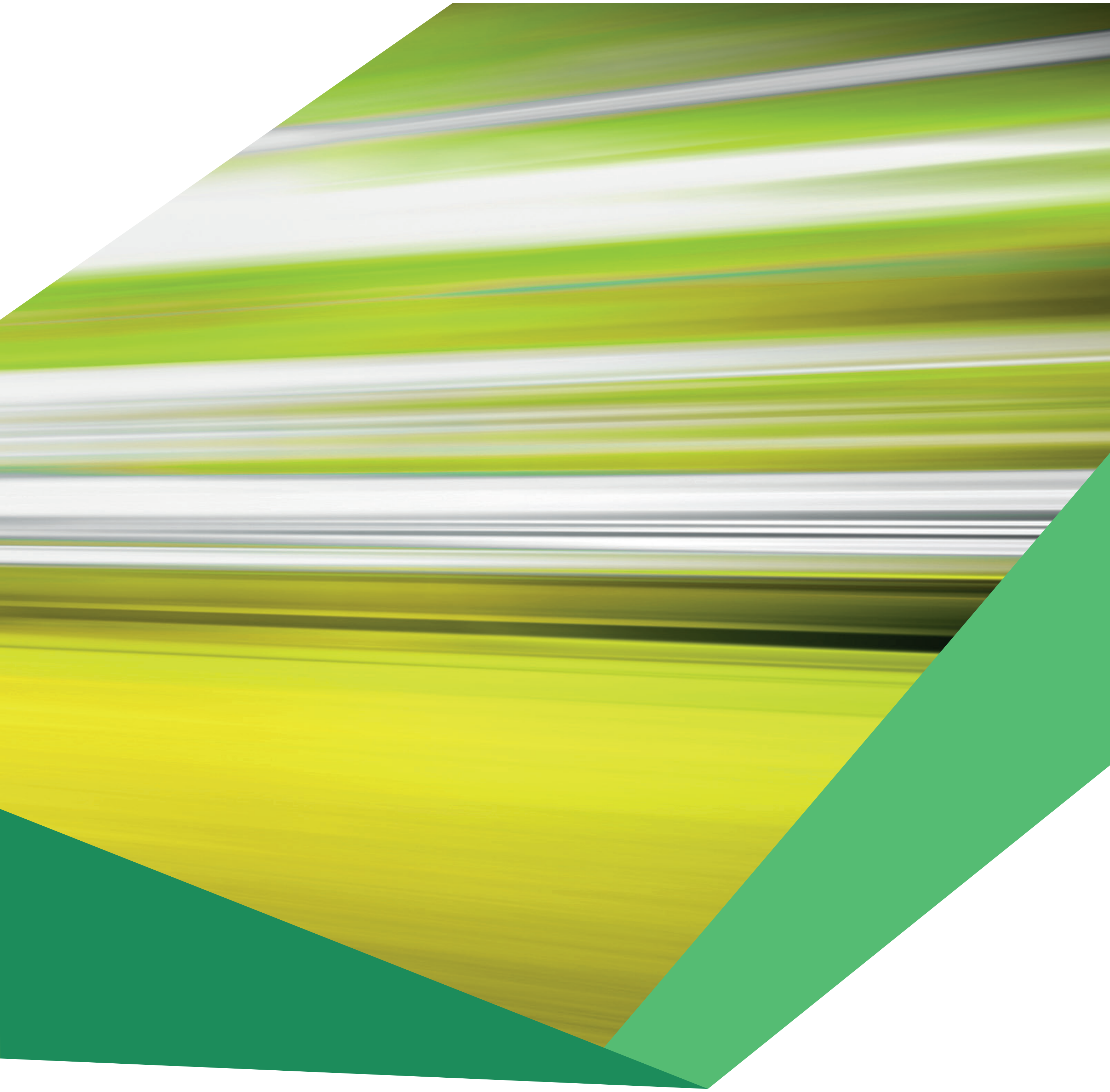

European Rail success stories Report

TER4RAIL

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1. SUMMARY

The **TER4RAIL Project – Transversal Explanatory Research Activities for Rail (www.ter4rail.eu) –** entails a coordination and support action to determine research activities among different actors that are beneficial for railways. The project objectives are:

- To identify and monitor new opportunities for innovative research, facilitating the cross-fertilisation of knowledge from other disciplines through the "Rail Innovative Research Observatory";
- To determine and assess the existing roadmaps that drive the future of railways and compare them with the interpretations obtained from the observatory;
- To produce strong arguments supporting rail, reinforcing the **European Railway Research Advisory Council's (ERRAC)** Rail 2050 Vision;
- To communicate all the main findings to the transport community, liaising with the Shift2Rail communication team with a correlated communication strategy;
- To select and synthetize a considerable amount of information regarding the future of railways and to transmit this in a consolidated, improved, clear, and understandable manner;
- To reinforce the cooperation between rail-related stakeholders to improve the efficiency of the consensual exploratory research in the rail sector, in order to facilitate emerging innovative ideas and the cross-fertilisation of knowledge from other disciplines.

"Rail transport already plays a vital role in supporting Europe's society, developing its economy, and protecting its environment. It has the potential to contribute much more." With these words, ERRAC, the European Rail Research Advisory Council (https://errac.org), introduced its "2050 Vision" document. This report contributes to highlighting the above mentioned potential, often not yet fully exploited. Rail can concretely become the backbone of the transport system of the future.

The success stories described in this document are just examples of the disruptive potential the rail sector has. The role of rail as a major driver in developing the strategic objective of smart, green and sustainable growth has been described by analysing three main "macro-areas". The first one is dedicated to public transport sector. The cases studies of Vienna and Nantes have been analysed and extensively presented. The aim is to highlight both a capital city of approximately 1.9 million inhabitants and a medium sized city/area with 600.000 inhabitants.

Urban Rail Vienna

Vienna is a very interesting example of positive development of urban rail in Europe, with harmonic co-operation between both metro and LRT transport. These two modes constitute the "engine" of the public transport in the city, accounting for 79.5% of the total ridership, 73.7% of the vehicles and 84.6% of the available seats. Numbers and statistics regarding the growth in network length, service expansion, investments in infrastructures, customer satisfaction are presented, highlighting their positive impact on the city and on the ridership. Currently, the public transport market share in Vienna is 38% and the number of annual PT passes over the last 10 years has constantly increased (+133%) while the number of car registrations remained stable. The transition towards the MaaS system, driven by digitalization, is also reported.

Urban Rail Nantes

Nantes Metropole, on the other hand, is the first French area that managed to reduce the market share of cars, due to a consistent and coordinated policy, continuously developing and encouraging the use of LRT network since the tram reintroduction in 1985. Nantes was one of the first cities engaged in shared mobility and soft modes, and has a very strong PTA that covers all facets of mobility under the same umbrella.

As a result of all these efforts, the service was widely recognized as extremely accessible, fast, efficient and pleasant, and the ridership registered an increase of 54% over the last 10 years.

High Speed Rail Madrid-Barcelona

The second macro-area is dedicated to the HSR expansion on the Madrid-Barcelona line in Spain, and the positive effects that this fast development has had on changing the "rules of the game", putting the rail system at the centre of the transport choices of millions of citizens and gaining increasingly high market share, especially in the competition with airlines (in 2012 HSR market share surpassed that of airlines for the first time, and has never stopped growing).

The Spanish case, hereby analysed can be also applied to other Countries, such as Italy, France and the BeNeLux region, where HSR became something similar to a "national (in some few cases cross-national) metro system" capable of moving millions of passengers in a few hours, bringing them to the heart of the cities. As an example, the total Paris-Barcelona travel time dropped from 12 hours in 1991 to about 6 nowadays.

The HSR explosion is also analysed from the environmental point of view, highlighting the CO2 emissions related to a Madrid-Barcelona trip by plane (92 kg/pax), car (74 kg) and train (13 kg), thus reaffirming the primary role the rail sector has in the fight against climate change.

Long freight trains

The third macro-area is freight transport. In the first success story, the **Marathon Train**, the longest freight train in Europe (1,524m), is presented. Marathon Train was the result of a European Commission co-funded project finished in 2012 and demonstrated in real operating conditions the benefits, in terms of capacity, time, cost-efficiency and energy saving, of a 1.5 km long freight train, with two radio-controlled locomotives (one in the front and one in the middle of the train). Two tests have been successively performed, on the 300km tracks between Lyon and Nimes, in France. As a result of the tests, the capacity increased by 50% while the operating costs decreased by 30%.

An additional 10% energy saving was registered. Commercial speed was not affected by the length of the train. M2O project, currently ongoing, is further exploiting the outcomes of the first project. The second freight story regards the **TIGER project** that can be considered the father of a modern way to organize the distribution of cargo in the main European ports.

Rail Dry Ports

The project tested in four European large port areas the concept of **"Dry Port"**. Dry Ports will efficiently and effectively link the maritime flow to the overland modes, decreasing the movements inside the seaports through a rail link between the vessel and the Dry Port, located a short distance from the dock. This new distribution system, currently replicated in many ports, allows for a saving of 15-20% of operating costs, reduces the dwelling/transit time by more than one third and the movements inside the port, increasing the service performances by 85% while reducing congestion and accidents.

Please note that this report constitutes part of the TER4RAIL Project Deliverable 3.2 "Case studies Report". An extended version of this report, with a complete overview of all the case studies presented and the full list of references is available on the project website **www.ter4rail.eu.**

2. EUROPEAN METROPOLITAN AREA(S) SUCCESS STORIES

Two European success stories have been selected and are presented in order to show how public transport, and in particular urban rail, can become the backbone of mobility in cities, promoting an easy, smooth, green and efficient way of moving millions of people every day. Vienna, a capital city in which about 2 million people live, and Nantes, a medium sized city with a strong public transport network are perfect examples of integration between collective transport (driven by metros and light rail) and private vehicles, delivering efficient and positively evaluated services to citizens.
These two examples are presented and analysed in the following pages with numbers, graphs and charts provided by the public transport operators and authorities. Considerations on current expansion plans and future challenges and trends are also provided.

2.1. Vienna

Vienna is the Austrian capital and most densely populated city, with 1.9 million inhabitants in 415 square km. The urbanisation trend is increasing in recent years, and the city will reach 2.2 million inhabitants in 2025. Urbanisation means "new mobility needs", which in order to be fully satisfied, require strong efforts, in terms of organisation and planning of services.

Wiener Linien is the public transport operator (PTO) in Vienna. It is the largest PTO in Austria, employing more than 8,600 people, and operates 5 metro lines, 129 bus lines and 28 tram lines, with a total of 1,093 vehicles per day, serving approximately 965 million passengers per year on its network. Vienna has the most extensive public transport network in Austria, at 263 km (670.3 km of track). In terms of fleet, 1,253 railcars and tramcars serve 2.65 million citizens every day (768 railcars, 485 tramcars), running for 213,000 km each day (equivalent to circling the world 5 times). Metro and LRT are the main "engines" of the Vienna public transport system. Combined, they account for 79.5% of the total ridership, 73.7% of the vehicles and 84.6% of the available seats. Total metro network length is 87.5 km (253.2 km of track). Average distance between stations is 761.9 m and average line length is 16.6 km. Ridership in 2019 was 463.1 million passengers. The first metro line was built in Vienna in 1969. With regards to LRT network, total length is 175.6 km (track length 417.1 km). Average line length is 7.9 km and average distance between stops is 396.2 m. Ridership in 2019 was 305.5 million passengers. The graph here below shows the evolution of the passenger who decided to use the public transport in Vienna in the last 24 years (update 2019). In this period, an impressive +40% in ridership was experienced, from 687 million (yearly) passengers in 1995 to 961 million passengers in 2019.

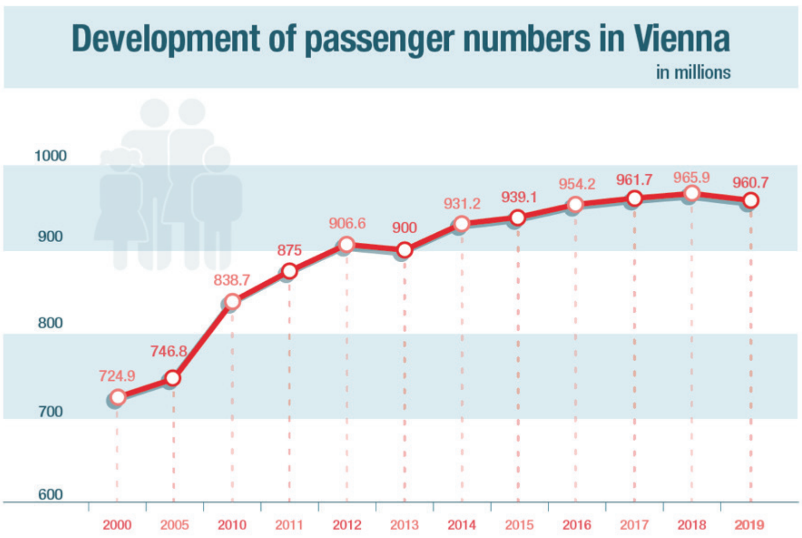


Figure 1: *Development of passenger numbers in Vienna, 1995-2019*
Source: *Wiener Linien*

The success of the public transport in Vienna, is also measurable considering the total number of annual passes sold to the citizens. The situation of the last decade is represented in the figure below. In the period 2010-2019, there was an increase in the number of annual passes of +147%. 852,000 people in Vienna use every day an annual pass. In 2010 there were only 355,000. This increase was particularly driven by full fare passes, since the number of pensioner passes registered a minor increase.

Annual passes constitute the 45% of the total tickets sold in Vienna in 2019, the biggest share. They are followed by youth ticket semester passes (17.8%), tickets sold at ticket desks (11.3%), monthly passes (10.2%), short term network tickets (7.8%), and weekly passes (3.8%).

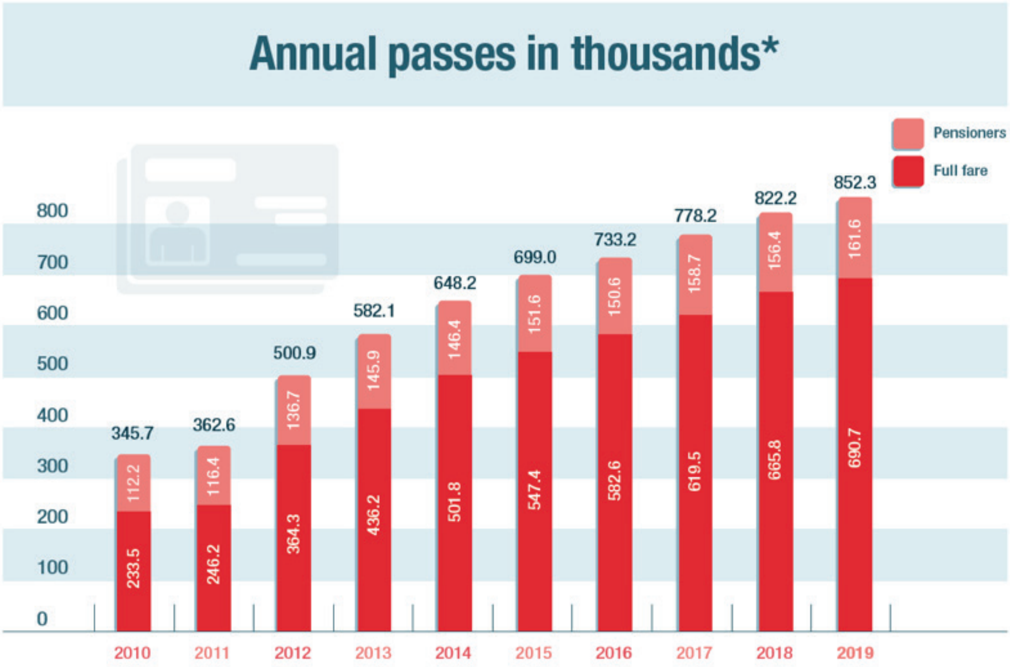


Figure 2: *Annual passes (in thousands), 2010-2019 –* ***Source:*** *Wiener Linien*

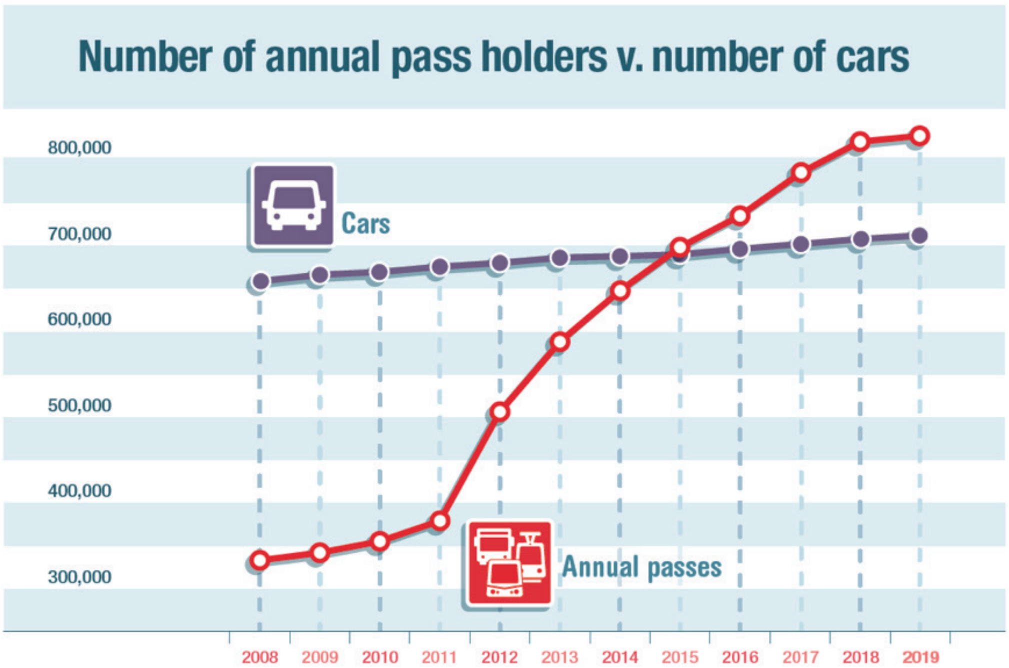
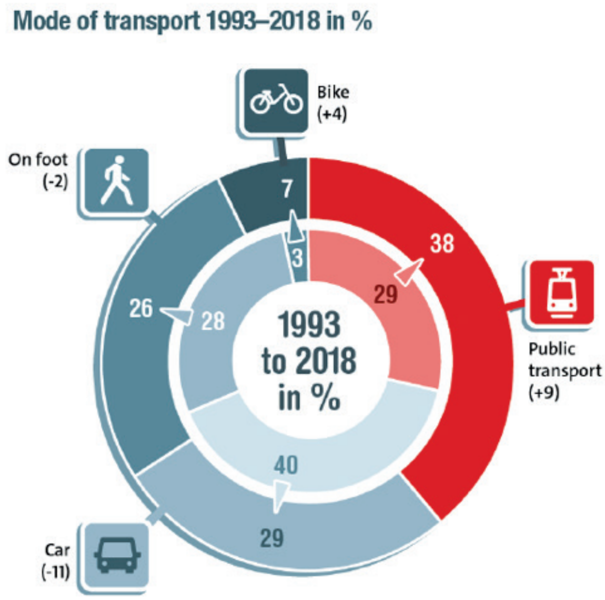


Figure 3: *Annual PT pass holders vs cars registered in Vienna, 2008-2019 -* ***Source:*** *Wiener Linien*



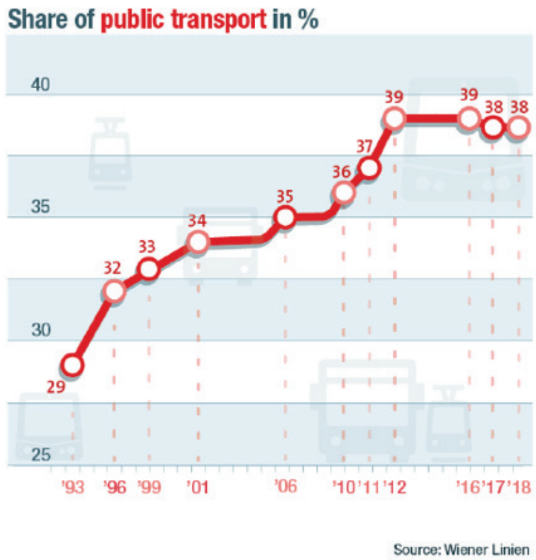


Figure 4: *Mode of transport 1993-2018 in % and evolution of public transport share, 1993-2018 –* ***Source:*** *Wiener Linien*

To measure the success of the public transport driven by urban rail (particularly metros) in Vienna, it is also interesting to evaluate the evolution of annual passes compared to the car usage (measured considering the new car registration). Number of car registrations, in the decade 2008-2019, have just registered a minor increase, ranging from 650 to 700,000 per year. The annual public transport passes, as shown in the previous picture, registered a massive increase. Citizens of Vienna clearly appreciated the service provided by the local PTO, and used it largely to move around the city for work or leisure purposes. The analysis of the modal split in Vienna, evaluated in different years, confirms the high level of customer satisfaction towards the public transport. Comparing 1993 to 2018, habits and behaviours of the Austrians have changed a lot: according to the numbers, they have decided to leave their cars behind (-11%) and this decrease was compensated by a more intense utilisation of public transport (+9%) and soft modes, like cycling (+4%). Analysing the public transport market share between 1993 and 2018 (but the same share is confirmed also in 2019), it is visible its "explosion", particularly boosted by the years 2010-2012, in which this share increased by 1/3. In general, in the considered period, public transport market share passed from 29% to 38%. Despite this is already a very positive evolution, in Vienna there is a huge potential to improve these numbers and make the car market share fall to 20%, leaving 80% to public transport combined with cycling and walking. This is a target set by the local PTO for 2025.

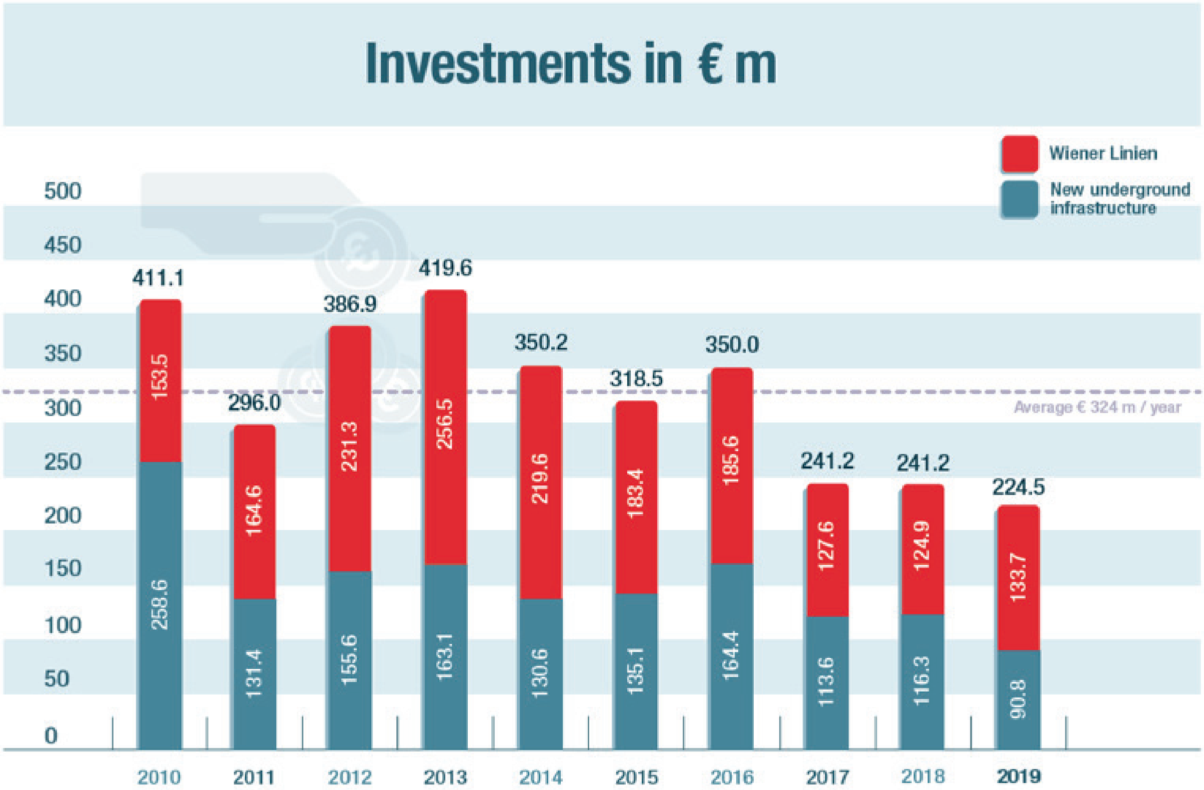


Figure 5: *Investments in public transport (m euros), 2010-2019 –* ***Source:*** *Wiener Linien*

The massive increase of public transport utilisation starting in particular from the year 2010 is also understandable analysing the investments that Wiener Linien (supported by the City of Vienna and by the Federal Government) made in the last decade. The year 2010 was a year of important investments: 411 million euros, 62% of which was for underground infrastructure. Since 2010, an average of 335 million euros per year have been invested in improvement of the service and construction/extension of lines. In 2010, the 4th expansion phase of Vienna underground started. Line U2 was extended (4.3 km) in 2013 and additional 4.5 km of U1 line were opened in 2017. Construction/extension of U2 and U5 are currently ongoing, with works planned on tracks, stations, interchanges and improvement of accessibility and smooth connections with other modes. With regards to metro and light rail, 8,000 km of track lines are currently being modernised in the city. The 5th expansion phase of Vienna underground will start in 2022. By this date, U1, U2 and U5 will be further extended (+6.6 km) and fully automated operations will be implemented and operating on the new U5 line. Particularly important is the U2xU5 project, a modern, smooth and easily accessible junction between lines U2 and U5. The project was presented in 2014 and will be completed starting from 2025-2027. FAO will be fully implemented on the U5. Automation in metros ensures more safety, also thanks to the platform screen doors that only open once the train has pulled into the station.

Delays caused by items on the tracks will also be eliminated. FAO also ensures flexibility, due to a better adaptation of schedules to peak times, and optimisation of speed and frequency according to the demand.

It finally means savings and personalisation of service, since employees will be available on trains or in stations to help and support passengers. A new generation of vehicles will be operated in Vienna in the next years, semi-automated on U1 and U4, and fully automated on U5.

Together with the investments, the fare revenues have also registered a strong increase in the same period, passing from the 411.4 million in 2010 to the 580.5 million euros in 2019 (a very slight decrease compared to 2018, due to the increase in yearly passes, which are cheaper than monthly passes). Vienna citizens love public transport.

Data collected from the annual surveys performed by Wiener Linien show that the levels of satisfaction of users increased significantly in the last decade. Passengers considering "very good" the service offered by the PTO were the 30% in 2010 and 54% in 2019. The percentage of people considering the service "bad" or "very bad" dropped from 5% to 1% over the same period. The service is appreciated by women slightly more than men. The quality of service, according to the surveys, is widely appreciated in all age ranges, particularly the 16-35 band. Only 5% of people in the age range 60-70 ranks the services as "bad" or "relatively bad".

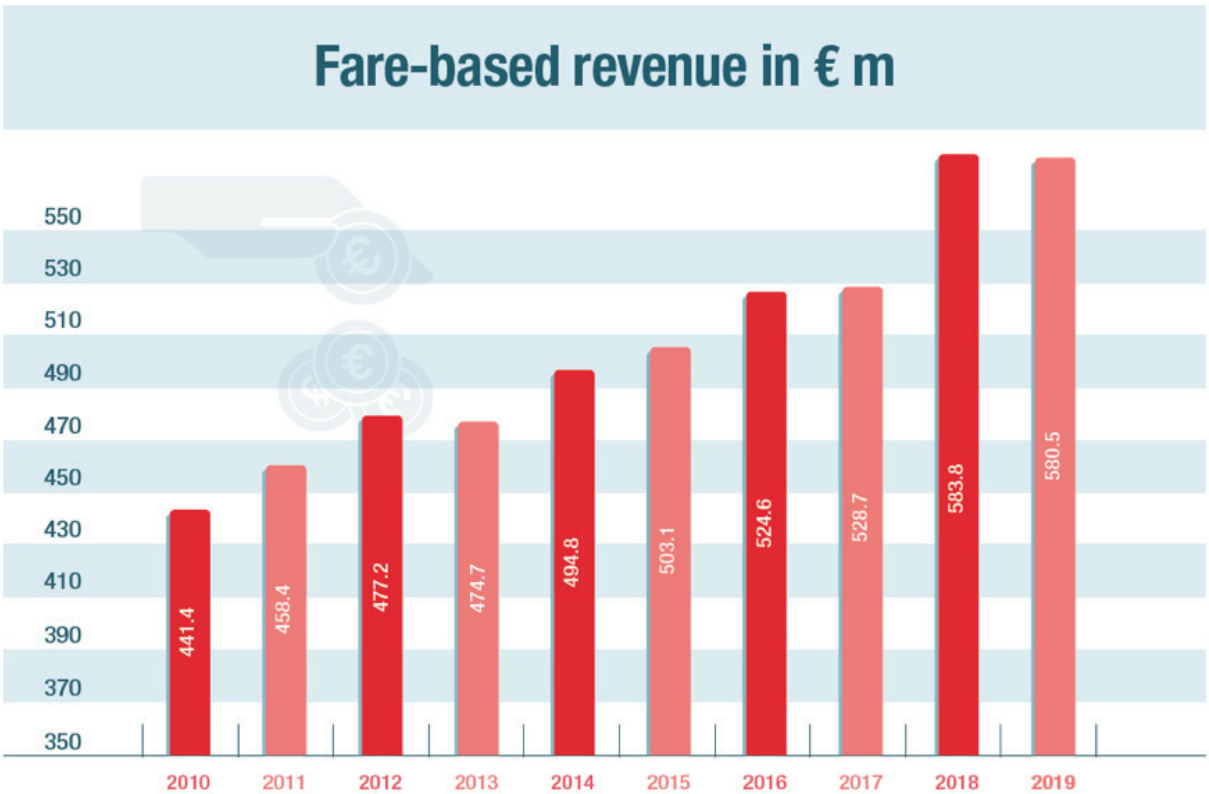


Figure 6: *Fare-based revenues (in m euros), 2010-2019 -* ***Source:*** *Wiener Linien*

In general, the perception of the service is extremely good both for men and women and practically in every age range, and this can better explain the reasons behind the very positive numbers (in terms of modal split, network utilization and annual passes) previously highlighted. Particularly appreciated by users is the accessibility of stations and LRT stops. All 109 metro stations are barrier-free and 95% of tram/bus stop are barrier-free. The citizens are involved in several phases of the decision making process.

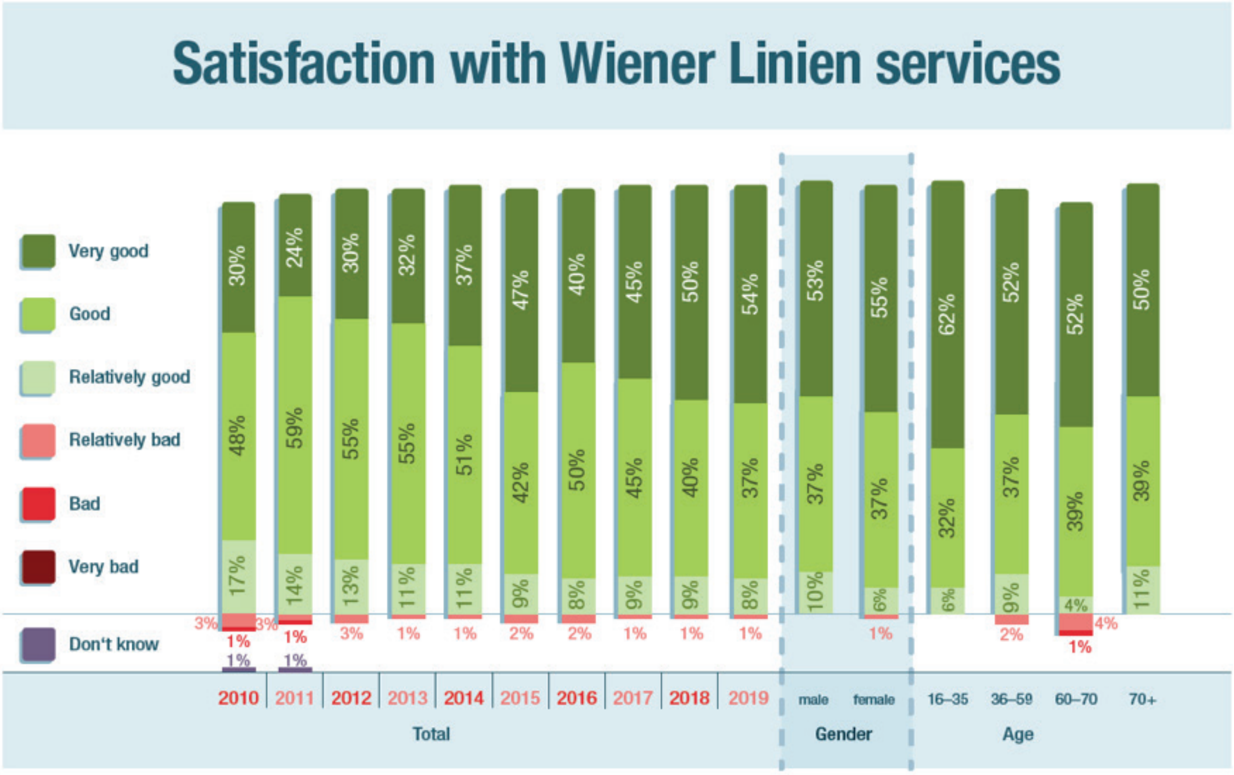


__Figure 7:__ Satisfaction with Wiener Linien services, 2010-2019 – __Source:__ Wiener Linien

In fact, the so-called ombudspersons act as a link between the construction site and the residents. The ombudspersons are always ready to listen to the concerns of the local residents, providing first-hand information and working to find solutions together. Each construction phase has its own contact persons who can be reached by local residents either at the construction office or by telephone. This involvement is extremely important since it increases the degree of acceptance of the possible disruptions due to long lasting works/ building sites by the citizenship, and increases the commitment of the citizens together with their feeling to be active part of the city evolution.

As said at the beginning of this success story, the population of the Austrian capital is expected to grow in the coming years. In order to cope with this expected increase in the mobility needs of citizens and in order to keep a high level of user satisfaction, the public bodies and the local PTO are working together in order to prepare and keep offering a highly satisfactory service to the passengers. In this regard, new construction/ extension/modernisation projects have been already discussed. One of the most important targets of Wiener Linien for the future is to increase e-mobility. The share of e-mobility in Vienna is currently around 50%, using e-buses and rail vehicles capable of saving 1,500 kg of CO_2 annually. The aim is to increase this percentage by 2030. New interchanges will be built in the next future, in order to improve the service and the connections between lines and between urban and suburban/ mainline networks. New services mean not only new travel routes, less journey time, smoother and easier connections, but also new employees. The U2xU5 project by itself created 16,000 new jobs. Finally, presenting the future plans, it is important to mention the progresses towards the full implementation of **MaaS – Mobility as a Service**, in Vienna. Cities face two major trends nowadays: urbanisation and a change in the mobility usage behaviour. Especially younger people are highly flexible in their modal choice. About 50% of the 14 to 29 year-olds prefer a joint use of mode instead of owning them. Digital technologies make it easy to access different services.

However, there is one major problem: all providers use their own systems, which are often incompatible with each other. That makes it nearly impossible for the people, to keep track on all mobility services in cities. Wiener Linien and Upstream Mobility (a technical enabler) have recognized this ambiguity and developed **WienMobil – an easy to use multimodal app**, which enables users to access the broad variety of mobility services in Vienna.

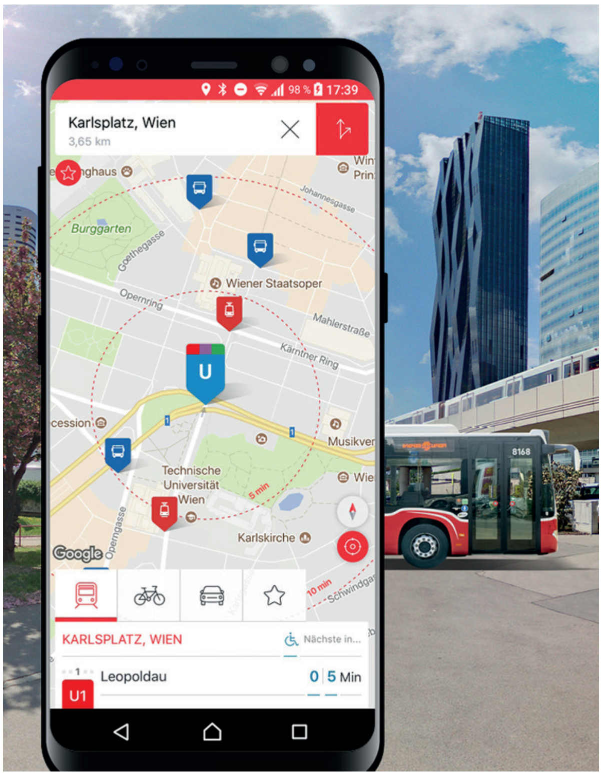


Figure 8: WienMobility app screenshot - ***Source:*** Wiener Linien

WienMobil combines public transport with taxis, parking, rental cars, car sharing and bike sharing. Users are able to find the best combination of modes for their individual journey. It is also possible to buy tickets for public transport and to book car-sharing vehicles directly in the app. Users can organise everything in one app so there is no need to switch between the apps of different providers. It is a pay-as-you-go version of MaaS, not yet containing a flat-rate tariff. WienMobil always calculates routes based on all potential modes of transport. Booking a journey relying on various modes of transport can be taken care of conveniently using the app. Billing with the relevant mobility partners is executed directly with these partners on the base of the payment method stored in the app. Various filters help to quickly identify the best route for the user's specific requirements and preferences. The environmental impact of a selected route is also displayed.

Public ownership guarantees the coherence with urban policy and the barrier-free and non-discriminating affordable access to mobility for everyone.

As Wiener Linien provides the public transport backbone to the city, the WienMobil app provides the citizens of Vienna with a multimodal planning and booking tool. To offer not only a digital but also a physical platform was the natural next step. The first WienMobil station was opened in 2018; five more were opened in 2019. These stations offer a physical platform for the additional mobility needs that cannot or do not want to be covered by public transport: E-bikes, cargo bikes, bike garages, E-charging for cars, hybrid rental cars.
What are the next steps for the deployment of MaaS in Vienna? Mobility flat rates for WienMobil are currently under development, together with the integration with other partners to the app for improving cooperation and enlarging the service to be delivered to the user.

These developments will enrich the mobility offer currently deployed in the city, contributing to serve efficiently the needs of a growing public transport oriented population.

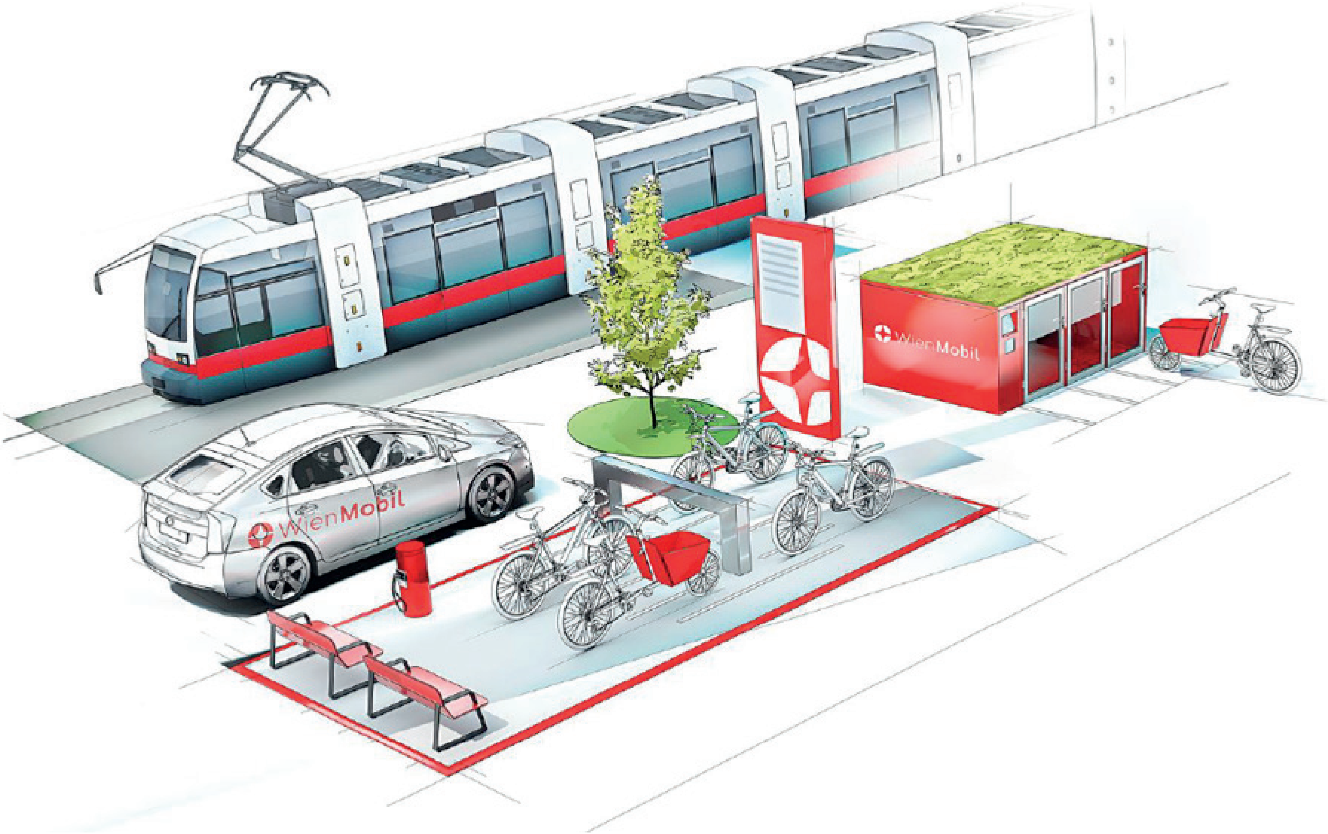


Figure 9: *Example of WienMobility station -* ***Source:*** *Wiener Linien*

2.2 Nantes

Nantes Metropole is an intercommunal structure of 24 communes, created in 2001 having as its main urban agglomeration the city of Nantes. It is located in the Loire-Atlantique department, in the Pays de la Loire region, western France. The Greater Nantes administration is actively involved in 10 fields of competence: urban planning, transport & mobility, public space & roads, environment, water, economy, university & research, international, social development, waste management and energy.

The total population of the entire area is 677,766 inhabitants[1] (2020). The city of Nantes is the focal point of a bigger area of 114 municipalities, not only densely populated but also in constant demographic expansion. The mobility needs of people living in the area are therefore increasing, particularly since the beginning of the new millennium. It is important to mention that the total number of jobs in both the Nantes Metropole and in the conurbation ring around Nantes Metropole area registered a tremendous increase starting from the year 1999, growing on average by 32% until 2011 and increasing ever since. In parallel, the average composition of households diminished on average by 8.5% (but the population grew). These numbers help us to understand the mobility challenges the area had to face in order to satisfy the mobility needs of a growing and differently organized population, both in the urban conglomeration and in the rural outskirts.

In order to face these challenges and to plan the organization of capacity properly in order to respond promptly to these new and evolving mobility needs, Nantes Metropole decided to focus on a light rail network, and in particular trams as the preferred engine of the public transport system. The former 110 km-long system, strongly damaged during the World War II and subsequently closed in 1958, was re-opened in 1985, after a forward looking decision (taken by the PTA) to abandon the idea of building a high-capacity motorway node in the city centre. Instead of building a new road infrastructure and to avoid all the negative consequences (in terms of pollution, noise, accidents, emissions and congestion), the political choice was focused on a ring-road to be built around the city, complemented by an efficient public transport network inside it. The first tram line was completed in 1985 and was called "Tram 1". The reasons why the urban rail was chosen as preferred mode are multiple. First of all, a bus network had limited capacity compared to trams that are capable to efficiently carry a higher number of passengers. Moreover, the trams were preferred to subways also for aesthetic reasons. In fact, they allow to discover the city in a different way and they constitute themselves integral part of the city landscape, contributing to the creation of a dynamic urban environment. The tram lines also constitute a physical and tangible link between different neighbourhoods, contributing to create a sense of unity among citizens. Before the opening of the first line, a private-public local company dedicated to the project was created. Its name was **SEMITAN**, which is still operating the lines. The whole project was funded by the local government and partially by the French State. The tram of Nantes was the first modern tram in France, and was planned not only by SEMITAN and the local/national authorities but even the citizens and users participated. This involvement has been one of the keys for the success of the project, as the engagement of the local population contributed in a relevant way to understanding their needs and priorities.

Since the Tram 1 line inauguration in 1985, other lines were built and extended through the years, reaching the current situation of 43 km of tramway lines (3 lines with average section of 433m, 91 stations in total), with expansion projects planned for the future. In parallel, park & ride facilities have been planned and built around the key nodes of the network, in order to encourage people to leave their cars in the outskirts and move in the city using the public transport system (21 park & ride points, for a total of 6,000 spaces). Tan (tramway, busway, bus, navibus) ticket holders have been given free access to park & ride facilities and this contributed to the great success of the rail-oriented public transport in Nantes, accelerating the transition from private vehicle to mass transit as preferred mode. Frequency and headways have been progressively adjusted in order to meet the increasing demand. Communication and information system have also been improved in order to keep users constantly informed about the status of their rides. This resulted in an incredible success and tram is currently the preferred mode for about 300,000 people every day. 5 regional and suburban rail lines connect the city to the region and the national network, allowing seamless

[1] *UN World Urbanization Prospects.*

transportation of people leaving outside the Nantes urban conglomeration. The mobility offer in the area is completed by a system of navibus and ferries, 7 km of busways and chronobuses, 45 lines of buses and a line of Proxitan, an on demand mobility system.

From 1985, the development of urban rail in the city of Nantes contributed in a significant way to reshape the public spaces and to make the whole city much more liveable and also more attractive from the touristic point of view. In fact, starting from the nineties, the city started to experience an unprecedented increase in the number of tourists and visitors. Due to the intense efforts in terms of forward looking planning and investments made by the authorities and all the entities involved in the design, construction and operation of light rail lines in Nantes Metropole, the city and its outskirts could benefit of higher life quality standards, improved connections between areas, a better organization of spaces, including more green areas and pedestrian zones, and lower levels of pollution, GHG emissions and noise.

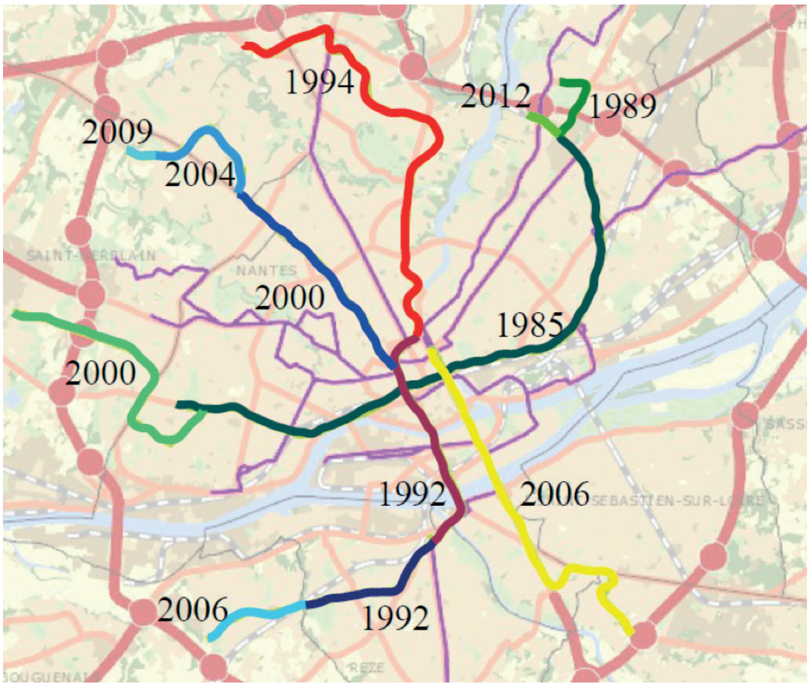


Figure 10: *The steps from 1985 to actual network*
Source: *Nantes Metropole*

1998

1999

2001

Nantes Métropole

Figure 11: *Pont Savetout in 1998, 1999 and 2001*
Source: *Nantes Metropole.*

Citizens could live the city in a completely different way, benefiting from all the positive externalities brought by an improved mobility, capable of promptly adapt to their needs. They also discovered not only the efficiency of trams in connecting easily different areas, but also the pleasure of using soft modes such as walking and cycling in order to reach the public transport stations and nodes. In this way, Nantes has been the first French city that managed to reduce the market share (modal split) of cars due to a consistent and coordinated policy carried out by the local authorities and the PTA, who continuously developed the LRT network since the tram reintroduction in 1985 and redesigned spaces in order to reduce parking areas providing a valuable alternative to private cars. Additionally, it should also be noted that the development of an efficient public transport network, driven by tramways, also impacted the real estate market contributing to make certain areas of the city much more attractive also under this point of view. Examples of the impressive impact the development of LRT systems had on the city are represented in the pictures "before and after" shown in these pages.

The Nantes tram network is used every year by 71 million passengers. Nantes is one of the European cities with the highest number of public transport trip per inhabitant (210). The network, operated by SEMITAN, has known a great success since its opening, as already discussed. But this success increased in the first 15 years of the new millennium, when the ridership grew by 54.6% (compared to 2001) and the total length grew by 26.5%. And the growth of these numbers is continuing, considering the latest figures.

In order to keep offering to the citizens and the tourists the same levels of service quality, a particular attention is dedicated by the public transport authority to the constant maintenance and renewal of the rail infrastructure and the fleet, in order to minimize the risks of derailment, people falling and problems to the operations (1 minute lost = 2 more vehicles for the same capacity). Safety is also a priority, and for this reason vehicles are equipped with several security cameras.

New challenges are ahead, for the Nantes PTA and PTO in order to keep the service efficient meeting the increasing and evolving demand needs. First of all, it is important to improve the quality of the service, investing in new vehicles (energy efficient) with a longer average life and higher standards of safety. Infrastructure is key, and for this reason renewal and maintenance of tracks and stations is performed regularly. Communication to the customers is also an aspect particularly relevant for the PTA and PTO that developed systems capable of giving to the passenger real time information both at the station and via digital tools. If all these aspects are tackled promptly and efficiently, Nantes can keep recording the extraordinary results experienced since the re-opening of the tram lines in 1985. As a particularly interesting indicator of this exceptional success, it is important to mention that, according to Nantes Metropole's reports, in 1983 only 50% of residents supported the tramway. This percentage raised to 93% in 1995. Today. The tramway is considered the pride of the city, a true reference and a sort of icon. The residents love the LRT system and consider this to be "pleasant, fast, qualitative, functional and safe". It is an integral part of the city's heritage. Particularly appreciated, according to the figures, are the easy boarding/accessibility (even for PRM), the punctuality, the reliability and the comfort during the ride.

Figure 12: *Place des Lauriers in 1998 and 2001*
Source: *Nantes Metropole.*

Figure 13: *Place du Château de Rezé in 1988 and 1997*
Source: *Nantes Metropole.*

3. EUROPEAN HIGH-SPEED SUCCESS STORY

With regards to the European main railway line, the high speed rail between Madrid and Barcelona in Spain has been selected as a profitable example of a rail success story.

High-speed services in Spain have been in operation since 1992 and its network reached 3,300 kilometres by 2019[2]. The Madrid-Barcelona high-speed line, in service since 2008, accounts for the highest number of passengers of the Spanish High-Speed system. It connects the two most populous agglomerations in Spain, meaning 11 million of potential users which is approximately 25% of the total Spanish population. From the environmental point of view, it has prevented the emission of 4.2 million tonnes of CO_2 emissions and contributed to energy savings of 19,000 GW/h, equivalent to what is consumed by the population of the cities of Madrid and Barcelona in a year.

Figure 14: *High-speed Rail network in Spain (2019)*
Source: *Modified from "Atlas High-Speed Rail In Spain". Spanish Railways Foundation, 2017*

[2] Source: Atlas High-Speed Rail 2019 and ADIF (Spanish railway administrator)

Evolution of the line and services

The distance between Madrid and Barcelona, the most populated cities in Spain, has always affected transportation and travel times. The route between these two cities has evolved through the history, since the 17th century with carriages and cavalry passing by Zaragoza and Tarragona, followed by the route of the **Royal Diligence Company** along the coast through Valencia, until the current high-speed railway line, as shown in Figure 1. With the opening of the first railway line in the peninsula, between Barcelona and Mataró (1848), the importance of communicating Madrid and Barcelona by this new mean of transport was soon acknowledged and, a couple of years later, the construction of the railway line was initiated.

By 1865, it was possible to travel by railway from Madrid to Zaragoza, and then from Zaragoza to Barcelona. The first direct night train service between Madrid and Barcelona was inaugurated by **Compañía de los Ferrocarriles de Madrid a Zaragoza y Alicante (MZA)** in 1879.

With the evolution of technology and the increase of speed, the travel time from Madrid to Barcelona began to decrease, reaching less than 12 hours in the 1930s. After the Spanish Civil War, little by little, improvements were incorporated in the rolling stock (new trains capable of reaching higher speeds), and on the infrastructure (double track, electrification and signalling), which enabled faster train services. With respect to other means of transport in those years, mainly bus and plane, rail had almost 90% of the passenger share of the route between Madrid and Barcelona until the arrival of the so-called **Puente Aéreo (Air Shuttle in Spanish)**[3] in 1974. This was a real revolution and the plane became the undisputed leader in trips between both cities, the modal share of air transport being practically 90% over rail and becoming one of the busiest air routes in the world. This situation continued till 2008, when the trend changed radically with the launch of the High-Speed Rail services between Madrid and Barcelona.

Looking at the Madrid-Barcelona high-speed corridor, two periods of time are considered:

The first period goes from the opening of the High-Speed section between Madrid and Lleida in 2003 until just before the **AVE (commercial name of the high-speed services)** entered in service in 2008. In that period of time, the duration of the trip was less than six hours, the corridor slightly exceeded half a million of passengers and the railways modal share started to raise, but remained between 12 and 13%.

The second period began in 2008 with the

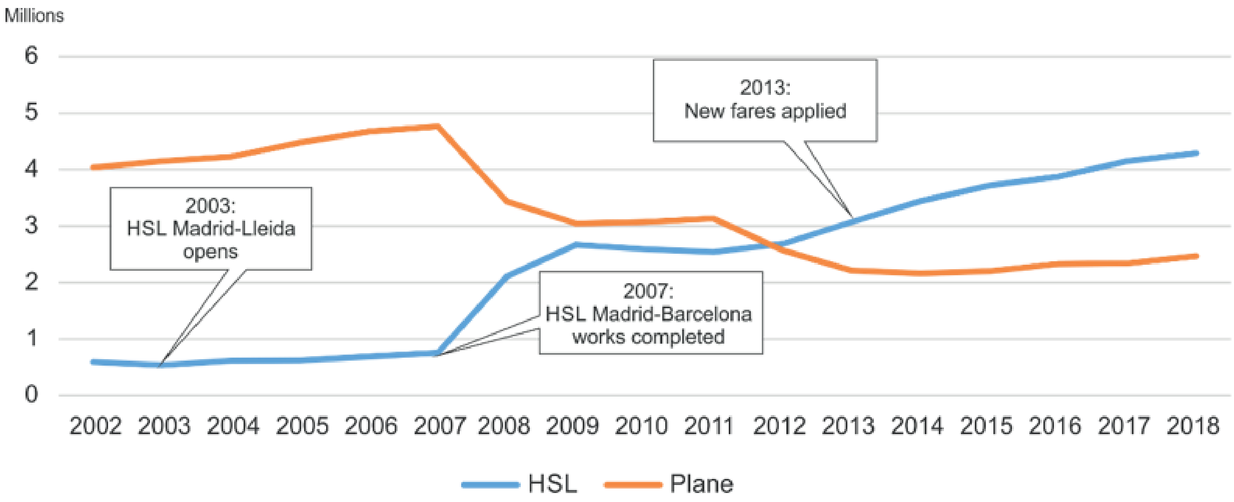


Figure 15: *Number of passengers in High-speed Rail and plane*
Source: *Observatorio del Ferrocarril and Anuario Estadístico de la Ciudad de Barcelona*

[3] "Air Shuttle" or "Puente Aéreo" is a flight service established by Iberia to connect Madrid and Barcelona with an open ticket, which allows the passenger to choose any flight and provides total flexibility for the booking.

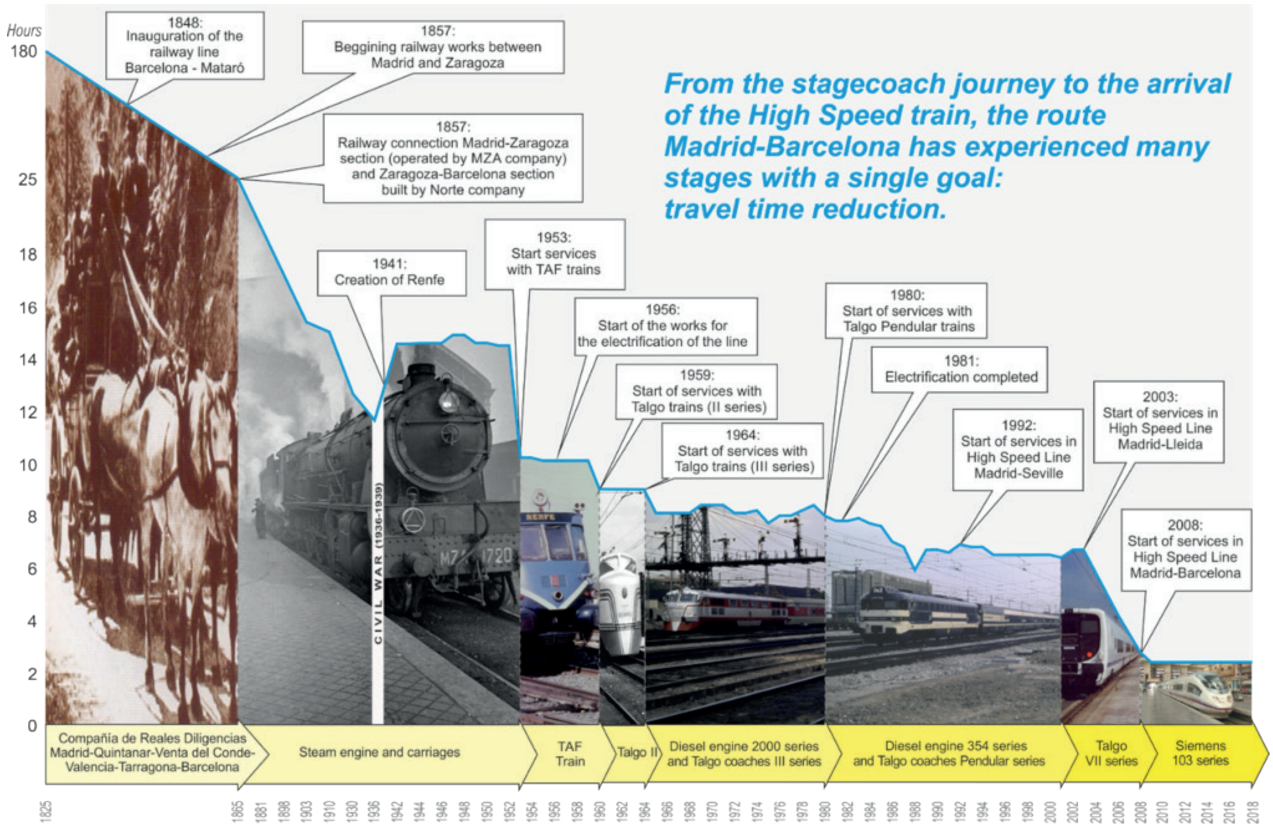


Figure 16: *Main facts in the Madrid-Barcelona route history -* ***Source:*** *FFE*

complete opening of the High-Speed line. This was the year of breakup: the AVE (commercial name of the high-speed services) began its services, offering the possibility of traveling from the centre of Madrid to the centre of Barcelona in two and a half hours. This boosted a spectacular growth in the number of passengers, reaching more than two million passengers by the end of the year 2008, the modal share for rail being 38%. However, the economic crisis moderately lowered the figures again.

In 2012, due to the stability of train passengers and the decrease in air travel, the moment of modal equilibrium occurred, reaching railways almost 50% of the passenger share. 2013 represented a new revolution with the entry into force of the new **RENFE fare policy** based on the "Revenue Management" method. The reduction in prices generated an increase in demand and at the end of that year, RENFE exceeded three million passengers on this line and definitively broke the modal balance, reaching 58.1%.

The Madrid-Barcelona high-speed line currently has 28 services per direction and day provided by RENFE. Twelve of which are direct trains with two hours and a half travel time. The rest of the services have a duration of three hours and ten minutes, and stops at all of the stations on the route.

The profile of the users in 2018, the year of its 10th anniversary, were mainly persons between 35 and 44 years old (31%), who travel with an average frequency of thirteen trips a year, mostly with round-trip tickets (27.06%) and promotional prices (25.3%). 62.1% of the total number of trips are made for professional reasons, followed by trips for leisure and family reasons (33.1%). Users value the service with 8.23 points –on a scale out of 10– and eight out of ten recommend traveling by AVE in this corridor. The most valued attributes are punctuality, speed, travel comfort and the location of the station.

CO2 emissions and external costs

The evolution of the railway infrastructure between Madrid and Barcelona throughout history has significantly reduced its environmental impact and CO2 emissions. In addition, the following measures contribute to a lower environmental impact:

- Exclusive use of electric traction in passenger services.
- Efficient energy consumption: use of regenerative braking technology, reaching a return rate to the electrical system between 6-10%. Likewise, the use of more efficient refrigeration and air conditioning systems achieve 30% of energy reductions.
- Use of new materials in the construction of trains, with lower weight per axle.
- Reduction of control and traction equipment.
- Implementation, as far as possible, efficient driving strategies on trains: reduction of the service brake use and partial drift circulation, with up to 30% of savings on some journeys.

The following figure illustrates CO2 emissions per passenger per transport mode at the Madrid-Barcelona corridor. The increase of the modal share of railways, gained to more polluting means of transport, contributes also to a better environmental performance of the corridor and has other environmental advantages such as lower contribution to local pollution and acoustic impact in urban areas, and lower levels of congestion and accidents.

In addition, rail transport in Spain is the mode that generates the lowest external costs per transported unit. This should be highlighted since the external costs of transport are highly relevant, reaching 7% of national GDP .

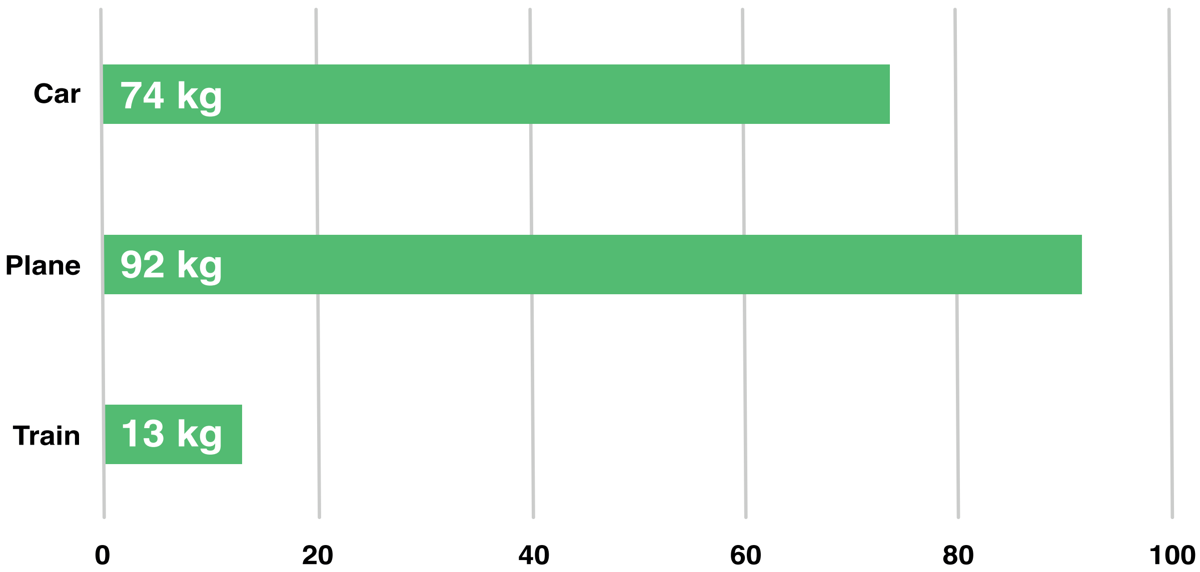


Figure 17: *CO2 Emission per passenger in Madrid-Barcelona High-Speed route Unit: CO2emission by traveller)*
Source: *Authors based on RENFE's data*

Infrastructure

The Madrid-Barcelona line, with the extension to the French border, was opened in several phases: from Madrid to Lleida (2003), from Lleida to Tarragona (2006), from Tarragona to Barcelona (2008), from Figueres to the border (2010) and from Barcelona to Figueres (2013).

The distance between the Madrid-Puerta de Atocha and Barcelona-Sants stations is 663 kilometres, including Zaragoza and Lleida bypasses. It inlcudes the intermediate stations of Guadalajara-Yebes, Calatayud, Zaragoza-Delicias, Lleida-Pirineus and Camp de Tarragona.

Looking at the technical characteristics of the infrastructure, the line has double track in standard gauge, is electrified at 25 kV and has a maximum speed of 300 km/h. The rail is 60 kg/m on a concrete sleeper, while the wheelbase is 4.70 meters. It has twelve substations and ERTMS Level 2 signalling. Even though it was built and exploited in standard gauge, the innovation and developments in gauge change technologies allowed to avoid the border effect with the Iberian gauge network.

Connection to the Trans-European Transport Network

The improvement of travel time has benefitted the Madrid-Barcelona corridor, but also international relations, thanks to the extension of the high-speed infrastructure to the north of Catalonia up to the border with France.

Even when international connections are not direct, current travel times have been reduced, especially with the European capitals that are further away such as Berlin, London, Brussels or Paris. For example, in the case of Berlin, a train journey from Barcelona prior to the introduction of High-Speed in Europe required a time of almost thirty hours, whereas it currently takes no more than eighteen hours. The same with the trip to Paris, which was a journey of 12 hours in 1991, whereas only takes half as long nowadays.

In the coming years, when the introduction of RENFE's low-cost trains and the services of new railway companies begin thanks to the liberalisation (several companies will be circulating in the corridors that will open up to competition: RENFE, SNCF -under the Rielsfera brand- and the Air Nostrum-Trenitalia consortium) it is expected that, not only new users will be gained from planes, but also from the other modes of transport, generating a significant modal transfer towards rail. The impact of the 2020 COVID-19 crisis on the route must also be evaluated in the short, medium and long term.

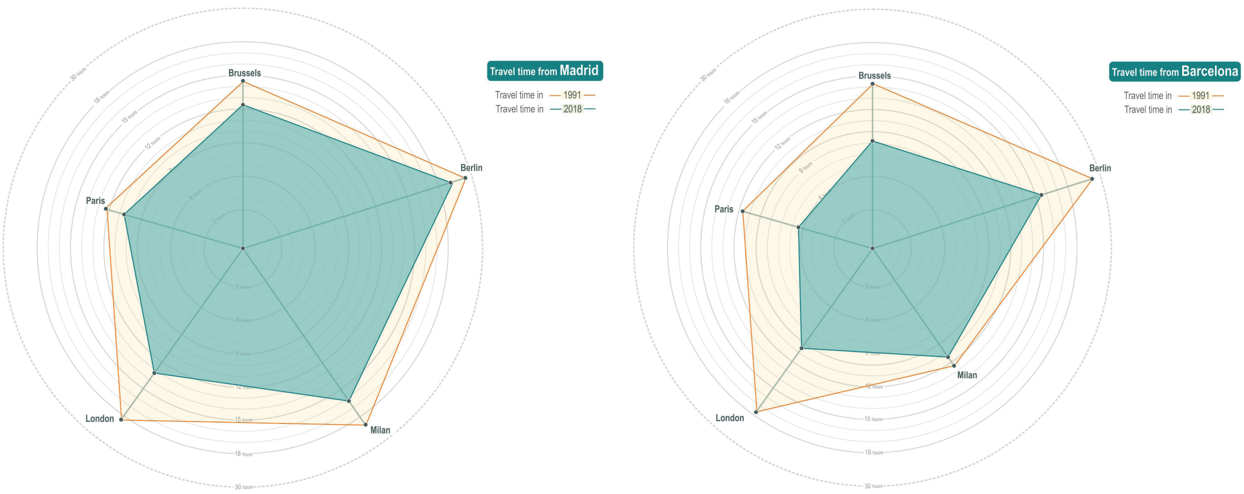


Figure 19: *Travel time from Madrid and Barcelona in 1991 and 2018*
Source: *"1991 RENFE timetable" guide and 2018 data of RENFE'S and SNCF website*

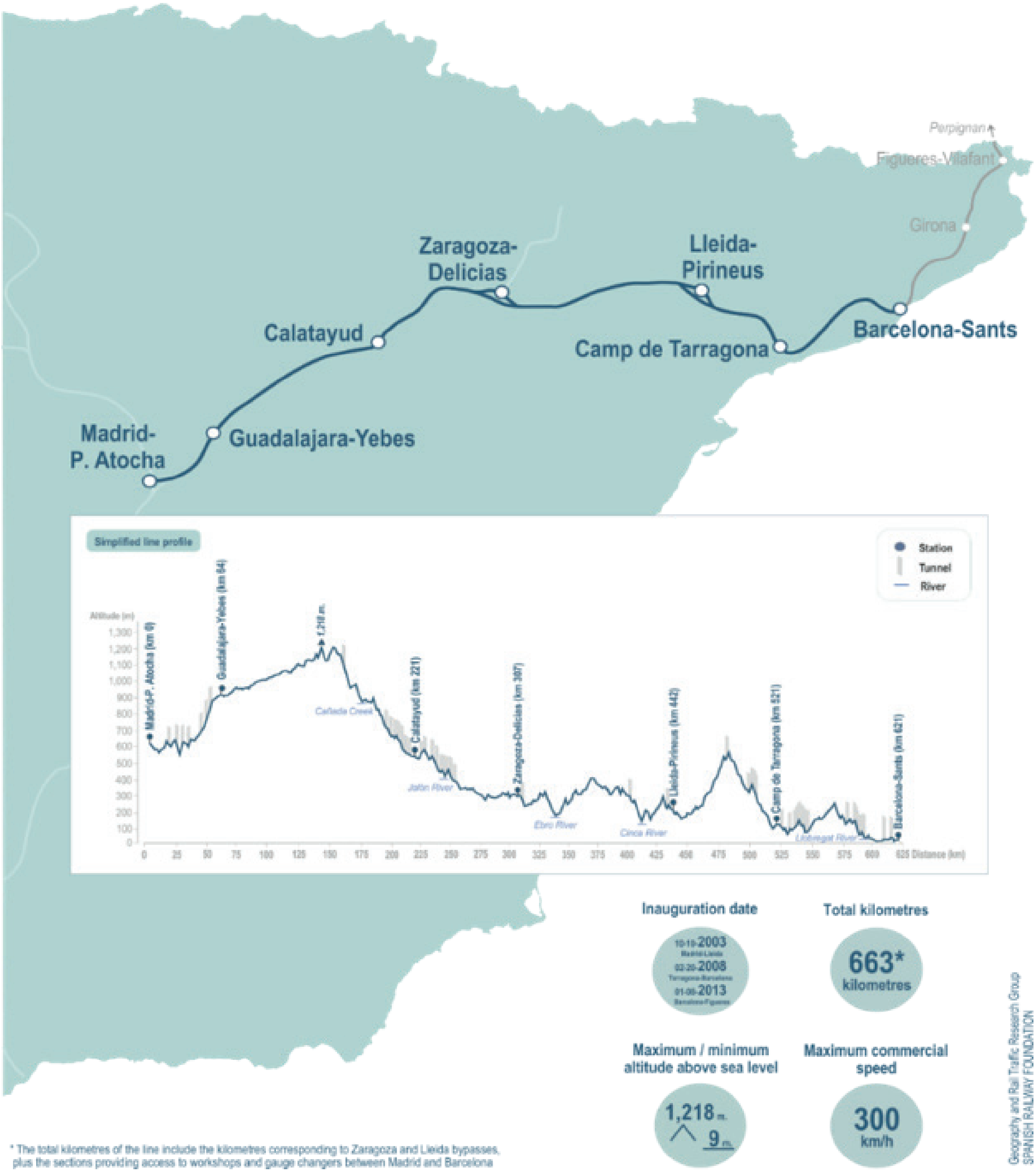


Figure 18: *Main characteristics of Madrid-Barcelona High-speed rail infrastructure*
Source: *Modified from "Atlas High-Speed Rail In Spain". Spanish Railway Foundation, 2017*

4. EUROPEAN RAIL FREIGHT SUCCESS STORIES

4.1. The "MARATHON 1,500m Train"

Longer and heavier trains are deployed in many areas of the world also in Europe, particularly in Russia. There are several reasons why these trains have not been developed in Central Europe which is the busiest area of commercial interchanges. A few examples are: lack of technology, old rolling stock, braking and signalling to be upgraded, infrastructures to be upgraded, axel load limited to 22.5 tons, psychological barriers and, last but not least, the lack of a clear policy in order to operate these trains on the existing lines. The necessary technology is now available.

In 2014 the **MARATHON Project (MAke RAil The HOpe for protecting Nature)** developed its conclusions around the concept of running a train of 1,500m length by coupling two classical trains of 750m each with the second locomotive radio controlled by the front one.

By doing so the train stability is enhanced and no additional major hazards are to be envisaged on the train dynamics. Both of the locomotives contribute to the traction and to the electric and pneumatic braking, specifically during acceleration the braking as well as releasing the pneumatic braking. Radio remote control is used for each of these actions. In case of a failure of the radio connection, a redundancy solution is based on the main brake pipe: the slave locomotive permanently measures the pressure and the variations of pressure and, according to each pre analysed situation, a set of actions is automatically executed (opening the circuit breaker, lowering the pantograph, reducing and cutting traction, service braking, emergency braking).
The MARATHON project executed two trials, not theoretical but real trains, originating from Germany and terminating in Spain.

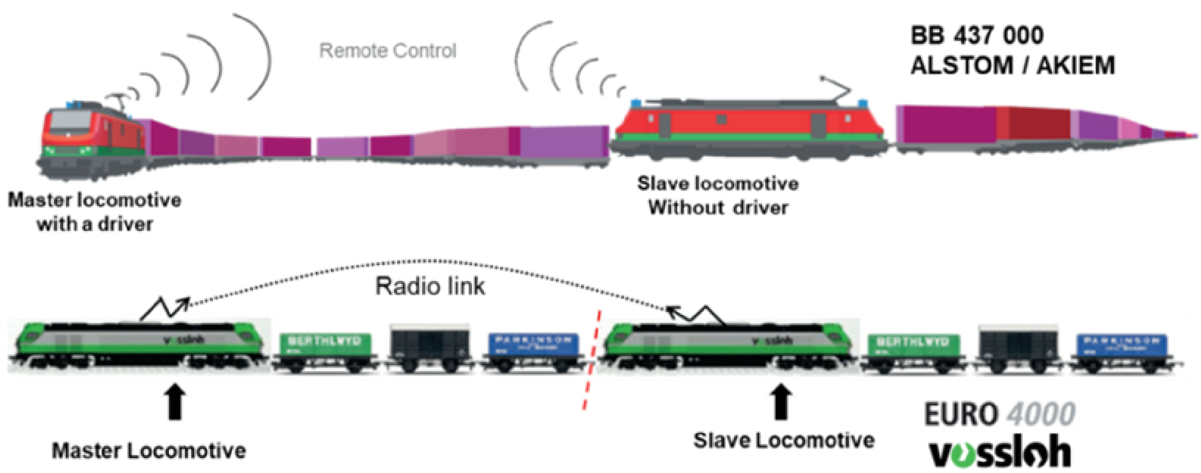


Figure 20: *Marathon Train – principle to train coupling and view of the pilot train -* ***Source:*** *Marathon project, 2014*

The basic market requirement – as input to the Marathon project - was the need to reduce the rail freight operating costs. In particular, the economies of scale generated at sea by the new gigantic vessels (18-20,000 TEUs) require to move containers on land in quantities to be compatible with the maritime transport chain. These long trains can run on the existing infrastructures between ports, terminals to remote areas where freight villages and hubs have the required specifications to receive them. Equally, these trains can run between two freight villages/hubs located in remote areas where the traffic attraction zones reproduce the correct market conditions for having the traffic volumes capable of filling up these trains.

The Marathon trains of 1,500m represent a unique opportunity for transporting substantial traffic volumes from point to point in an industrial way at much reduced operating costs valued at no less than 30%. In addition to reduced costs, the Marathon trains generate extra capacity on the traditional rail lines by reducing the rail tracks occupancy hence maximizing the use of the existing resources and minimizing the need for new investments. In particular, it is possible to run 5 Marathon trains in the slot allocated to 6 conventional short trains, which equates to carrying more than double the capacity of freight with a lower number of trains paths.

Regarding fulfilling the environmental objectives of reducing the transport carbon footprint, a saving of 10% of energy consumption has been monitored during the test of Marathon project.

Some adjustments to the rail infrastructures are however necessary although of relatively modest nature.

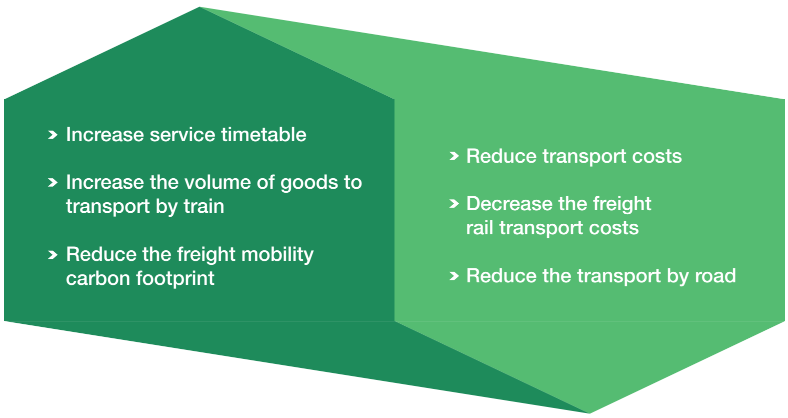


Figure 21: *Marathon Train benefits –* ***Source:*** *Handbook Marathon Project - 2014*

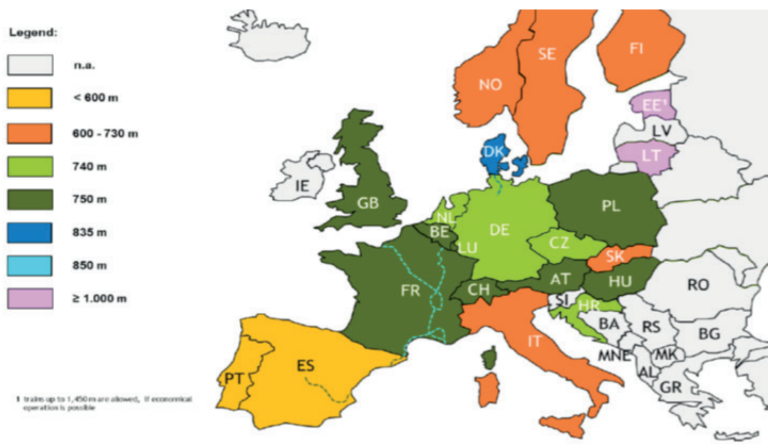


Figure 22: *Max. train length per country*
Source: *CER Longer trains - Facts & Experiences in Europe Results of the CER working group on longer and heavier trains 2018, 4th edition*

“Technical” topic

The project **“M2O”** - “MAke RAil The HOpe for protecting Nature to future OPERATION” (co-financed under the S2R JU initiative) is ongoing with the purpose to set up a reliable transfer of data and commands between the locos based on GSM-R technology.

“Non-technical” topics

Research initiatives in aspects completely different from the technical ones may be influential in accelerating the implementation process.

In principle, the main stakeholders are the:

- Railway undertakings (RUs) consider longer trains as a key approach to competitive rail freight and they encourage the “ASAP” approach.
- Infrastructure managers (IM) face investment effort while increasing transport capacity, however, capacity and/or freight is not their investment priority. So a more consistent win-win situation for both RUs and IMs need to be realized.

1. Infrastructure

Evaluate the infrastructural investments and its timing consistently with demand dynamics, identifying funding.

2. Operations

Identifying investments in operational capability for different stakeholders optimizing infrastructural investments.

4. Business Case

Develop business model supporting collaborative approach in maximizing benefits.

3. Road Map

Outline road map

prioritizing and balancing different actions while building consensus.

Figure 23: *Summary of main actions for implementing the Marathon train –* ***Source:*** *NEWOPERA Aisbl, 2019*

4.2. The TIGER "Dry Port"

TIGER is the acronym for Transit via Innovative Gateway concepts solving European-intermodal Rail needs. The TIGER project approach has become the maritime industrial distribution system of choice from the major European Sea Ports. This is a success story well consolidated and adopted on a large scale in Europe. What is described in this report is the initial pioneering project initiative to be followed by leading Intermodal and Sea Ports operators, Shipping Lines, Dry Ports, Rail Freight traction companies as well as IMs for the rail lines infrastructure adaptations.

The world sea traffic doubled between 2000 and 2006 and continued thereafter with the overland Infrastructures unchanged. The increase in the vessels' sizes exceeding 20,000 TEUs, calling at fewer ports with a greater number of movements, evidenced the inadequacy of the traditional container distribution system plagued by port congestion. The objectives of keeping the traffic moving through European ports, increasing the rail market share was the biggest challenge for the TIGER project since in 2020 most of the North/South Gateway Ports are expected to reach their technical capacity. The industrial distribution by rail via inland Dry Ports appeared the only viable proposition becoming the TIGER project's objective. The project started in 2009 and ended in 2013.

Project Objectives are listed as follows:

- Introduce a new business model via Dry Ports;
- Reduce port congestion through Dry Ports & Hinterland innovative distribution models;
- Maximize capacity on existing rail lines, better utilizing existing resources;
- Industrialize/Optimize transport (maritime & overland);
- Deliver a better service by reducing costs and transit times;
- Introduce innovative logistics solutions and best practices;
- Share benefits among multiple actors of the supply chain;
- Internationalize the solutions.

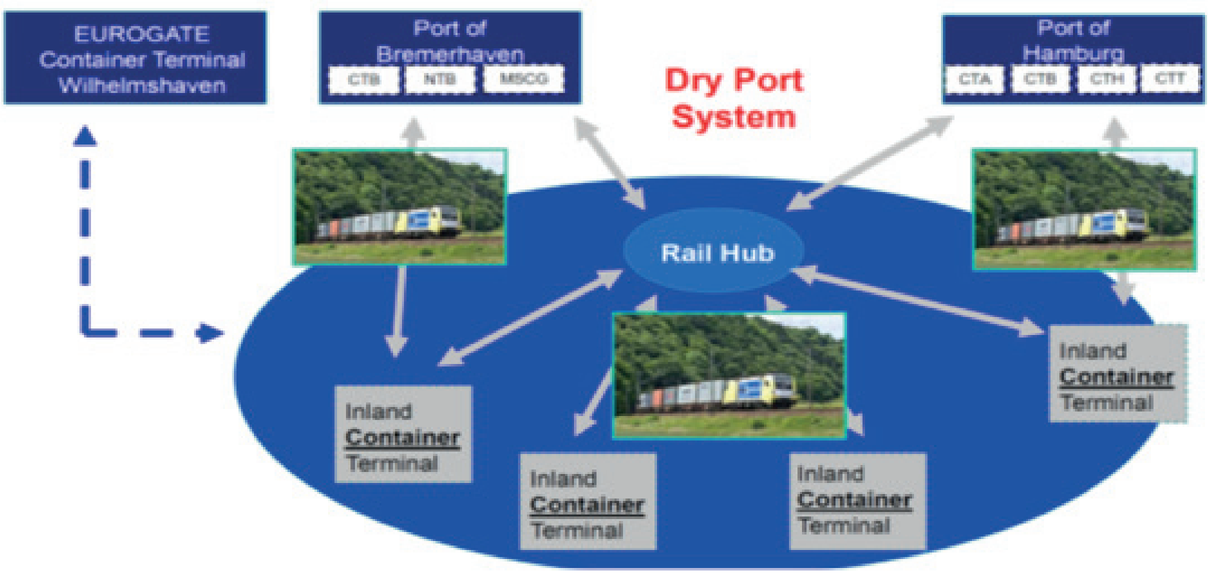


Figure 24: *Dry Port system supporting Bremerhaven and Hamburg*
Source: *TIGER project, 2013*

Figure 24: Dry Port system supporting Bremerhaven and Hamburg
Source: TIGER project, 2013

The Dry Port hub, located on major European freight TEN-T corridors' Core or Comprehensive Network constitute the vital nodes where freight bundling, optimization and transport industrialization became effective through the combination of sea bound traffic with continental traffic. Mega hubs were examined to be built/expanded/ restructured in strategic nodes in traffic attraction zones during the project lifetime. Rail traffic industrialisation was redesigned based on transferring daily massive traffic flows to Dry Ports via multiple shuttle trains.

The O-D Hub functions were studied in order to distribute on a hub and spoke principles, intercepting the additional volumes of the continental European traffic for the final destinations.

TIGER developed these modernization concepts generating effective transport industrialization from the sea to Dry Ports promoting investments by private and public actors in the 4 demonstration ports of Genoa, Hamburg, Bremerhaven, Wilhelmshaven and Gioia Tauro as well as in

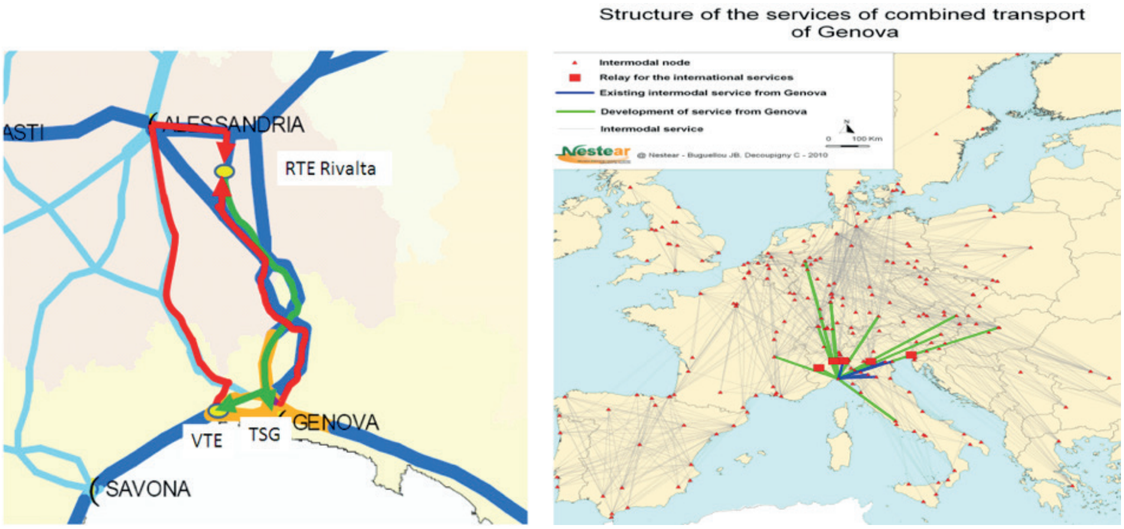


Figure 25: RTE Dry Port system supporting Genoa Port & new competitive reach
Source: TIGER project, 2013

the Dry Ports of Lehrte, Rivalta, Munich-Riem, Nienburg, Duisburg and Poznan.

In the Lehrte and Munich-Riem hubs, several operating innovations were introduced, such as the momentum train positioning under catenary avoiding manoeuvring and the train-to-train container shifting avoiding extra movements and terminal quay usage. In Nienburg, a disused marshalling yard, was brought back into service and a new technique of wagon sorting was introduced. The trains with homogeneous traffic go directly under the ship eliminating handling costs and land usage in the sea terminals.
In Genoa, an electronic seal allowed the direct transport from ship to Rivalta Dry Port by rail without customs intervention. From RTE terminal, Genoa opened up new rail connections increasing its competitive reach in Central Europe.

These concepts immediately produced visible and tangible effects. Trade as a whole and the

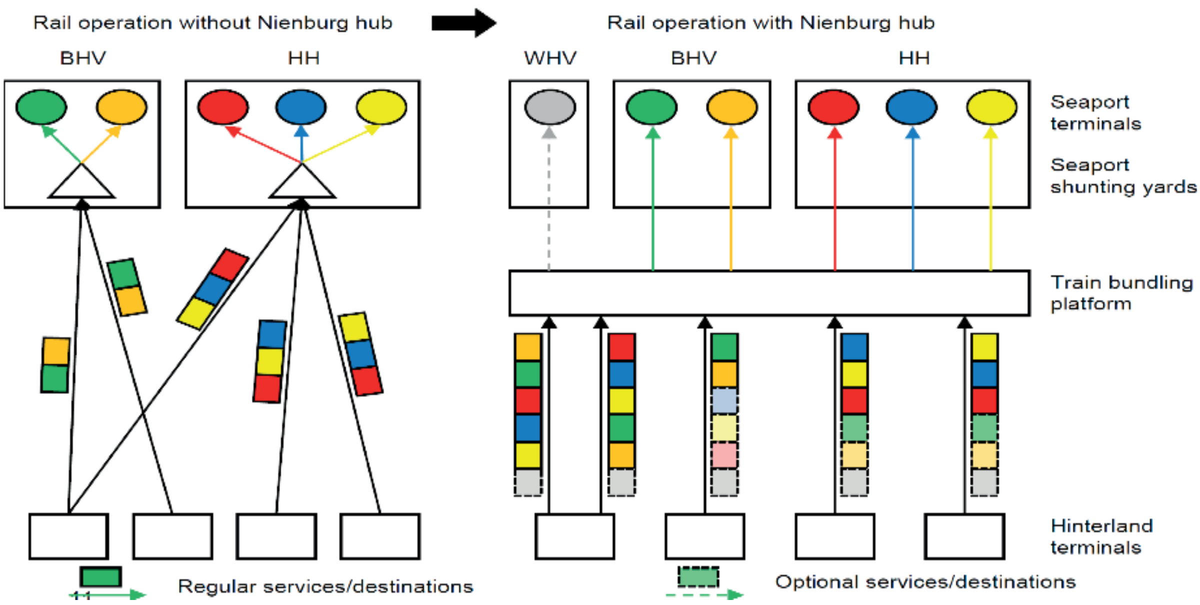


Figure 26: Hub model applied in Nienburg – ***Source:*** TIGER project, 2013

Transport Community replicated the TIGER project initiative into large scale industrial traffic management distribution concept all over Europe. During the project lifetime the following substantial results were achieved:

- Improved management: IT-System in terminal operation including timing control of rail-rail transfer, IT system for train capacity management as well as IT-System for Real-time train monitoring with ETA-information;
- Operating costs reduction increasing train capacity by 15-20%. Also reduced costs in terminals and Mega Hub through increased volumes handled. Reduced sea ports costs avoiding shunting movement inside the port;
- Reduced dwelling & transit time: In Genoa 37% immediate plus 20% planned. Dwell time in Hamburg reduced by 92%;
- Increased slot utilization in Hamburg Seaport Terminal by 100%;
- Service performances improvement through increased punctuality by 85-90%;
- Reduced port congestion through increased Dry Port-Mega Hub rail connections. 33 new rail connections via Munich-Riem up to 70% increased capacity;
- Improved sea ports accessibility together with enlarged competitive reach;
- Reduced emissions and accidents caused by road vehicles.

Other specific service advantages and cost reductions were achieved in other Dry Ports connected to the main North sea ports such as Nienburg, Bremen, Munich-Riem, Nuremberg, Mannheim, Frankfurt, Stuttgart, Lehrte , as well as other terminals outside Germany.

The transport chain became more sustainable through a better use of the available resources. A number of bottlenecks had to be corrected and new management systems/tools had to be introduced.

Modal shift from road to rail is a must through a profound modernisation of the rail economy based on lower costs while at the same time delivering better services. This paradigm was solved by generating extra capacity by increasing productivity and by new local investments in hardware and software.

TIGER project brought the vessels nearer to the points of cargoes' origin/destination. It reduced port congestion and created an innovative distribution model capable of utilizing existing resources, maximizing capacity of rail lines, reducing transit time and increasing logistic chain efficiency. TIGER effectively implemented the idea of maritime integrated with overland services in economies of scale through an efficient network of inland Hubs. The TIGER solutions have been progressively developed in the main European ports, evidencing the mutual benefits for different modes deriving from an efficient and effective development of a synergic approach.

This innovative distribution model was adopted thereafter all over Europe, allowing other sea Ports/ Dry Ports to extract the same benefits in a domino effect. This system improved the port and rail line productivity through inland hubs, integrating this combination of sea/rail into the European co-modal Network. Deployment of innovative technologies contributing to a considerable improvement in the service quality offered to the market place, transit time reduction and performance control through track & trace. Administrative/bureaucratic barriers were abated adopting e-freight, e-seals and e-customs. The introduction of ICT systems governing train capacity, bookings, loading/ unloading, service quality, traffic bundling and schedules improved the train productivity and the capacity optimization considerably. Process modifications were necessary to secure a proper migration from the previous status quo to the new production models.

Extensive training/re-training activities were necessary for introducing and/or upgrading the management and personnel skills to the usage of the new tools be they SW or HW. Security controls were simplified through the adoption of e-seals reducing physical cargo inspection that is a major cause of additional costs/delays. Re-engineering of the working cycle in the interfaces Ship-to-Shore and Shore-to-Train eliminated idle time and interruptions. The duty cycle became seamless.

Several barriers were eliminated favouring the adoption of one contractual interface capable of governing the entire process.

The ultimate results are: increased efficiency, elimination of handlings and less port land use, better services, increased competitiveness of European industries, better ports' accessibility, a more sustainable freight mobility improving the life's quality of the Citizens living around the Ports.

In TIGER the outputs fulfilled the market uptake on full commercial basis. TIGER mobilised substantial private investments in the order of 500m € in hubs, equipment, terminal infrastructures, bottlenecks corrections, technology management systems, software and training of human resources. This industrial business model was replicated all around Europe with evident show cases in Hamburg, Wilhelmshaven, Antwerp, Rotterdam and Genoa benefiting entire communities.

The Dry Ports became extended pots' quays. Established and new private operators increased substantially the number of shuttle trains connections to/from ports improving their competitive reach and attractiveness.

This achieved migration into a new transport chain system involving both the maritime and the overland traffic, constituted a step change in freight mobility operations towards an effective and efficient shift to rail achieved opportunity.

5. PERSPECTIVES

Can rail become the backbone of the European transport system of the future? This question accompanied the TER4RAIL consortium through the whole project lifetime. And the answer is Yes. This was demonstrated through the analysis of documents, projects, roadmaps, deliverables, data and statistics collected on all facets of the rail sector by the members. And the answer is yes even when analysing the success stories described in this short report.

These are some examples coming from the real world of efficient and effective implementation of rail services in Europe, and these constitute a great demonstration of the disruptive potential rail can have in shaping the future of the transport system, be it public transport, mainline or freight. Rail can become the backbone of the European transport system of the future, and strong arguments are provided in the TER4RAIL project research (and in this report, too). But this is not a process taking place automatically.

Strong cooperation is required between rail stakeholders and between rail and experts coming from other sectors/scientific disciplines, bringing added value and concretely making a step towards a multimodal transport system with rail at the centre. To do so, greater levels of financial investment in R&D are also required, and further research on important topics such as digitalization, artificial intelligence, machine learning and big data, putting them at the service of the user.

Finally, the involvement of the public authorities, the planning bodies and the user's communities is fundamental both for guaranteeing a fruitful deployment of the above mentioned activities and for producing the necessary behavioural step change required.

6. ABBREVIATIONS & ACRONYMS

Abbreviations/ Acronyms	Description
ATC	Automatic Train Control
AVE	Alta Velocidad Española
AVLO	Alta Velocidad Low cost
CER	Centre for European Railways
ERA	European Railway Agency
ETCS	European Train Control System
FAO	Fully Automated Operations
HSR	High Speed Railway
IM	Infrastructure Manager
M2O	Marathon2Operation
OSS	One Stop Shop
PTA	Public Transport Authority
PTO	Public Transport Operator
RU	Railway Undertaking
S2R JU	Shift2Rail Joint Undertaking
SPC	Single Point of Contact
STM	Specific Transmission Module
TEN-T	Trans European Network-Transport
TEU	Twenty foot Equivalent Unit
TSI	Technical Standards for Interoperability
WP	Work Package

TER4RAIL CONSORTIUM

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TER4RAIL FACTS AND FIGURES

- Call number: S2R-OC-IPX-02-2018
- EU Contributions: €500 000
- Project duration: 01/12/2018 - 30/11/2020
- Partners: 7 partners from 5 countries
- Project coordinator: EURNEX e. V.
- Grant agreement n°826055

This project has received funding from the Shift2Rail Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement no. 826055 (TER4RAIL)