,2	125,4
	4	Transport performance	%	6,8	6,8
	5	Speed (c. satisfaction)	%	84	84
3. Punctuality and reliability	6	Punctuality rate	%	92	89
	7	Reliability rate	%	0,986	0,995
	8	Punctuality & reliability (c. satisfaction)	%	79	79
4. Frequency	9	Frequency (c. satisfaction)	%	67	67
5. Convenience	10	Connection with railway (c. satisfaction)	%	65	65
	11	Connection with other modes (c. satisfaction)	%	76	76
	12	Parking facilities (c. satisfaction)	%	44	44
6. Comfort and travel experience	13	Comfort of seats (c. satisfaction)	%	85	85
	14	Availability of seats (c. satisfaction)	%	82	82
	15	Cleanliness of stations (c. satisfaction)	%	82	82
	16	Cleanliness of trains (c. satisfaction)	%	75	75
	17	Information about timetables (c. satisfaction)	%	85	85
	18	Information during the journey (c. satisfaction)	%	62	62
	19	Personnel on board (c. satisfaction)	%	66	66
7. Prices, marketing and sales	20	Rail fares	€ / km	0,77	0,76
	21	Ease of buying tickets (c. satisfaction)	%	85	85
	22	Through-tickets satisfaction (c. satisfaction)	%	79	79
	23	Tickets for several modes (c. satisfaction)	%	70	70
	24	Handling complaints (c. satisfaction)	%	57	57

8. Accessibility	25	Accessibility of stations for PRM	%	61	61
	26	Assistance by staff for PRM (c. satisfaction)	%	62	62
	27	Accessibility of trains for PRM (c. satisfaction)	%	57	57
9. Safety	28	Fatalities per length	Victims / 1000 km	0,05	0,05
	29	Fatalities per traffic	Victims / M passenger x km	0,99	0,99
	30	Security in stations (c. satisfaction)	%	84	84
	31	Security on-board (c. satisfaction)	%	91	91
10. Sustainability	32	Electrified ratio	%	0,64	0,64

Table 21: KPI values of the Spanish railways for the regional and long distance trains

- **KPI's of the Spanish railways for the market segments**

Category	#	KPI	Units	Commuters in Spain	Business in Spain	Holiday in Spain	Leisure in Spain
1. Network reach	1	Route density per km	km /k km^2	31,60	31,60	31,60	31,6
	2	Route density per capita	Km/ M. inh	341,00	341,00	341,00	341
2. Travel time	3	Average speed of trains	km/h	88,2	125,4	125,4	88,2
	4	Transport performance	%	6,8	6,8	6,8	6,8
	5	Speed	%	84	84	84	84
3. Punctuality and reliability	6	Punctuality rate	%	92	89	89	92
	7	Reliability rate	%	0,99	1,00	1,00	0,99
	8	Punctuality & reliability	%	71	70	82	79
4. Frequency	9	Frequency	%	60	54	68	68
5. Convenience	10	Connection with railway	%	65	65	65	65
	11	Connection with other modes	%	76	76	76	76
	12	Parking facilities	%	45	50	50	43
6. Comfort and travel experience	13	Comfort of seats	%	85	85	85	85
	14	Availability of seats	%	76	84	88	79
	15	Cleanliness of stations	%	81	71	85	81
	16	Cleanliness of trains	%	79	66	79	70
	17	Information about timetables	%	82	84	89	85
	18	Information during the journey	%	58	80	64	61
	19	Personnel on board	%	68	62	74	63
7. Prices, marketing and sales	20	Rail fares	€ / km	0,77	0,76	0,76	0,77
	21	Ease of buying tickets	%	85	93	86	85
	22	Through-tickets satisfaction	%	71	79	79	79
	23	Tickets for several modes	%	68	52	73	71
	24	Handling complaints	%	57	56	65	54
8. Accessibility	25	Accessibility of stations for PRM	%	60	69	65	55
	26	Assistance by staff for PRM	%	62	72	68	54
	27	Accessibility of trains for PRM	%	54	59	58	52
9. Safety	28	Fatalities per length	Victims / 1000 km	0,05	0,05	0,05	0,05
	29	Fatalities per traffic	Victims / M pass. x km	0,99	0,99	0,99	0,99
	30	Security in stations	%	84	84	84	84
	31	Security on-board	%	91	91	91	91
10. Sustainability	32	Electrified ratio	%	64	64	64	64

Table 22: KPI values of the Spanish railways for the regional and long distance trains

7.3.2 Weighting of the KPIs within performance categories

As seen in section 6.2.3, the categories having more than one KPI, the factors are weighting in a certain percentage. In the case study of the Spanish railways, the weighing of the KPI's within the categories will be the same as defined in the description of the assessment model, given in Table 9.

7.3.3 Calculation of scores and rankings

As pointed in section 6.2.4, the calculation of the scores and rankings gives the performance of each factor relative to the references considered. These will be calculated for the case of the Spanish railways considering the regional and long distance trains, and the four market segments.

$$ranking = 1 - score = 1 - \frac{x - (2\mu - max)}{2(max - \mu)}$$

The values of the rankings for each KPI for the overall assessment of the railway in Spain, for the two types of railways and the four market segments are the following:

Category	#	KPI	**General**	**Regional**	**Long distance**	**Commuter**	**Business**	**Holidays**	**Leisure**
1. Network reach	1	Route density per area	0,80	0,80	0,80	0,80	0,80	0,80	0,80
	2	Route density per capita	0,68	0,68	0,68	0,68	0,68	0,68	0,68
2. Travel time	3	Average speed of trains	0,20	0,00	0,27	0,00	0,27	0,27	0,00
	4	Transport performance	0,43	0,43	0,43	0,43	0,43	0,43	0,43
	5	speed satisfaction	0,27	0,27	0,27	0,27	0,27	0,27	0,27
3. Punctuality and reliability	6	Punctuality	0,17	0,33	0,10	0,33	0,10	0,10	0,33
	7	Reliability	0,27	0,38	0,14	0,38	0,14	0,14	0,38
	8	Punctuality & rel. satisfact	0,23	0,23	0,23	0,10	0,34	0,13	0,23
4. Frequency	9	Satisfaction with frequency	0,81	0,81	0,81	0,78	1,00	0,67	0,75
5. Convenience	10	Connection rail services	0,28	0,28	0,28	0,28	0,28	0,28	0,28
	11	Intermodality	0,15	0,15	0,15	0,15	0,15	0,15	0,15
	12	Parking facilities	0,65	0,65	0,65	0,66	0,32	0,33	0,63
6. Comfort and travel experience	13	Comfort of seating areas	0,38	0,38	0,38	0,38	0,38	0,38	0,38
	14	Availability of seats	0,28	0,28	0,28	0,18	0,07	0,05	0,34
	15	Cleanliness sretations	0,24	0,24	0,24	0,23	0,35	-0,03	0,21
	16	Cleanliness trains	0,18	0,18	0,18	0,00	0,17	0,08	0,30
	17	Information stations	0,50	0,50	0,50	0,44	0,42	0,05	0,44
	18	Information journey	0,64	0,64	0,64	0,47	0,05	0,40	0,56
	19	Assistance on board	0,38	0,38	0,38	0,07	0,50	0,15	0,41
7. Prices, tickets and sales	20	Prices	0,66	0,66	0,66	0,66	0,66	0,66	0,66
	21	Ease of buying tickets	0,33	0,33	0,33	0,33	-0,67	0,30	0,36
	22	through-tickets	0,21	0,21	0,21	0,72	-0,05	0,25	0,17
	23	tickets for several modes	0,47	0,47	0,47	0,81	0,75	0,36	0,42
	24	Handling complaints	0,10	0,10	0,10	-0,04	0,02	-0,05	0,12
8. Accessibility	25	Accessibility stations PRM	1,10	1,10	1,10	0,95	0,32	0,58	0,79
	26	Assistance staff to PRM	0,89	0,89	0,89	2,25	0,32	0,39	0,84
	27	Accessibility trains PRM	1,60	1,60	1,60	1,29	0,42	0,98	0,87
9. Safety and security	28	Fatalities per length	0,48	0,48	0,48	0,48	0,48	0,48	0,48
	29	Fatalities per traffic	0,09	0,09	0,09	0,09	0,09	0,09	0,09

	30	Security in stations	0,29	0,29	0,29	0,29	0,29	0,29	0,29
	31	Security on-board	0,27	0,27	0,27	0,27	0,27	0,27	0,27
10. Sustainability	32	Electrified ratio	0,46	0,46	0,46	0,46	0,46	0,46	0,46

Table 23: Rankings of the KPI's of the railways in Spain

7.3.4 Importance, Priorities and Significances

Once the performance indicators of the different KPI's are defined, the next step is to set how relevant are them to the users of the different Spanish railways and the different market segments. For that, the same importances, priorities and significances for each performance category as defined in the Table 13 for the type of railways and in Table 16 for each market segment.

7.3.5 Outputs of the railways in Spain

As seen in section 6.2.6, the final results are the product of the rankings per the significances.

The results of the assessment model for the Spanish railways are calculated in three levels: in general, for each type of railways and for each market segments. At first the results are given in the next subsections and finally will be compared and discussed to the outcomes of the interviews.

7.3.5.1 General results of the KPI's for the railways in Spain

Passengers railways in Spain has a two major lacks of performance. Before considering the level of significances of each category to the users, we observe that accessibility is the category ranking the worst, suggesting that users don't find the Spanish railways prepared to accommodate passengers with reduced mobility.

	Without significances	With significances
1. Network reach	0,07	0,11
2. Travel time	0,03	0,05
3. Punctuality and reliability	0,02	0,03
4. Frequency	0,08	0,12
5. Convenience	0,03	0,03
6. Comfort	0,04	0,04
7. Prices, tickets and sales	0,04	0,03
8. Accessibility	0,12	0,06
9. Safety and security	0,03	0,01
10. Sustainability	0,05	0,02

Table 24: General results of the assessment of the railways in Spain

When considering the significances, so the categories that are more relevant for the decision of the users when choosing to travel by railways, frequency appears to be the category with major lack of performance followed by network reach.

7.3.5.2 Results of the KPI's by type of railways and market segments

Finally the outcomes considering the two type of railways and the four market segments are given.

Category	#	KPI	Regional	Long dist.	Commuter	Business	Holidays	Leisure
1. Network reach	1	Route density per area	0,13	0,10	0,10	0,10	0,14	0,14
	2	Route density per capita	0,11	0,09	0,09	0,09	0,12	0,12
2. Travel time	3	Average speed of trains	0,00	0,05	0,00	0,05	0,04	0,00
	4	Transport performance	0,07	0,08	0,07	0,08	0,06	0,06
	5	speed satisfaction	0,04	0,05	0,05	0,05	0,04	0,04
3. Punctuality and reliability	6	Punctuality	0,05	0,01	0,06	0,02	0,01	0,04
	7	Reliability	0,06	0,02	0,06	0,02	0,02	0,05
	8	Punctuality & rel. satisfact	0,04	0,03	0,02	0,06	0,02	0,03
4. Frequency	9	Satisfaction with frequency	0,13	0,11	0,13	0,13	0,06	0,10
5. Convenience	10	Connection rail services	0,03	0,02	0,02	0,02	0,02	0,03
	11	Intermodality	0,02	0,01	0,01	0,01	0,01	0,02
	12	Parking facilities	0,07	0,06	0,06	0,03	0,03	0,07
6. Comfort and travel experience	13	Comfort of seating areas	0,02	0,04	0,02	0,04	0,05	0,03
	14	Availability of seats	0,02	0,03	0,01	0,01	0,01	0,03
	15	Cleanliness stations	0,01	0,03	0,01	0,04	0,00	0,02
	16	Cleanliness trains	0,01	0,02	0,00	0,02	0,01	0,03
	17	Information stations	0,03	0,06	0,03	0,05	0,01	0,04
	18	Information journey	0,04	0,07	0,03	0,01	0,05	0,05
	19	Assistance on board	0,02	0,04	0,00	0,06	0,02	0,04
7. Prices, tickets and sales	20	Prices	0,05	0,08	0,06	0,04	0,08	0,08
	21	Ease of buying tickets	0,03	0,04	0,03	0,04	0,04	0,04
	22	through-tickets	0,02	0,02	0,06	0,00	0,03	0,02
	23	tickets for several modes	0,04	0,05	0,07	0,04	0,04	0,05
	24	Handling complaints	0,01	0,01	0,00	0,00	0,01	0,01
8. Accessibility	25	Accessibility stations PRM	0,03	0,05	0,04	0,01	0,03	0,03
	26	Assistance staff to PRM	0,02	0,04	0,10	0,01	0,02	0,04
	27	Accessibility trains PRM	0,04	0,07	0,06	0,02	0,04	0,04
9. Safety and security	28	Fatalities per length	0,02	0,02	0,02	0,03	0,03	0,01
	29	Fatalities per traffic	0,00	0,00	0,00	0,01	0,01	0,00
	30	Security in stations	0,01	0,01	0,01	0,02	0,02	0,01
	31	Security on-board	0,01	0,01	0,01	0,02	0,02	0,01
10. Sustainability	32	Electrified ratio	0,01	0,01	0,02	0,01	0,01	0,02

Table 25: Results of the assessment model of the railways in Spain

As it can be seen, the following parameters are the less performing according to the assessment model. There are three that show a major lack of performance:

- Network density per area, especially for regional trains and for holiday and leisure travellers
- Frequency of trains, especially for regional trains and for commuter travellers
- Assistance staff to PRM

A second group of parameters show a medium lack of performance:

- Transport performance, for both long and regional distance trains
- Prices, for long distance trains and holidays and leisure travellers
- Tickets for several modes,
- Accessibility trains for PRM's
- Parking facilities, for regional trains and leisure travellers

The third group of parameters with minor lack of performance:

- Average speed of trains and speed satisfaction
- Punctuality and reliability
- Comfort of seating areas

7.3.5.3 Results of the performance categories

Results of the framework evaluation model:

	Regional	Long distance	Commuters	Business	Holidays	Leisure
1. Network reach	0,12	0,10	0,10	0,10	0,13	0,13
2. Travel time	0,05	0,06	0,05	0,06	0,05	0,04
3. Punctuality and reliability	0,05	0,02	0,04	0,04	0,02	0,04
4. Frequency	0,13	0,11	0,13	0,13	0,06	0,10
5. Convenience	0,03	0,03	0,03	0,02	0,02	0,03
6. Comfort	0,02	0,04	0,01	0,03	0,02	0,03
7. Prices, tickets and sales	0,03	0,04	0,04	0,02	0,04	0,04
8. Accessibility	0,03	0,05	0,06	0,02	0,03	0,04
9. Safety	0,01	0,01	0,01	0,02	0,02	0,01
10. Environment	0,01	0,01	0,02	0,01	0,01	0,02

Table 26: Results of the assessment model of the railways in Spain

The categories with major lack of performance are the following:

- Network reach and Frequency are the categories with major lack of performance, especially for holidays and leisure regarding the network reach, and for commuters and business regarding the frequency.
- Travel time, Punctuality and reliability, Prices and Tickets and Accessibility and have a medium to low lack of performance. Convenience and comfort also show a minor lack of performance

7.4 Analysis and comparison of the results to the users' perception

As introduced in section 2, the research has performed 12 interview to users of the Spanish railways. The collection of observation and feedback given by the users will be contrasted here to the results of the assessment model applied to Spain obtained in the previous point. The results of each performance category will be compared with the corresponding feedback from the users.

- **Analysis of the network indicators**

The indicators relative the extension of the network show very low levels of performance. Spain has clearly a low density of railways. The total length of the network respectively of the area of the country is below the European media and comparable to the value of Lithuania and lower than Bulgaria. It can be argued that Spain is a mountainous land which makes for the railways to be difficult to reach all parts of the country, however other mountainous countries such as Switzerland and Austria have much higher railway densities, confirming that the low number observed denotes a lack of railway network. Considering the population, Spain is also in the bottom of the ranking, even though in this indicator the most populated countries in Europe (France, Italy and the UK) are below the European average except Germany which is slightly above and thus the situation of Spain is less evident.

This matches totally the feedback from the users, since several interviewees raised the lack of connections as a major deficiency of the Spanish railways. and general perception that network is not enough extended. Extend network is the most common answer on the question "what needs to improve"

- **Analysis of the travel time**

The results of the assessment model about the travel time show only low- to medium lack of performances, thus in general railways offer good travel times.

Accordingly, the indicators show moderately good levels relative to the European standards.

However, the general perception of the interviewed users is that except high speed, all other trains are too slow. The reduction of the train travel of the conventional railways is also within the priority demands of the users when asking "what needs to improve". In fact the average speeds in Spain are very

heterogeneous. In the direct connections with high speed lines the travel times are short because trains are very fast. However there are two factors hidden in the data of the parameters used which are exposed in the feedback of the users. At first the speeds of the conventional trains which sometimes is very slow. And secondly the lack of efficient connections between the high speed services and the conventional and other transport modes which in total increases drastically the travel time.

When observing the results of the KPI's in the assessment model, these give more hints about the true situation. The KPI average speeds of trains does not show any outstanding lack of performance, same as speed satisfaction. These two parameters might by highly influenced by the effect of the high speed lines. However, the KPI transport performance shown values within medium level of lack of performance, especially for long distance, commuters and business travellers.

Thus, this confirms the importance of the parameter transport performance in the assessment model.

- **Analysis of the punctuality and reliability**

The assessmet model show only medium-to low lack of performances in four of the cases analysed. In the rest of the cases, the lack of performance is low. This suggest that trains in Spain tend to be punctual and the improvement of the factor is not the priority of the system.

This matches the feedback of the users, since in general punctuality and reliability are perceived good.

All goes aligned with the indicators of the punctuality, which show that the train services in Spain are within the most punctual in Europe as well as very reliable.

- **Analysis of the rail frequencies**

The assessment of the frequencies show major lack of performance and in 7 out of the 8 analysed cases, it corresponds with the highest ranking category in lack of performance. For the users of both type of railways it appears to be the priority factor, and for all but holiday travellers it results too as the major factor in terms of lack of performance.

Several respondents complain about lack of frequencies, especially the regional trains, but also for long distance trains other than high speed lines. This confirms the sensibility of the model to this factor.

Certainly, apart from the low values of satisfaction with frequency on the Spanish railway, as seen in Figure 29, the frequencies of the trains in Spain except direct high speed connection are generally much lower than other in Europe.

- **Analysis of the transport convenience**

The assessment does only show a minor lack of performance of the transport convenience. When observing the contributing factors we see that the results of the connection rail services and intermodality are quite good. Instead for the parking facilities they show two cases of medium level of lacking performance, for the regional train users and leisure travellers.

Nonetheless, in the interviews the transport users raised some examples of rail stations without public transport connections such as the cases of the high speed station outside city centres.

This might suggest that the used KPI's are not fully sensible to the situation. The three parameters ask about the satisfaction on the existing connection, but it does not inform about the lack of connections. In case of the connections between railway lines this should be enhanced, probably with the creation of a physical KPI that would add objective data to the level of synchronisation of the different railways services. However, the lacking of connection to other transport modes might be cause by external reasons which would not be part of the scope of the thesis, and thus should not be included in the model.

- **Analysis of the comfort and on-train experience**

The assessment of the comfort and on-train experience is made of several parameters: the comfort and availability of seats, the aesthetics and good maintenance of the trains and stations, the information to the users before and during the trip as well as the assistance by personnel on board. The results of these KPI's are discussed below:

- The assessment method shows some lack of performance in the comfort of the seats for long distance trains, business travellers and holiday travellers. This coincides with the feedback from the users, who gave some critics about comfort especially in the long distance conventional trains, contrasting with the very comfortable high speed trains. Although this confirms the viability of the model, it also shows a limitation of the model. In fact, the differences between conventional and high speed trains is a very usual critic in the feedbacks given by the users in Spain. However, this can't be caught by the assessment method as there is no separation between conventional and high speed but just between regional and long distance. The inclusion of high speed trains as an additional category of type of trains would be recommended as an improvement measure to the model.
- Regarding the seat capacity, both assessment and user's feedback show good valuation.
- The appearance of the stations in terms of cleanliness show in general good results in the assessment method, except for business travellers who might be more exigent in their perception. The appearance of the trains has good results in the assessment and also by the user's insight,

even though many users pointed the generalized “graffiti” of the Spanish trains. The graffiti might be very ostentatious but since they are not impacting the comfort of the users as they are only applied to the appearance of the units but not inside, where travellers spend the most of their journey time.

- The assessment shows conversed results on regards of the information, with medium lack of performance in the long distance trains in the stations and during the journey. This also coincides with the feedback from the users that pointed that some conventional trains have a lack of screens and indicators on platforms.
- The assistance on board shows some lack of performance for the long distance, business and leisure travellers. This coincides with the feedback of the users that claimed the lack of personnel on board and thus showed some concerns related with their personal security.

In conclusion, except for the connections and transfer, which could be improved with the creation of a new specific KPI, the rest of subgroups forming the comfort category are sensible to the users’ demands.

- **Analysis of the prices, tickets and sales**

Considering the assessment results of the this category, there are no significant lack of performances in any of the trains and market segments for the railways in Spain. Considering the results of the KPI, there are some cases of medium level of lack of performance especially for the rail fares and tickets for several modes in the case of commuters. This coincides exactly with the feedbacks of the users since some of them complained against the excessive prices and the lack of options for the tickets when changing trains to other transport modes in the commuter railways (“rodalies” / “cercanias”). The results of the KPI’s are discussed below:

- In fact the rail fares in Spain are generally above the European average. The major differences are observed in the shorter distances, so for the regional trains. For the long distance there are fewer differences even though the Spanish fares are also more expensive than the average in Europe. This is aligned with the feedback from the users since the majority feel that the fares could be cheaper or that at least they are not fair enough.
- Regarding the through tickets (tickets for different railway services), the results of the assessment are good even though there were a pair of specific examples given by the interviewed experts showing the lack of a ticket to travel using different railways (especially in case of different rail operators).

- Instead, as mentioned the tickets including several modes show a lack of performance, and this also goes aligned with the users' responses, as several answers pointed that combined cards with buses, metro or tramways should be more flexible.
- Finally, in terms of aftersales, both the assessment results and feedback from users are positive.

In conclusion the assessment model of this category responds correctly to the user's demands.

- **Analysis of the railway's accessibility**

The assessment method shows very low performance of the accessibility for persons of reduced mobility in the railways in Spain. The three parameters analysed, accessibility in stations and in trains for disabilities as well as the assistance by staff por persons with disabilities. Instead, interviews revealed a positive feedback from the users, since there was unanimously an affirmative answer on the question "Are stations and trains adapted for PRM's". Some expert user also pointed that there have been many efforts to improve the accessibility on stations with works on platforms and lifts, and to rail carriages with the introduction of low-floor vehicles.

However this is a parameter that must be considered by users with disabilities as other users might not have the proper perspective to correctly value the performance. There were no users from interviews with disabilities so in this case their views can't be fully contrasted. In order to solve that, it would be recommended that the KPI's distinguish whether the respondents are persons with reduced mobility. A feedback from a PRM user complaining against the accessibility to the railways or confirming it's accessibility will be certain, instead feedback from users without reduced mobility can't be fully trusted.

- **Analysis of the safety and security indicators**

The assessment method show a few lack of performance due to security in stations and trains, but very ranking below the other parameters. This confirms the general view of the users, as even though security is perceived to not be good enough, it's not considered to be a barrier on the use of railways.

This coincides with the feedback of the users, as some of them showed concerns about their personal security in stations and specially on-board, as pointed by them, mainly due to the attitude of other passengers and the lack of guards.

However, neither the assessment nor the interviews pointed any concern about safety. That contrasts with the reality, since in 2013 Spain suffered the deadliest rail accident in Europe in the last 20 years, when a high speed train travelling from Madrid to Ferrol derailed at a high speed in a curve outside the station of Santiago de Compostela in Galicia. The data from the black box proved that the train was

running at 195 km/h before the derailment, more than doubling the speed limit of 80 km/h in that curve. As a result, 79 passenger died and 140 were injured, causing a big impact in Spain and Europe [39].

But the fact is that even though this tragedy, considering the rail victims per network length in the last 10 years, Spain accumulated 21 fatalities per 1000 km, being the 7th safest network in Europe. Considering the traffic, Spain is also within the safest countries in Europe, much safer than the average.

To conclude, users do not care about the risk of transport safety (which means, they trust the trains as safe transport mode). Instead they are much more concerned about their personal security, mostly the danger other users may cause.

- **Analysis of the sustainability indicators**

The 64% of the railways in Spain are electrified, which means the majority of the network is operated by electric trains, more sustainable than the diesel units. The results of the model going aligned with that and show all very low values (meaning no lack of performance).

There were no respondents claiming against the sustainability so according to the results of the assessment, this was not a blocking point for the demand.

7.5 Adjustment and improvement measures

As discussed in the previous point, the results of the assessment model to the Spanish railways converge to the feedback of the interviews to the travellers in Spain in most of the cases. This is a first step to verify the feasibility of the use of the assessment model.

Yet as pointed in some cases there are potentially improvements on the model that might enhance the accuracy of the results. The proposed measures are listed and described here. Some were already introduced and suggested in the previous section 7.4, other are newly proposed after having an holistic view of the validation results of the model.

1) <u>Update the data collection</u>

   - ✓ **Update customer satisfaction survey:** customer satisfaction survey was performed on march 2018, although this is quite fresh, it would be recommended to update the requirements of the users as people needs change faster than ever.
   - ✓ **Update rail fares data:** Rail fares data were taken on 2016, and thus it would be recommendable to update that with current prices.

2) Adjust the KPI's data collection

- ✓ **Filter Customer satisfaction respondents:** make sure all data feedback in the customer satisfaction comes only from railway users. This is the case for the Eurobarometer survey of the 2018, but not for the survey of 2011. Thus for the most recent subjective KPIs, data comes only from railway users. However, for the KPI's dating on 2011, data was not filtered and respondents might be also non railway users, with clear less knowledge about their statements .
- ✓ **Accessibility KPIs respondents:** as pointed before in section 7.4, it would be necessary to ensure that respondents of the accessibility of the railways are persons with reduced mobility with experience in the railways so the data of this performance category is fully trustable and meaningful.

3) Creation of new KPI's

- ✓ **Stablish objective indicators to parametrize timetable frequencies:** the current model only includes a subjective indicator for the definition of the performance on frequencies. It would be recommendable to complement that with an objective parameter that could set running frequencies, possibly to differentiate between rush and peak hours. Since there are no homogenous statistics available between countries for that, it would be necessary to collect data from the timetables and create a database with new reference values.
- ✓ **Stablish objective indicators to parametrize the convenience:** similar to the previous point, the current model only includes subjective measures related with the satisfaction of the connecting services. However, in order to complement this with factual data, an indicator measuring the level of "synchronization" between different railway lines and with other transport means would be recommended.
- ✓ **Specific conditions of the high speed trains.** As introduced in the previous point, in addition to the regional and long distance trains travellers demands included in the model, it might be recommendable to discern between conventional and high speed. In the two last decades railways in Europe experienced the emerge of new high speed networks. These are normally performing extraordinary well as many countries used them as an emblem of their national infrastructure development. Yet, high speed might come together with a decline of the conventional railways since the major part of the budgets would be dedicated to the new lines. Thus, it would be recommended that the model can distinguish between the two type of railways to be able to uncover this kind of situations and potential different performances that now might remain hidden.

4) Effectiveness and systematics of the modelling

- ✓ **Verification of the importances**: the assessment model is based on the Check the model used by CE Delft (2011) [25] to get the importance of each factor to the user's demand of the railways. Since priorities of the users changes on time and the paper this is based dates back on 2011, it would be recommendable to ensure these importances are still valid. For that a specific research using surveys to the users would be needed.
- ✓ **Verification of the priorities:** the priorities of the groups have been established the same even though these might be slightly different between different countries and cultures. It would be recommendable to conduct surveys to identify which are the priorities in the group of users in which the assessment is intended to do.

5) Changes on the analysis area

- ✓ **Analysis of regions instead of countries:** until now, the assessment model has been designed and applied to sovereign states of the EU. This is interesting since railways are usually commanded in a national level. However, there are also several regional railways controlled and financed by regional authorities. Thus, having the possibility to assess railway in reduced areas would be very useful for the later creation of specific strategies and decision of investments. This will be exemplified in the next section with the assessment of railways in Vorarlberg and Catalonia.
- ✓ **Analysis of connecting points and railway lines:** apart from adjusting the model to the analysis of regions, it would be also of major interest to be able to assess the performance of lines independently from the rest of the network and also the assessment of the connectivity using railways between two geographic points an origin to a destination. This would require a further development of the model but it will certainly be useful for the assessment of specific railway lines with lack of performance that need to be identified what are the priority investments.
- ✓ **Analysis of countries outside EU:** The model has been developed for the assessment of countries in the European Union. In order to be able to assess further countries, data should be collected for further countries.

8. Application examples of the assessment model

In this section the assessment tool defined in section 6 will be applied to three further cases. At first the model will be applied to the case of the railways in Austria, in order to exemplify and compare results with the outcomes of the assessment model applied to the railways in Spain done in the previous section. Afterwards, the tool will be adjusted to be able to be applied to regions. As pointed in section 7.5, the assessment model has been developed for sovereign states of the EU. In this section the tool will be adapted for the analyse of regions within countries, specifically the "NUTS" (Nomenclature of Territorial Units for Statistics) as defined by the EU (2021) [40]. Two examples will be performed, at first the Austrian State of Vorarlberg and secondly the Autonomous Community of Catalonia in Spain.

8.1 Application of the model to Austria

In the previous section, the assessment model was applied to Spain in order to prove its effectiveness. Once the model has been validated and the limitations and potential improvements identified, in the present section the tool will analyse the railways in Austria. This analysis will be also used for gauging the model. For that, the results will be compared with those of the Spain.

Austria is the country of the EU with major propensity to travel by rail with 1504 p-km per inhabitant as seen in section 5.1, the second in Europe after Switzerland (2451 p-km / inh), and the third in the world after Japan (3400 p-km / inh) [41]. That makes Austria another perfect example to validate the model when comparing the results with Spain, a country with relative much lower usage of railways per capita. Thus, Austria will not only be a new example for the application of the model but also a way to observe the sensibility of the tool to opposite systems in terms of performance.

The assessment model will follow the same process as defined in Figure 60.

Figure 63: The six steps of the assessment model of the railways in Austria

8.1.1 Reference values and KPI's

The reference values are the same used in the assessment model applied to the case of Spain, so those values shown in section 6.2.2. As a reminder, two tables need to be used:

- Reference values for regional and long distance trains: same values as defined in Table 7.
- Reference values for market segments (considering four travelling purposes: commuters, business, holidays and leisure activities): same values as defined in Table 8.

The specific KPI values of the railways in Austria are given in the next Table 27. The weighting of the KPI's within the performance categories will be identical as the previously defined in Table 9, which are also the same used for the assessment of the Spanish railways.

Category	#	KPI (units)	General	Regional railways	Long distance railways	Commuter	Business	Holidays	Leisure
1. Network reach	1	Route density (km /k km^2)	60,0	60,0	60,0	60,0	60,0	60,0	60,0
	2	Route density per capita (Km/ m. inh)	561,4	561,4	561,4	561,4	561,4	561,4	561,4
2. Travel time	3	Average speed of trains (km/h)	77,5	53	102	53	102	102	53
	4	Transport performance (%)	8,7	8,7	8,7	8,7	8,7	8,7	8,7
	5	Commercial speed satisfaction (%)	83,0	83	83	83	83	83	83
3. Punctuality and reliability	6	Punctuality (%)	91,6	96,3	86,8	96,3	86,8	86,8	96,3
	7	Reliability (%)	0,99	0,99	0,99	0,99	0,99	0,99	0,99
	8	Punctuality and reliability satisfaction (%)	86	86	86	88	78	88	84
4. Frequency	9	Satisfaction frequency (%)	80	80	80	80	70	84	84
5. Convenience	10	Connection rail services (%)	65	65	65	65	65	65	65
	11	Connection other modes (%)	68	68	68	68	68	68	68
	12	Parking facilities for cars and bikes (%)	58	58	58	62	50	48	64
6. Comfort and travel experience	13	Comfort of seating areas (%)	82	82	82	82	82	82	82
	14	Availability of seats (%)	81	81	81	78	79	84	85
	15	Cleanliness & maintenance station (%)	89	89	89	91	87	89	88
	16	Cleanliness & maintenance trains (%)	80	80	80	76	71	83	83
	17	Information timetables & platforms (%)	86	86	86	92	85	91	86
	18	Information during the journey (%)	72	72	72	69	66	76	75
	19	Personnel on board (%)	75	75	75	69	75	79	76
7. Prices, marketing and sales	20	Prices (1 - € / km)	0,77	0,78	0,75	0,78	0,75	0,75	0,78
	21	Ease of buying tickets (%)	71	71	71	77	75	66	71
	22	availability of through-tickets (%)	76	76	76	82	69	80	75
	23	tickets for several modes (%)	70	70	70	81	54	71	70
	24	Handling complaints (%)	41	41	41	51	31	42	39

8. Accessibility	25	Accessibility stations PRM (%)	83	83	83	81	78	80	88
	26	Assistance staff PRM (%)	80	80	80	73	70	87	80
	27	Accessibility trains PRM (%)	68	68	68	67	67	64	70
9. Safety and security	28	Fatalities length (1 / (Victims / 1000 km))	0,02	0,02	0,02	0,02	0,02	0,02	0,02
	29	Fatalities traffic (1 - Victims / Mpas x km)	0,98	0,98	0,98	0,98	0,98	0,98	0,98
	30	Security in stations (%)	87	87	87	87	87	87	87
	31	Security on-board (%)	93	93	93	93	93	93	93
10. Sustainability	32	Electrified ratio (%)	0,72	0,72	0,72	0,72	0,72	0,72	0,72

Table 27: KPI's of the railways in Austria

8.1.2 Calculation of rankings

The calculation of rankings follows the procedure described in section 6.2.4. As a reminder, the scores and rankings are obtained considering the values of the KPI's and the arithmetic means and maximum reference values, as shown in the next formulae already seen before:

$$ranking = 1 - score = 1 - \frac{kpi - (2\mu - max)}{2(max - \mu)}$$

The rankings are calculated for the overall situation of the network, for the two type of railways and for the four market segments as shown in the next table:

KPI	General	Regional	Long distance	Commuter	Business	Holidays	Leisure
Route density per area	0,56	0,56	0,56	0,56	0,56	0,56	0,56
Route density per capita	0,48	0,48	0,48	0,48	0,48	0,48	0,48
Average speed of trains	0,52	0,72	0,45	0,72	0,45	0,45	0,72
Transport performance	0,33	0,33	0,33	0,33	0,33	0,33	0,33
speed satisfaction	0,32	0,32	0,32	0,32	0,32	0,32	0,32
Punctuality	0,12	0,00	0,17	0,00	0,17	0,17	0,00
Reliability	0,25	0,22	0,28	0,22	0,28	0,28	0,22
Punctuality & rel. satisfact	0,00	0,00	0,00	0,00	0,22	0,00	0,10
Satisfaction with frequency	0,31	0,31	0,31	0,22	0,47	0,00	0,18
Connection rail services	0,28	0,28	0,28	0,28	0,28	0,28	0,28
Intermodality	0,46	0,46	0,46	0,46	0,46	0,46	0,46
Parking facilities	0,24	0,24	0,24	0,21	0,32	0,40	0,08
Comfort of seating areas	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Availability of seats	0,33	0,33	0,33	0,11	0,23	0,23	0,16
Cleanliness stations	0,03	0,03	0,03	0,04	0,00	0,00	0,03
Cleanliness trains	0,00	0,00	0,00	0,08	0,00	0,00	0,00
Information stations	0,42	0,42	0,42	0,00	0,33	0,00	0,38
Information journey	0,29	0,29	0,29	0,17	0,36	0,16	0,15
Assistance on board	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Prices	0,67	0,63	0,71	0,63	0,71	0,71	0,63
Ease of buying tickets	1,11	1,11	1,11	1,00	2,33	1,30	1,00
through-tickets	0,33	0,33	0,33	0,11	0,41	0,21	0,33

tickets for several modes	0,47	0,47	0,47	0,31	0,70	0,42	0,45
Handling complaints	0,48	0,48	0,48	0,21	0,57	0,50	0,56
Accessibility stations PRM	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Assistance staff to PRM	0,00	0,00	0,00	0,00	0,36	0,00	0,03
Accessibility trains PRM	0,50	0,50	0,50	0,36	0,08	0,00	0,27
Fatalities per length	0,59	0,59	0,59	0,59	0,59	0,59	0,59
Fatalities per traffic	0,23	0,23	0,23	0,23	0,23	0,23	0,23
Security in stations	0,17	0,17	0,17	0,17	0,17	0,17	0,17
Security on-board	0,19	0,19	0,19	0,19	0,19	0,19	0,19
Electrified ratio	0,35	0,35	0,35	0,35	0,35	0,35	0,35

Table 28: Calculation of rankings of the KPI's for the railways in Austria

8.1.3 Importances and priorities

As defined in section 6.2.5, the next step after the definition of the KPI's is to set the relevance of the factors to the users of the two types of railways and the different market segments in Austria. In this case the same importances, priorities and significances for each performance category as defined in the tables Table 13 for the type of railways, and in Table 16 for each market segment, are used.

8.1.4 Outputs of the assessment of the railways in Austria

As seen in section 6.2.6, the outcomes of the assessment model are evaluated firstly as overall results and secondly considering the type of railways and market segments.

- **Overall results of the railways in Austria**

In general, passengers railway in Austria have no major lack of performance. Before considering the level of significances of each category we observe that prices, tickets and sales is the category ranking the worst, suggesting that this is the factor with major need of improvement.

	Results without significance	Results with significance
1. Network reach	0,05	0,07
2. Travel time	0,04	0,05
3. Punctuality and reliability	0,01	0,02
4. Frequency	0,03	0,04
5. Convenience	0,03	0,03
6. Comfort	0,02	0,02
7. Prices, tickets and sales	0,06	0,06
8. Accessibility	0,02	0,01
9. Safety and security	0,03	0,01
10. Sustainability	0,04	0,02

Table 29: Results of the assessment of the railways in Austria

When considering the general significances, so the categories that are more relevant for the decision of the users when choosing to travel by railways, network reach appears to be the category with major lack of performance, although this is relatively low compared to the lack of performance observed in the analysis of the Spanish railways which resulted 0,11 as shown in Table 24.

- **Results by type of railways in Austria**

The assessment of the performance categories for the long distance trains of the Austrian railway shows a more equilibrated situation than the regional trains. There are no major lacks of performances for any of the two type of railways, but the model suggests that network reach for regional and prices, tickets and sales for the long distance might be improved in the first place to get an increase of usage. That can be interpreted as several users of regional trains can't reach their destination by trains and thus can't travel with railways, and several long distance travellers find railways too expensive and choose other modes.

	Regional	Long distance
1. Network reach	0,09	0,07
2. Travel time	0,07	0,06
3. Punctuality and reliability	0,01	0,02
4. Frequency	0,05	0,04
5. Convenience	0,04	0,03
6. Comfort	0,01	0,03
7. Prices, tickets and sales	0,05	0,07
8. Accessibility	0,00	0,01
9. Safety and security	0,01	0,01
10. Sustainability	0,01	0,01

Table 30: Results of the assessment model by type of railways in Austria

The second less performing category for both railways is travel time, so the second priority action to catch more users would be the reduction of travel time.

- **Analysis by market segments in Austria**

Finally the results of the assessment model for the four type of travellers are discussed below.

	Commuters	Business	Holidays	Leisure
1. Network reach	0,07	0,07	0,09	0,09
2. Travel time	0,07	0,06	0,05	0,05
3. Punctuality and reliability	0,01	0,04	0,02	0,01
4. Frequency	0,04	0,06	0,00	0,02
5. Convenience	0,03	0,03	0,03	0,04

6. Comfort	0,01	0,02	0,02	0,02
7. Prices, tickets and sales	0,04	0,05	0,07	0,07
8. Accessibility	0,01	0,01	0,00	0,00
9. Safety and security	0,01	0,02	0,02	0,01
10. Sustainability	0,02	0,01	0,01	0,02

Table 31: Results of the assessment model by market segment of the railways in Austria

The interpretation of the results for each market segment is the following:

- Commuters in Austria would require an increase of the network extension and a reduction of travel time as main measures to travel more by railways. Yet the result show that the lack of performance in these two categories is “moderate to low”. The rest of categories are performing relatively well.
- Business travellers in Austria would require mostly an increase of the network extension, but also a reduction of the travel time and an increase of frequency to get more incentives to travel by railways. Finally, the prices could be reduced or the options for tickets and sales improved. Like the commuters, the assessed categories of this segment group have no major lack of performances.
- Passengers going to holidays would travel more by train if they had more possible destinations, since at first the model shows a lack of performance in the network reach. The second more important factor preventing an increase of the rail usage on this market segment are the high prices and lack of ticketing options. Reduction of travel time would be the third group of measures in level of importance for the travellers going to holidays.
- Travellers going into leisure activities are very likely the same that holiday travellers.

In conclusion, the results of the assessment to the railways in Austria show maximum values of lacking performance of 0,09 and only for three performance categories in all the evaluated cases, followed by nine cases ranking 0,07. According to the Table 17, this corresponds to a medium lack of performance. Afterwards, there are five categories ranking 0,06 which corresponds to a “low-to-medium” lack of performance as seen in Table 17. In all, the railways in Austria don’t show any “medium-to high”, neither “high” lack of performance. This results contrasts with the assessment of the railways in Spain, which resulted in several major lacks of performances as shown in section 7.3.5.3. This confirms the effectiveness of the model to reflect the level of performance of the evaluated system considering the rail usage. As seen in the section 5.1 Austria has a railway system with a relatively major propensity of travel compared to Spain. Consequently, we can affirm that the model is sensible to the different cases of railways in terms of usage and the assessment of performance goes aligned with the desired objective of the thesis.

8.2 Application and adjustment of the model for the assessment of regions

When reducing the focus from the countries to the regions, the specific issues of the railway might flourish and thus observed in a better perspective. The data of the customer satisfaction of railway users is available for different regions of each country and thus a more detailed analysis can be undertaken considering the specific responses of the users as well as the statistics of the railways in in those areas. Two examples will be shown in the present study as a way to show the application of the model to regions.

The concept of region used in this section is the NUTS as defined by the EU (2021) [40]. There are three levels of NUTS depending on the population. For the present study, the two analysed regions are considered NUTS of level 2. At first, the region of Vorarlberg which corresponds to one of the 9 states or Bundesländer of Austria. Secondly, the region of Catalonia which correspond to one of the 17 autonomous communities of Spain.

Even though both regions considered are part of the level 2 of the NUTS, they are very different in size and population. Whilst Vorarlberg is a relative small and less populated region (even though its relative high population density), Catalonia is within the largest and most populated regions of the NUTS level 2 classification in Europe [42] [43]. This will also give the opportunity to analyse the sensibility and efficiency of the model to different types of regions such as them.

If the data is available or it can be collected, the same model could be also applied for NUTS of level 1 (normally geographic area) and level 3 (normally provinces or smaller administrative areas).

8.2.1 Application of the model to Vorarlberg

The assessment model will be applied to the state of Vorarlberg, in Austria. The process will follow the steps defined in Figure 60 and already applied to the railways in Spain and Austria, although some KPIs will not be used and the assessment will be limited in general and for the four cases of market segments.

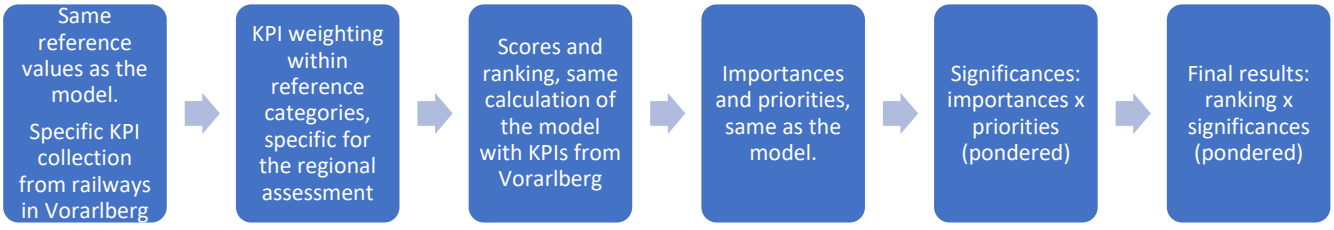


Figure 64: The six steps of the assessment model of the railways in Vorarlberg

8.2.1.1 Reference values and KPI's

The references values in the assessment of Vorarlberg are the same as used in the previous analysis done in this thesis. The values are shown in section 7.3.1.

The collection of KPI values will be slightly different than the assessment of the countries seen before. As it will be exposed here, some of the data is not available and thus not all KPI's will be able to be used.

The following objective parameters will be specifically calculated for the region of Vorarlberg:

- ✓ Network reach, both indicators will be calculated considering the length of the railways, the area of the region and the inhabitants of Vorarlberg
- ✓ Transport performance, it is available for the region [30]
- ✓ Punctuality, data is available for the trains of the region [44]
- ✓ Electrified ratio, data will be calculated considering the amount of electrified railways in the region

On the other hand, following objective parameters will not be specific for the region of Vorarlberg:

- Regarding rail fares, it is assumed that there are no differences in a national level.
- The data is not available for the fatalities per length and traffic.
- The average speed of trains is also not available. This category will not be used in the model and thus its weighting to the category "travel time" will be 0%. Instead, transport performance will account for the 60% of the value and the commercial speed satisfaction for the 40%.

In order to calculate the KPI of the first category "network reach", the length of the railway lines dedicated to passenger services is calculated.

Line	Distance
Bahnstrecke Lindau–Bludenz	67,75 km
Bahnstrecke St. Margrethen–Lauterach	9,58 km
Montafonerbahn	12,87 km
TOTAL length railways in Vorarlberg	90,17 km

Table 32: Physical KPI's used for the region of Vorarlberg. Source: [45]

It must be noted that the "Bregenzerwaldbahn" narrow gauge railway is not included in the calculation since it does not have commercial services but only used as heritage railway with the sporadic operation of steam trains.

The map of the considered railways is sown below:

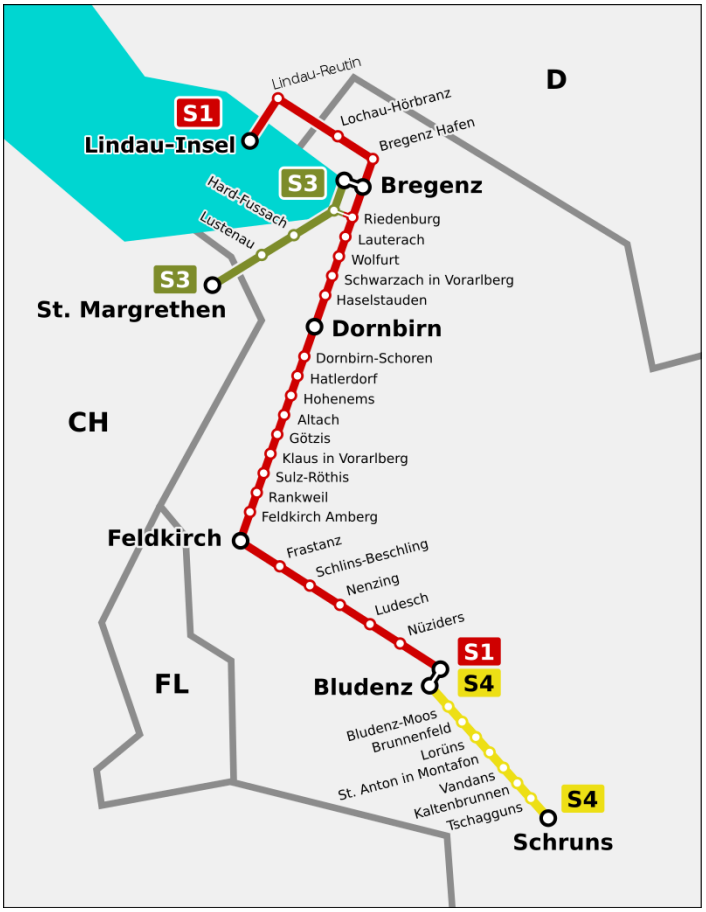


Figure 65: Railways in the region of Vorarlberg, Austria. Source: [45]

Additionally, the geo-demographic data of the region is the following [42]:

- Population: 397094 inhabitants
- Area: 2601 km^2

In conclusion the objective KPI's for the region of Vorarlberg are calculated as follows:

Performance category	KPI	Value
Network reach	Route density per km	34,7 km / k km^2
	Route density per capita	227,1 km / M inh
Travel time	Transport performance	2,1 inh. 1,5h / inh. 120km
Punctuality	Punctuality ratio	97 %
Sustainability	Electrified ratio	100 %

Table 33: Physical KPI's used for the region of Vorarlberg. Own creation.

Regarding the subjective parameters coming from the satisfaction of the users, the following table shows the values used for Vorarlberg. Since the customer satisfaction values of the region of Vorarlberg are not available, it will be assumed for this example that satisfaction of the railway users coincide with the respondents classified as "west Österreich" (NUTS level 1) [40]. For information, the interviews

classified the Austrian respondents within the three NUTS level 1 regions of “Ost Österreich”, “Sud Österreich” and “West Österreiche” so Est, South and West Austria [24].

KPI	west Österreich	Austria
Punctuality & reliability satisfaction	84 %	86 %
Satisfaction with frequency	77 %	80 %
Parking facilities for cars and bikes	52 %	58 %
Availability of seats	77 %	81 %
Cleanliness & maintenance stations	88 %	89 %
Cleanliness & maintenance trains	76 %	80 %
Information timetables & platforms	83 %	86 %
Information during the journey	67 %	72 %
Assistance / personnel on board	70 %	75 %
Ease of buying tickets	66 %	71 %
availability of through-tickets	72 %	76 %
availability of tickets for several modes	64 %	70 %
Handling complaints	60 %	69 %
Accessibility of stations for PRM	76 %	83 %
Assistance by staff for PRM	68 %	80 %
Accessibility of trains for PRM	54 %	68 %

Table 34: Perception KPI’s used for the railways in Vorarlberg. Source: [24]

Commercial speed satisfaction, connection with rail services, connection with other modes, comfort of seating areas, security in stations and security on-board come from an older survey, which data is not available for the different regions of the European countries, so they will not be used in this evaluation.

8.2.1.2 Performance categories: weighing of the KPI’s

Considering that some of the KPIs are not available, the internal weighing of the KPI’s within the same categories will differ from those show in section 6.2.3 for the assessment of national railway systems of countries. The following are the weighing of the KPI to be used for the assessment of Vorarlberg:

Category	#	KPI	Weighting
1. Network reach	1	Route density per km	50%
	2	Route density per capita	50%
2. Travel time	3	Average speed of trains	0%
	4	Transport performance	100%
	5	Commercial speed satisfaction	0%
3. Punctuality and reliability	6	Punctuality (% of trains with delay <5min)	50%
	7	Reliability (% of cancelled trains)	0%
	8	Punctuality and reliability customer satisfaction	50%

4. Frequency	9	Satisfaction with frequency	100%
5. Convenience	10	Connection with rail services	0%
	11	Intermodality: Connection with other modes	0%
	12	Parking facilities for cars and bikes	20%
6. Comfort and travel experience	13	Comfort of seating areas	0%
	14	Availability of seats	20%
	15	Cleanliness and maintenance of stations	10%
	16	Cleanliness and maintenance of trains	10%
	17	Information about timetables and platforms	20%
	18	Information during the journey	20%
	19	Assistance / personnel on board	20%
7. Prices, tickets and sales	20	Fares	20%
	21	Ease of buying tickets	20%
	22	availability of through-tickets	20%
	23	availability of tickets for several modes	20%
	24	Handling complaints	20%
8. Accessibility	25	Accessibility of stations for disabilities	35%
	26	Assistance by staff for persons with disabilities	30%
	27	Accessibility of trains for disabilities	35%
9. Safety and security	28	Fatalities per length	50%
	29	Fatalities per traffic	50%
	30	Security in stations	0%
	31	Security on-board	0%
10. Sustainability	32	Electrified ratio (% of electrified lines)	100%

Table 35: Weighting of the KPI's within performance categories for the railways in Vorarlberg. Own creation.

8.2.1.3 Calculation of scores and rankings

The scores and rankings are calculated according to the formulae described in section 6.2.4, same as used for the previous examples of Spain and Austria. The ranking values for the KPI's in the assessment of Vorarlberg are shown below. Note that some performance categories have been removed due to the lack of data as discussed in the previous subsection.

Performance category	Rankings				
	General	Commuter	Business	Holidays	Leisure
Route density per km	0,77	0,77	0,77	0,77	0,77
Route density per capita	0,79	0,79	0,79	0,79	0,79
Transport performance	0,69	0,69	0,69	0,69	0,69
Commercial speed satisfaction	0,00	0,00	0,00	0,00	0,00
Punctuality rate	0,00	0,00	0,00	0,00	0,00
Punctuality and reliability	0,07	0,07	0,07	0,07	0,07
Satisfaction with frequency	0,42	0,42	0,42	0,42	0,42
Parking facilities for cars and bikes	0,41	0,41	0,41	0,41	0,41
Availability of seats	0,56	0,56	0,56	0,56	0,56
Cleanliness and maintenance of stations	0,06	0,06	0,06	0,06	0,06
Cleanliness and maintenance of trains	0,14	0,14	0,14	0,14	0,14

Information about timetables and platforms	0,67	0,67	0,67	0,67	0,67
Information during the journey	0,46	0,46	0,46	0,46	0,46
personnel on board	0,21	0,21	0,21	0,21	0,21
Ease of buying tickets	1,39	1,39	1,39	1,39	1,39
availability of through-tickets	0,50	0,50	0,50	0,50	0,50
availability of tickets for several modes	0,65	0,65	0,65	0,65	0,65
Handling complaints	0,02	0,02	0,02	0,02	0,02
Accessibility of stations for PRM	0,35	0,35	0,35	0,35	0,35
Assistance by staff for PRM	0,56	0,56	0,56	0,56	0,56
Accessibility of trains for PRM	1,90	1,90	1,90	1,90	1,90
Fatalities per length	0,59	0,59	0,59	0,59	0,59
Fatalities per traffic	0,23	0,23	0,23	0,23	0,23
Electrified ratio	0,00	0,00	0,00	0,00	0,00

Table 36: Rankings of the performance categories for the railways in Vorarlberg. Own creation.

8.2.1.4 Importances, priorities and significances

Since the assessment of the railways will be conducted for the different market segments, the same importances, priorities and significances for each performance category as defined in Table 16 for each market segment are used.

8.2.1.5 Outputs of the assessment of the railways in Vorarlberg

As exposed in section 6.2.6, the outcome of the model indicate the level of performance of each category, and are interpreted in the way that the higher results indicate the major lack of performance.

At first the overall results of the region of Vorarlberg are shown here:

	Results without significance	Results with significance
1. Network reach	0,08	0,11
2. Travel time	0,07	0,10
3. Punctuality and reliability	0,00	0,00
4. Frequency	0,04	0,06
5. Convenience	0,01	0,01
6. Comfort	0,04	0,04
7. Prices, tickets and sales	0,05	0,05
8. Accessibility	0,10	0,05
9. Safety and security	0,04	0,02
10. Sustainability	0,00	0,00

Table 37: Assessment overall results for the railways in Vorarlberg

The interpretation of the results is discussed below:

- Considering the performances of the 10 categories without taking into account the importance they have in the choice of travel by rail, we observe that the railways in Vorarlberg do not have major lack of performance, although accessibility ranks within the medium-to high lack of performance. This is due to the negative feedback given by the users when asking for the level of accessibility of the railways in the region.
- Considering the importance to the users' choice of traveling by rail, network reach becomes the category with major lack of performance followed by the travel time.

Secondly, the results by market segment are shown here:

	Commuters	Business	Holidays	Leisure
1. Network reach	0,10	0,10	0,14	0,14
2. Travel time	0,12	0,12	0,09	0,09
3. Punctuality and reliability	0,00	0,00	0,00	0,00
4. Frequency	0,07	0,06	0,04	0,06
5. Convenience	0,01	0,01	0,01	0,01
6. Comfort	0,02	0,05	0,05	0,03
7. Prices, tickets and sales	0,04	0,03	0,06	0,06
8. Accessibility	0,04	0,04	0,04	0,04
9. Safety and security	0,02	0,02	0,02	0,01
10. Sustainability	0,00	0,00	0,00	0,00

Table 38: Assessment results for each market segment for the railways in Vorarlberg

The interpretation of the results is discussed below:

- The commuter travelers find a major lack of performance in travel time. The model suggest that a reduction in travel time would increase the use of commuters in the railways in Vorarlberg as a first measure. Secondly, the network reach does also ranks poor, so an extension of the network would be the second group of measures to implement for this segment of travelers.
- The results for business travelers in Vorarlberg are very similar than the commuters, with the two main categories with lack of performance being travel time and network reach.
- Holidays travelers the network reach is the category with major lack of performance. The ranking obtained in this category is very high, suggesting that for this segment group this is a strong barrier for an increase of the rail usage. Travel time is the next category with lack of performance for the holiday travelers.
- The results for leisure travelers are almost identical to the holidays travelers, with network reach as major lack of performance category, followed by travel time.

8.2.2 Application of the model to Catalonia

In a similar way than the previous point for the region of Vorarlberg, in this section the assessment model will be applied to the region of Catalonia, Spain. The process will follow the same steps as exposed in the previous examples and shown in the Figure 60. Like the analysis of Vorarlberg, this will be limited to the general assessment and to the four market segments.

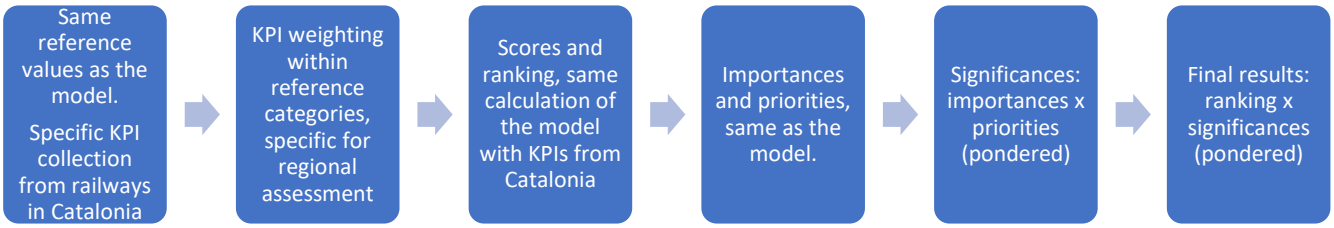


Figure 66: The six steps of the assessment of the railways in Catalonia

8.2.2.1 Reference values and KPI's in Catalonia

In the same way as the previous assessed railway systems, the first step for the regional evaluation is the collection of reference values and KPI's. The reference values will be the same as defined in 6.2.2.2.

The values of the KPI's will be obtained in the same way as in the previous assessment of the region of Vorarlberg and will be distinguished between the objective and subjective parameters.

The following objective parameters will be specifically defined for the railways of Catalonia:

- ✓ Network reach, both indicators will be calculated considering the length of the railways, the area of the region and the inhabitants of Catalonia
- ✓ Transport performance, it is available for each of the four provinces Barcelona, Tarragona, Girona and Lleida
- ✓ Punctuality, data is available for the trains of the region
- ✓ Electrified ratio, data will be calculated considering the amount of electrified railways in the region

Regarding rail fares, it is assumed that there are no differences in a national level.

In order to calculate the KPI of the first category "network reach", the length of the railway lines dedicated to passenger services is calculated. The map of the considered railways in the region is shown below:

Figure 67: Railways in the region of Catalonia, Spain [46]

The calculation of the overall length of railways in the region is based on adding the distances of the different operative lines of regional and long distance trains.

Type of railway	Line	Distance (km)
ADIF conventional railways	Barcelona-Mataró-Blanes-Maçanet	73
	Barcelona-Girona-Portbou	162,1
	Barcelona-Vilafranca-Tarragona	95,2
	Barcelona-Manresa-Lleida-Aragó	173,1
	Tarragona-Reus-Lleida	103,5
	Tarragona-Tortosa/València	110,9
	Montcada-Vic-Puigcerdà	148,8
	Barcelona-(Aeroport)-Vilanova-Picamoixons	102,3
	Reus-Móra la Nova-Aragó	87,3
	Castellbisbal/El Papiol-Mollet	27,3
	Estacions i línies de la ciutat de Barcelona	44,5
	Total conventional	1128
ADIF High Speed railway	LAV Aragó-Lleida-Barcelona	204
	LAV Barcelona-Figueres	129

	LGV Figueres-Perpinyà	45
	LAV Camp de Tarragona-Corredor del Mediterrani	19,5
	Total High Speed	397,5
Ferrocarrils de la Generalitat de Catalunya	Línies metropolitanes	189
	Montserrat	5,2
	Cremallera de Núria	12,5
	Línia Lleida-La Pobla (this is the only non-electrified line in the region)	89,3
	Total FGC	296
	TOTAL length railways in Catalonia	1821,5

Table 39: Length of the railway lines in Catalonia [46] [47]

Additionally, the geo-demographic data of the region is the following [43]:

- Population: 7727029 inhabitants
- Area: 32108 km^2

Finally, the physical KPI's can be calculated:

Performance category	KPI concept		KPI value
Network reach	Route density per km		56,73 km / k km^2
	Route density per capita		235,73 km / M inh
Travel time	Transport performance (inh. 1,5h / inh. 120km)	Barcelona	13,9
		Girona	2,2
		Lleida	3,7
		Tarragona	1,7
		Catalonia	5,75
Punctuality	Punctuality rate		94 %
Sustainability	Electrified ratio		95,1 %

Table 40: Physical KPI's used for the railways in Catalonia. Own creation.

The subjective indicators coming from the perception of the users are shown in the table below. Since customer satisfaction of the specific region of Catalonia are not available, it will be assumed for this example that satisfaction is the same than the respondents of "Noreste" so the north-east of Spain were the region is located.

KPI	North-east Spain	Spain
Punctuality & reliability satisfaction	79 %	79 %
Satisfaction with frequency	65 %	67 %
Parking facilities for cars and bikes	41 %	44 %
Availability of seats	83 %	82 %

Cleanliness & maintenance stations	83 %	82 %
Cleanliness & maintenance trains	76 %	75 %
Information timetables & platforms	85 %	85 %
Information during the journey	61 %	62 %
Assistance / personnel on board	65 %	66 %
Ease of buying tickets	85 %	85 %
availability of through-tickets	77 %	79 %
availability of tickets for several modes	69 %	70 %
Handling complaints	57 %	57 %
Accessibility of stations for PRM	59,3%	60,7%
Assistance by staff for PRM	59,7%	61,9%
Accessibility of trains for PRM	53,9%	56,7%

Table 41: Perception KPI's used for the railways in Catalonia. Source: [24]

For information, the interviewees were classified between North-west, North-east, Madrid, Centre, East, South and Canary Islands. According to this classification the most of the north-east respondents are users of the railways in Catalonia which enhances the validity of the assessment.

8.2.2.2 Weighting of the KPIs within the performance categories in Catalonia

Considering that some of the KPIs are not available, the internal weighing of the KPI's within the same categories will differ from those show in section 6.2.3 for the assessment of national railway systems of countries. The following are the weighing of the KPI to be used for the assessment of Catalonia:

Category	#	KPI	Weighting
1. Network reach	1	Route density per km	50%
	2	Route density per capita	50%
2. Travel time	3	Average speed of trains	0%
	4	Transport performance	100%
	5	Commercial speed satisfaction	0%
3. Punctuality and reliability	6	Punctuality (% of trains with delay <5min)	50%
	7	Reliability (% of cancelled trains)	0%
	8	Punctuality and reliability customer satisfaction	50%
4. Frequency	9	Satisfaction with frequency	100%
5. Convenience	10	Connection with rail services	0%
	11	Intermodality: Connection with other modes	0%
	12	Parking facilities for cars and bikes	20%
6. Comfort and travel experience	13	Comfort of seating areas	0%
	14	Availability of seats	20%
	15	Cleanliness and good maintenance of stations	10%

	16	Cleanliness and good maintenance of trains	10%
	17	Information about train timetables and platforms	20%
	18	Information during the journey	20%
	19	Assistance / personnel on board	20%
7. Prices, tickets and sales	20	Fares	20%
	21	Ease of buying tickets	20%
	22	availability of through-tickets	20%
	23	availability of tickets for several modes	20%
	24	Handling complaints	20%
8. Accessibility	25	Accessibility of stations for disabilities	35%
	26	Assistance by staff for persons with disabilities	30%
	27	Accessibility of trains for disabilities	35%
9. Safety	28	Fatalities per length	50%
	29	Fatalities per traffic	50%
	30	Security in stations	0%
	31	Security on-board	0%
10. Environment	32	Electrified ratio (% of electrified lines)	100%

Table 42: Weighting of the KPI's within performance categories for the railways in Catalonia

8.2.2.3 Importances, priorities and significances in Catalonia

Just like the assessment of the region of Vorarlberg, the assessment of the railways in Catalonia will be conducted for the different market segments, but not for the different types of railways. Thus, the same importances, priorities and significances for each performance category as defined in Table 16 will be used.

8.2.2.4 Calculation of scores and rankings

Once all the KPI's values are calculated, the rankings of each parameter can be calculated taking into account the formulae seen in section 6.2.4 and the reference values defined for the model.

Performance category	General	Commuter	Business	Holidays	Leisure
Route density per km	0,58	0,58	0,58	0,58	0,58
Route density per capita	0,78	0,78	0,78	0,78	0,78
Transport performance	0,49	0,49	0,49	0,49	0,49
Commercial speed satisfaction	0,00	0,00	0,00	0,00	0,00
Punctuality (% of trains with delay <5min)	0,17	0,17	0,17	0,17	0,17
Punctuality and reliability	0,23	0,23	0,23	0,23	0,23
Satisfaction with frequency	0,88	0,88	0,88	0,88	0,88
Parking facilities for cars and bikes	0,74	0,74	0,74	0,74	0,74
Availability of seats	0,22	0,22	0,22	0,22	0,22
Cleanliness and maintenance of stations	0,21	0,21	0,21	0,21	0,21

Cleanliness and good maintenance of trains	0,14	0,14	0,14	0,14	0,14
Information about timetables and platforms	0,50	0,50	0,50	0,50	0,50
Information during the journey	0,68	0,68	0,68	0,68	0,68
Assistance / personnel on board	0,42	0,42	0,42	0,42	0,42
Ease of buying tickets	0,33	0,33	0,33	0,33	0,33
availability of through-tickets	0,29	0,29	0,29	0,29	0,29
availability of tickets for several modes	0,50	0,50	0,50	0,50	0,50
Handling complaints	0,10	0,10	0,10	0,10	0,10
Accessibility of stations for disabilities	1,19	1,19	1,19	1,19	1,19
Assistance by staff for PRM	1,02	1,02	1,02	1,02	1,02
Accessibility of trains for disabilities	1,91	1,91	1,91	1,91	1,91
Fatalities per length	0,48	0,48	0,48	0,48	0,48
Fatalities per traffic	0,09	0,09	0,09	0,09	0,09
Electrified ratio	0,05	0,05	0,05	0,05	0,05

Table 43: Rankings of the performance categories for the railways in Catalonia

8.2.2.5 Outputs of the assessment of the railways in Catalonia

As exposed in section 6.2.6, the outcome of the model indicate the level of performance of each category, and are interpreted in the way that the higher results indicate the major lack of performance.

At first the overall results of the assessment of the railways in the region of Catalonia are shown:

	Results without significance	Results with significance
1. Network reach	0,07	0,10
2. Travel time	0,05	0,07
3. Punctuality and reliability	0,02	0,03
4. Frequency	0,09	0,13
5. Convenience	0,01	0,01
6. Comfort	0,04	0,04
7. Prices, tickets and sales	0,02	0,02
8. Accessibility	0,14	0,07
9. Safety and security	0,03	0,01
10. Sustainability	0,01	0,00

Table 44: Overall results of the assessment model for the railways in Catalonia

The interpretation of the results is discussed here:

- Considering the performances of the 10 categories without taking into account the importance they have in the choice of travel by rail, we observe that the railways in Catalonia have a major lack of performance in the accessibility. This is due to the negative feedback given by the users when

asking for the level of accessibility of the railways in the region. After that, frequency and network reach are the categories with poorest rank.

- Considering the importance to the user's choice of traveling by rail, frequency reach becomes the category with major lack of performance followed by the network reach. Third category in lack of performance are travel time and accessibility.

Secondly, the results by market segment are shown:

	Commuters	Business	Holidays	Leisure
1. Network reach	0,09	0,09	0,12	0,12
2. Travel time	0,08	0,09	0,07	0,06
3. Punctuality and reliability	0,03	0,03	0,03	0,03
4. Frequency	0,15	0,12	0,08	0,12
5. Convenience	0,01	0,01	0,01	0,02
6. Comfort	0,02	0,05	0,05	0,03
7. Prices, tickets and sales	0,02	0,01	0,03	0,03
8. Accessibility	0,06	0,06	0,06	0,06
9. Safety and security	0,01	0,02	0,02	0,01
10. Sustainability	0,00	0,00	0,00	0,00

Table 45: Market segment results of the assessment model for the railways in Catalonia

The interpretation of the results is discussed here:

- For the commuter travellers in Catalonia, frequencies are suffering from a major lack of performance. This is due to the very negative feedback given by the users in this region. This very negative ranking is only observed in this market segment, meaning that this could be a major barrier for the commuter passengers in Catalonia. Network reach and travel time are the next categories in lack of performance.
- The assessment of business travellers also suggest that frequency is highly lacking of performance although not that much as the commuters. Also, network reach and travel time rank equally as second category with most lack of performance.
- For the holidays travellers, network reach is the major, suggesting that they can't reach their destinations and this is the main reasons why there are no more users of this kind.
- Leisure travellers' results are similar than the holiday travellers although in this case frequency also rank as poor as network reach, so both categories are the major barriers for this type of users when choosing the transport modes to their leisure activities.

9. Conclusions and final discussion

As seen at the beginning of this thesis, modern railways can be the most capacious, efficient, safe and sustainable passenger transport modes. These advantages were the key to help railways become the major motorized system of people transportation in the 20th century and since the industrial revolution in the 19th century. Certainly, railways have been the system responsible for carrying the most of the worldwide passenger-km until the beginning of the 21st century, when aviation overtook the lead of the global mobility.

Although there are several reasons for this change of trend on the world transportation, several authors pointed a decline of the railways that started in the 1970's which turned the mobility from the rail and public transportation towards the private, initially road, and later also to the aviation coinciding with the culmination of the globalisation era. The reasons for the decline are both external and internal to the railway, because even though the exposed competitive advantages, railways are also a technically complex transport system that require major investments on building, operating and maintaining the lines and trains. A lack of proper conditions of the network and a poor maintenance of the rail carriages will easily jeopardize the performance of the operation and the previous advantages will not be attained. Instead, the railways will suffer from deterioration on the conditions such as transport time, frequencies, comfort or even safety, in definitive a fall of the services perceived by customers. And as seen in the second 4 of the thesis, these are within the most decisive factors defining the demand of a railway system. Clearly, trains with long time connections, little frequencies and low reliability will discourage passengers, who will prefer using other transport modes.

Hence, the intrinsic advantages of the railways are very depending on to the efficiency of the systems and only the railways performing well will be competitive against other transport modes. Consequently, only railways performing well will be potentially attractive to the users and be able to catch further passengers. For that reason, this thesis has created a methodology to assess the performance of the rail transport in a country or region in order to identify the priority factors to be improved. Nonetheless, the aim is not to improve the performance of railways, but to improve their usage through performance improvement. Since budget of railways is limited, not all factors can be improved at the same time and so this tool serves as decision maker to identify which are the most important elements to improve, and thus in what area should the investments be focused when looking for an increase on the use of railways.

For the construction of the tool, a large amount of academic research was consulted in order to stablish the theoretical framework in which the assessment model relies. The developed tool is innovative in joining all performance factors together, finding standard values and including the priorities of the users and the relevance to the demand. For that, 32 key performance indicators have been defined as inputs

and 10 performance categories as outputs. The 10 categories represent the basic constituting factors of the railway system. The outputs are given for the overall performance of the railway system and considering the priorities of the different users, taking into account the regional and long distance trains and their four main purpose for travelling: commuting, business holidays and leisure activities.

Using the assessment model proposed, the results are given in specific numeric values. These results should to be interpreted as the level of performance of the different constituting factors of a railway system. In other words, the outcome of the model gives a numeric value for each of the defined performance category that serve as comparative about how good each factor is performing. The higher values obtained are those that require major attention, since they are the parameters with major lack of performance, so those in which corrective and improvement strategies must be prioritized. Therefore, the model informs about the items of the system that would require the investments in a first place.

In order to validate the assessment model developed, a case study in Spain has been performed. For that, the indicators measured on the Spanish railways have been applied to the developed assessment tool, and the results have been compared to the feedback given by a group of Spanish travellers. This feedback was collected in 12 interviews to rail users with different transportation needs in Spain, which apart from bringing the necessary information for the validation of the model, also gave uncovered and precious information that otherwise would have been impossible to get.

Finally in this validation phase, potentially improvements of the model were highlighted, such as the update of the data, the adjustment and creation of new KPI's, the adjustment of the tool to be applied to regions and lines, as well as the actions for the verification of its efficiency. The details of these recommendation can be found in section 7.5. These measures suppose that the proposed model could be developed further with the aim of increasing the efficiency, precision and accuracy.

Similarly, the limitations of the model must also be noted. At first, the analysis of the outcomes is based on grouping the results together to obtain a numeric value. This process implies a loss of information that might be relevant to understand the lack of the performance of the system. Additionally, the model is built with the arithmetic means of the reference values. The use of the mean implies statistical risks as this is not a robust indicator, since it might be altered by outlier values. Nonetheless this has been partially mitigated with the restriction of the reference values to the 18 countries of the EU instead of the original 27 from the sources. These are the countries having a major propensity to rail (so major levels of rail usage in terms of passenger-km / inhabitants) and less disparity of KPI values. Moreover, the subjective KPIs are based on survey of customer satisfaction from different countries, which may have different levels of expectations. Thus, users with high exigences may value worse systems that factually are performing better than others in which people have lower expectations, and thus show better

satisfaction. And finally, in the assessment model adjusted to the regions, some KPI's were removed due to the lack of the specific data to those areas. This means that the evaluation of the regions is built with less data than the countries so relevant data for the final assessment might be missed.

Additionally, as a way to exemplify the methodology developed in a real context and to consider the system particularities, the assessment model has also been applied to the case of the railways in Austria, Vorarlberg and Catalonia. The results obtained served to give validation to the model, and showed different lacks of performance levels in these systems that go aligned with the railway usage per capita. The results might be used by the national and regional authorities when deciding the priority actions to improve their railways and to stablish in what should they focus the future investments.

Indeed, once the priority performance categories are identified, the next step would be the definition of specific actions. Considering the nature of railways, the generalization of strategies might not be enough to define all the required actions to improve the performance of a rail system. This is one of the reasons why this step was not part of the scope of the thesis. As pointed before, railways are the oldest of the motorized land transport modes. Quickly after the rise of the rail technology in the early 19th century, railways spread to Europe in a way that every network followed its own construction and operation criteria, often incompatible with those used in the neighbouring regions. Even though current regulations seek the interoperability of the different railway systems, especially in Europe, still today every network has unique characteristics that have to be taken into account. Hence, the design of the strategies requires a deeper analysis of the particularities of the rail network to fully understand the reasons for its lower performance factors, and better design the potential improvements. Thus, the thesis informs about the directions of the actions to be undertaken without entering into details of the type of works to be done, which would be part of another research.

Accordingly, this work serves as a basis for further scholars looking for a systematic method of evaluating the performance of a railway system. The further development of this tool might include the potential improvements pointed before and listed in section 7.5, which would bring the tool a major level of robustness and accuracy. Furthermore, the work could be used by professionals looking for the generic design of improvement strategies of a railway system as shown in section 6.3. This would be the next step of this tool, in a way that by analysing the indicators of the system, the model could give the best actions to improve the condition of the railways. The development of this second feature would require larger investigation on the different possible solutions, the particularities of the targeted railways and therefore the creation of more specific data. In conclusion, this thesis is the base for designing specific strategies on how to increase the passenger rail usage by improving the efficiency of the system.

10. Bibliography

This is the reference list used on the present master thesis.

[1] International Energy Agency (2019). The Future of Rail. Opportunities for energy and the environment. https://www.iea.org/reports/the-future-of-rail

[2] Z. Tomes (2006). Long-term structural decline of railways. Masaryk University Brno. http://www.itregep.cz/media/65214/long_term_decline.pdf

[3] J. Campos and P. Cantos (2004). Rail Transport Regulation. Economic Development Institute of the World Bank. https://documents1.worldbank.org/curated/en/284281468764045820/135535322_20041117180643/additiona.

[4] European Environment Agency (2021). Train or plane? Transport and environment report 2020. European Union, 2021. https://www.eea.europa.eu/publications/transport-and-environment-report-2020

[5] C. Brand, J. Preston (2003). Which technology for urban public transport?. Proceedings of The Institution of Civil Engineers-transport. University of Oxford, UK. https://www.researchgate.net/publication/245408797_Which_technology_for_urban_public_transport

[6] L. Wang, X. Duan (2018). Modelling intercity accessibility surfaces through different transport modes in the Yangtze River Delta mega-region, China. Journal Data in Brief. July 2018. https://doi.org/10.1016/j.dib.2018.07.054

[7] Arie Bleijenberg (2020). Air2Rail: Reducing CO2 from intra-European aviation by a modal shift from air to rail. Study commissioned by the European Federation for Transport and Environment. https://www.transportenvironment.org/sites/te/files/publications/2020_03_Air2Rail_Koios_strategy_rev.pdf

[8] United Nations (2014). Transport. IPCC (The Intergovernmental Panel on Climate Change). Cambridge University Press, Cambridge, United Kingdom and New York, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf

[9] EEA (2014). TERM 2014: transport indicators tracking progress towards environmental targets in Europe. https://www.eea.europa.eu/publications/term-report-2014 Image source from the infographics: https://www.eea.europa.eu/media/infographics/co2-emissions-from-passenger-transport/image/image_view_fullscreen

[10] European Commission (2016): A European Strategy for low-emission mobility https://ec.europa.eu/clima/policies/transport_en

[11] EEA (2020). Greenhouse gas emissions from transport in Europe. https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases-7/assessment

[12] U.S. Department of Energy (2020). Transportation Energy Data Book. Edition 38. SC David, RG Boundy. August 2020. https://tedb.ornl.gov/

[13] Ethify (2018). Leistung und Effizien verschiedener Mobilitätsformen pro beförderter Person (Mittelverter). https://ethify.org/content/life

[14] European Transport Safety Council (2003). Transport safety performance in the EU a statistical overview. http://etsc.eu/wp-content/uploads/2003_transport_safety_stats_eu_overview.pdf

[15] RSSB (2020). Traveller fatality risk for different transport modes. https://www.rssb.co.uk/what-we-do/Insights-and-News/News/Rail-still-safer-than-road-during-Covid-19

[16] Federal Statistical Office (2020). Transport accidents. Risk comparisons. Transport accidents | Federal Statistical Office (admin.ch)

[17] F. FitzRoy and I. Smith (1995). The demand for rail transport in European countries. St Salvator's College, St Andrews, UK. Transport Policy, Vol 2, 1995. https://doi.org/10.1016/0967-070X(95)96745-7

[18] H. Pan et al (2017). What determines rail transit passenger volume? Implications for transit oriented development Planning. Tongji University, Shanghai, China and University of Washington, Seattle, USA. Transportation Research Part D 57 52–63. http://dx.doi.org/10.1016/j.trd.2017.09.016

[19] P. Wanke et al (2018). Investigating the drivers of railway performance: Evidence from selected Asian countries. Habitat International, Volume 80, October 2018, Pages 49-69. https://doi.org/10.1016/j.habitatint.2018.08.004

[20] L. Oliveira (2019). What passengers really want: Assessing the value of rail innovation to improve experiences. Transportation Research Interdisciplinary Perspectives, Volume 1. https://doi.org/10.1016/j.trip.2019.100014

[21] Y. Wang et al. (2017). Influencing Mechanism of Potential Factors on Passengers' Long-Distance Travel Mode Choices Based on Structural Equation Modeling. Sustainability 2017. https://doi.org/10.3390/su9111943

[22] F. Nordenholz et al. (2016). Analysing the modal shift to rail potential within the long-distance passenger travel market in Germany. 44th European Transport Conference, 2016. https://doi.org/10.1016/j.trpro.2017.07.010

[23] P. Anciaes et al. (2019). The impact of fare complexity on rail demand. Transportation Research Part A: Policy and Practice Volume 120, February 2019, Pages 224-238. https://doi.org/10.1016/j.tra.2018.12.020

[24] European Commission (2019). Flash Eurobarometer 463. Europeans' satisfaction with passenger rail services. Fieldwork January- February 2018. https://europa.eu/eurobarometer/surveys/detail/2172

[25] CE Delft (2011). External Costs of Transport in Europe. Update Study for 2008. Delft, September 2011. Commissioned by the International Union of Railways UIC. http://ecocalc-test.ecotransit.org/CE_Delft_4215_External_Costs_of_Transport_in_Europe_def.pdf

[26] D. Marchetti, P. Wanke (2019). Efficiency in rail transport: Evaluation of the main drivers through meta-analysis with resampling. Transportation Research Part A: Policy and Practice, Elsevier, vol. 120(C), pages 83-100. https://doi.org/10.1016/j.tra.2018.12.005

[27] European Commission (2021). Seventh monitoring report on the development of the rail market under Article 15(4) of Directive 2012/34/EU of the European Parliament and of the Council. Brussels, 13.1.2021. https://ec.europa.eu/transport/modes/rail/market/market_monitoring_en

[28] Eboli and Mazzulla (2012). Performance indicators for an objective measure of public transport service quality. Department of Land Use Planning, University of Calabria. http://hdl.handle.net/10077/6119

[29] European Commission (2016). Study on the prices and quality of rail passenger services. London, 2016. https://ec.europa.eu/transport/modes/rail/news/2016-06-17-study-prices-quality-rail-pax-services_en

[30] Poleman, Dijkstra, Ackermans (2020). Rail Transport Performance In Europe: Developing a new set of regional and territorial accessibility indicators for rail. European Commission. Luxembourg, 2020. https://ec.europa.eu/regional_policy/en/information/publications/working-papers/2020/rail-transport-performance-in-europe

[31] Eurostat (2021). Rail accidents victims by type of accident (ERA data). https://data.europa.eu/data/datasets/9ny3msxopxtzmq0pguxza?locale=en

[32] The European Commission (2011). Flash Eurobarometer n° 326: Survey on passengers' satisfaction with rail services. Analytical report. Fieldwork: march 2011. Publication: June 2011. https://ec.europa.eu/transport/sites/default/files/modes/rail/studies/doc/2011_06-survey-passengers-satisfaction-with-rail-services.pdf

[33] S. Duranton et al. (2017). 2017 European Railway Performance Index. The Boston Consulting Group, April 2017 https://www.bcg.com/en-ch/publications/2017/transportation-travel-tourism-2017-european-railway-performance-index

[34] E. Grisé, A. El-Geneidy (2018). Where is the happy transit rider? Evaluating satisfaction with regional rail service using a spatial segmentation approach. Transportation Research Part A: Policy and Practice. Volume 114, Part A, August 2018, Pages 84-96. https://doi.org/10.1016/j.tra.2017.11.005

[35] E. Nathanail (2007). Measuring the quality of service for passengers on the Hellenic railways. University of Thessaly, Greece, 200. https://doi.org/10.1016/j.tra.2007.06.006

[36] L. Eboli, G. Mazzulla (2012). Structural Equation Modelling for Analysing Passengers' Perceptions about Railway Services. University of Calabria, November 2012. https://doi.org/10.1016/j.sbspro.2012.09.729

[37] V. Braunn, V. Clarke (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3 (2). pp. 77-101. University of the West England (UWE), Bristol. https://www.researchgate.net/publication/235356393_Using_thematic_analysis_in_psychology

[38] OECD (2021). Passenger transport. Rail, Million passenger-kilometres, 1998 – 2019 https://data.oecd.org/transport/passenger-transport.htm

[39] Wikipedia (2021): Accidente ferroviario de Santiago de Compostela. https://es.wikipedia.org/wiki/Accidente_ferroviario_de_Santiago_de_Compostela

[40] Eurostat (2021). Nomenclature of territorial units for statistics. https://ec.europa.eu/eurostat/web/nuts/background

[41] Statistics Japan (2018): Statistical Handbook of Japan. https://www.stat.go.jp/english/data/handbook/index.html

[42] Wikipedia (2020): Vorarlberg. https://en.wikipedia.org/wiki/Vorarlberg

[43] Wikipedia (2020): Catalonia. https://en.wikipedia.org/wiki/Catalonia

[44] OBB (2021). Pünktlichkeit. https://www.oebb.at/de/rechtliches/puenktlichkeit/vorarlberg

[45] Wikipedia (2019). S-Bahn in Vorarlberg. https://de.wikipedia.org/wiki/S-Bahn_Vorarlberg

[46] Trenscat (2020). Xarxa convencional de via ampla a Catalunya. https://www.trenscat.com/renfe/

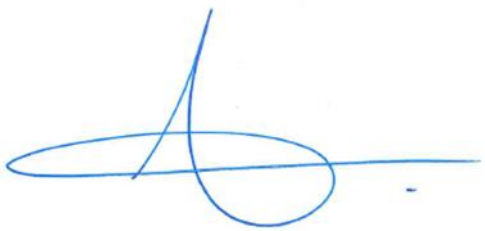
[47] Trenscat (2019). Ferrocarrils de la Generalitat de Catalunya. https://www.trenscat.com/fgc/

11. Appendix

The appendix contains the templates and translated transcriptions of the 12 interviews done as well as the 1st and 2nd phase of its qualitative thematic analysis.

Statutory declaration

I hereby declare on oath that I have prepared this master´s thesis independently and without the use of other than the specified aids. The positions taken directly or indirectly from external sources are identified as such. The work has not yet been submitted in the same way or a similar form to another examination authority and has not yet been published.



Dornbirn, 7.1.2022 Joaquim Font Canyelles