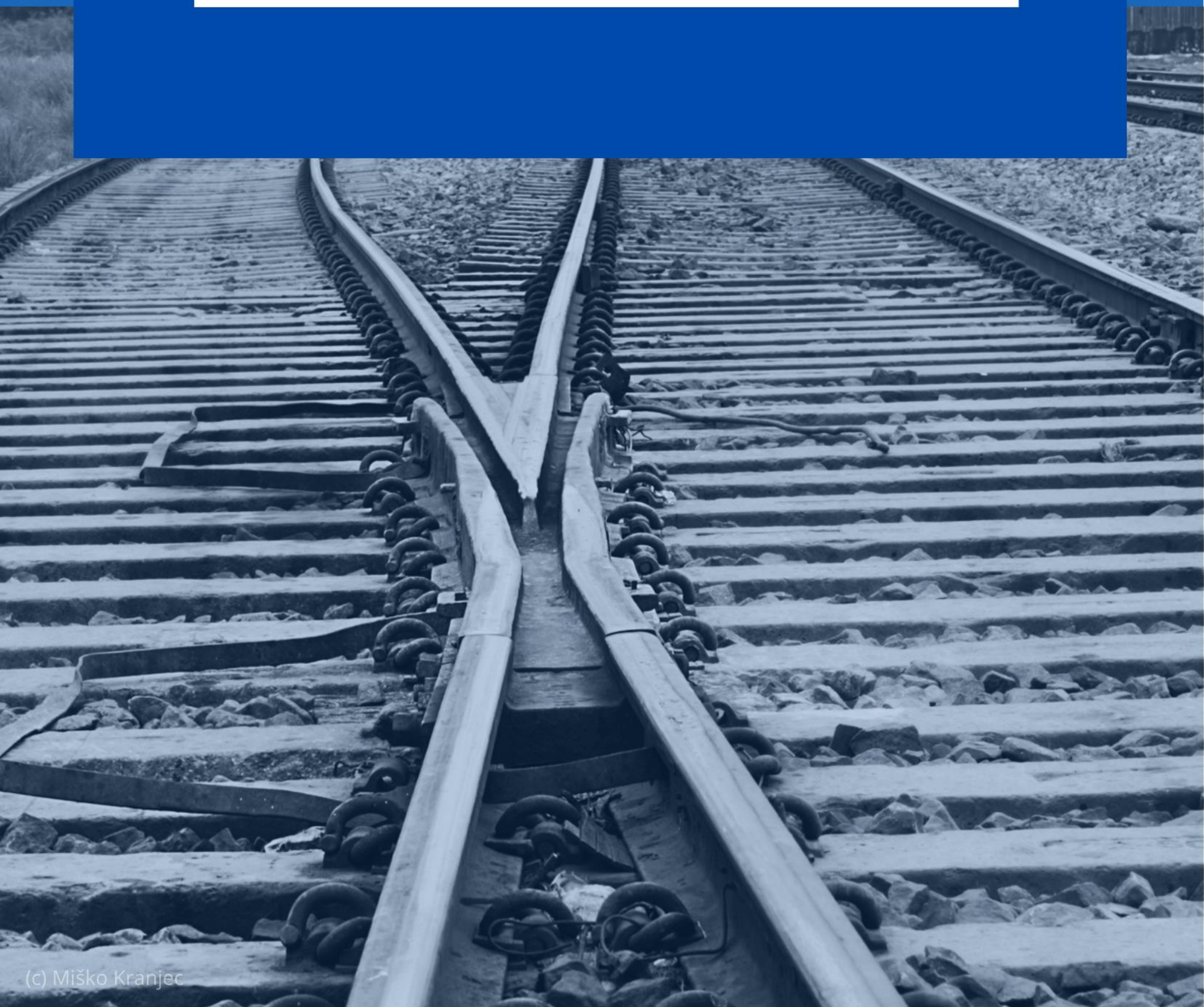
CEI
CENTRAL EUROPEAN INITIATIVE

REGIONE AUTONOMA FRIULI VENEZIA GIULIA

POLITECNICO DI MILANO

Study on the improvement of passenger rail connections between the Friuli Venezia Giulia Region and the Western Balkans, with a focus on the Trieste - Ljubljana - Zagreb - Belgrade route



(c) Miško Kranjec

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Contents

INTRODUCTION

This study examines the potential demand and the impacts on modal shift and climate change (in terms of reduction of CO2 equivalent emission per year) of some preliminary hypotheses of an international passenger rail service between the stations of Trieste, Ljubljana, Zagreb, Belgrade and other regional hubs of local public transport.

The analysis follows a methodological approach (**Figure 1**) that:

1- Analize the characteristics of the existing railway infrastructure and of the ongoing investment in order to identify any critical infrastructural gaps;
2- Analyse the on-going investment in order to verify whether the identified critical gaps could be bridge up in the future (and when) thanks to the planned investment;
3- estimate the potential travel demand for an international passenger rail service along the route using travel demand forecasting model that takes into consideration the newly estimated travel times by rail and the supply of alternative travels options (by car and collective transport modes);
4- design an optimal service configuration leveraging the potential demand estimates.

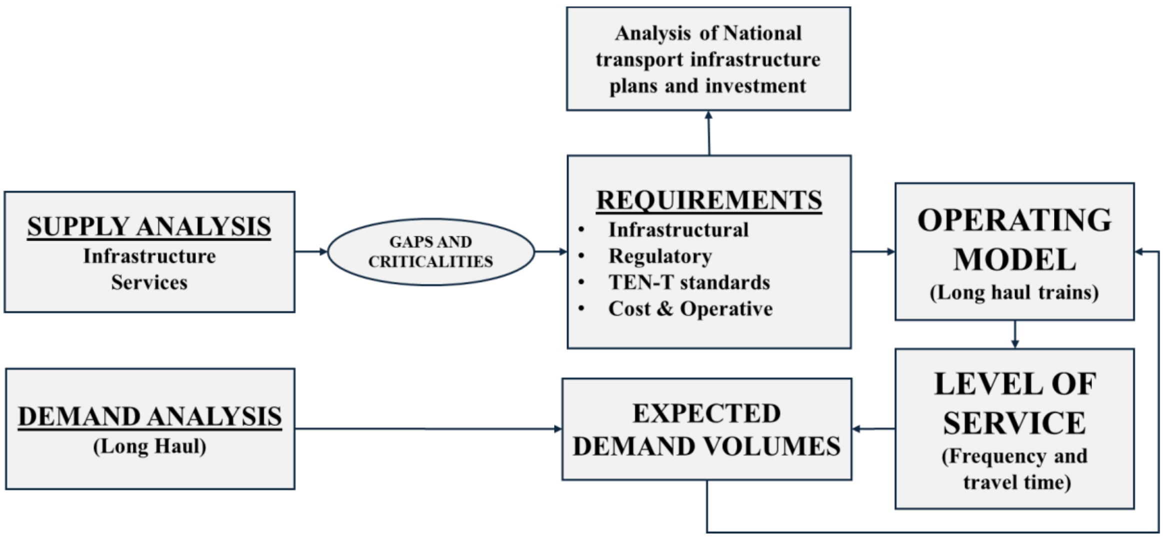

Figure 1 - The methodological approach of the study

The **Trieste-Ljubljana-Zagreb-Belgrade railway route** (**Figure 2**) represents a strategic crossroads between Central Europe, the Balkans, and the Mediterranean. Western

Balkans have a history of railway connections that for years have created **a bridge between Europe and the East**, with iconic routes such as the Simplon Orient Express. However, the political transformations of the 20th century led to the discontinuation of many international services, reducing regional connectivity.

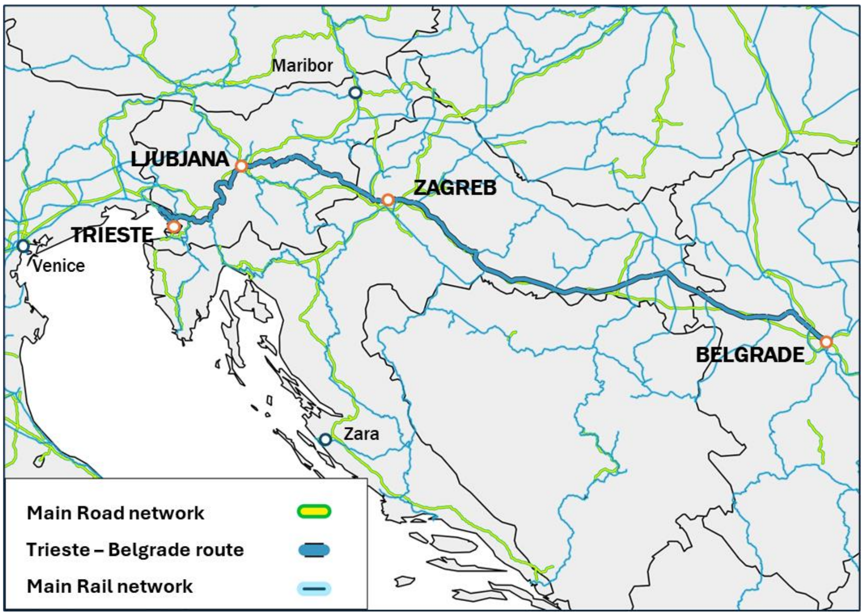

Figure 2 - The Trieste - Ljubljana - Zagreb - Belgrade railway route

Recently, railway connections in the area have come back in the spotlight, as the interest in sustainable long-distance travel options by railway, has increased following the EU environmental strategy for decarbonization ("*Fit for 55*"), as represented by the EU smart and sustainable mobility strategy (COM/2020/789) and the action plan to boost long distance and cross-border passenger rail (COM/2021/810), as well as in the "*Strategy for Sustainable and Smart Mobility in the Western Balkans*" of the Transport Community.

Furthermore, the recent upgrade of the **TEN-T network** (Regulation EU/2024/1679) defining new requirements for the Core, Extended Core and Comprehensive networks, has identified among the new European Transport Corridors (ETC), the **Western Balkans - Eastern Mediterranean (WBEM) corridor** that stretches from the central European countries, all the way to the Eastern Mediterranean Sea, cutting through the Western Balkans. The Trieste-Ljubljana-Zagreb-Belgrade railway route represents one of the TEN-T Core branches of the north-western portion of corridor.

Figure 3 - The Western Balkans /Eastern Mediterranean (WBEM),

Key challenges for the WBEM corridor are the upgrade of the railway infrastructure addressing gaps in signalling system, electrification and infrastructure development (e.g. doubling single track links), which are critical for ensuring **seamless and efficient connections**. Achieving **interoperability** via the deployment of the European Rail Traffic Management System (ERTMS) is essential as well for standardizing operations across different national networks and enhancing safety and efficiency. Commercial speeds and the time required for border crossings represent additional hurdles, as they directly impact the corridor’s attractiveness for freight and passenger services. Finally, high safety and maintenance standards remain fundamental topics for the corridor’s development.

1 ESTIMATION OF EXISTING AND POTENTIAL TRANSPORT DEMAND

1.1 State-of-the-art on transport demand analysis in the area

Currently there are no available studies on the transport demand along the entire Trieste–Ljubljana–Zagreb–Belgrade railway route, although there are some projects that have analysed the demand in some specific sections of the route or that focus their scope of application on the same region.

The study entitled *Estimation of the Existing and Potential Transportation Demand for a* ***Trieste-Rijeka Train Passenger Service*** (Pesenti et al., 2023)[1] evaluates the viability of a direct rail service connecting Trieste, Italy, and Rijeka, Croatia. Key objectives include estimating current and future passenger demand and exploring scenarios that could boost rail use along the line. The study highlights challenges such as limited historical data and fragmented demand estimates. Employing a linear additive model, the research provides demand forecasts ranging from a conservative 7,300 to an optimistic 66,650 annual passengers, with a realistic expectation between 28,400 and 36,000. The analysis underscores significant seasonality in demand, driven mainly by tourism, and points out opportunities for increasing ridership through improved infrastructure and better service integration. Recommendations suggest targeting the development of cycling tourism and enhancing last-mile connectivity to attract more passengers. Additionally, the study emphasizes the importance of collaboration between Italy, Slovenia, and Croatia to optimize the corridor's potential and achieve economic and environmental benefits.

The ***MIMOSA*** **Project**[2] was an Interreg Italy-Croatia strategic project (EUSAIR -labelled) that aimed to improve limited cross-border connectivity by delivering impactful, multimodal and smart solutions. It addressed the shared goal of enhancing multimodality

[1] The study, complemented with the analysis of accessibility of public transport, was functional to the launch in April 2024 of the experimentation of a direct passenger train between Villa Opicina and Rijeka (operating (until September 2024), as part of the Interreg project Central Europe SUSTANCE.

[2] "Maritime and multimodal sustainable passenger transport solutions and service"

while minimizing environmental impacts from transport. Two *MIMOSA* studies, in particular, have focussed on travel demand analyses between the two countries:

- The *Passenger Transport Demand Analysis*[3] study utilizes qualitative and quantitative approaches to demand analysis to highlight significant preference for car travel, with notable seasonal peaks for Italian tourism in Croatia. Opportunities for promoting rail and bus services are identified, suggesting targeted strategies to shift travel behavior toward more sustainable options.
- The *Quantitative Analysis of the Existing Demand*[4] study aims at establishing a quantitative foundation for understanding current travel patterns between Italy and Croatia, with a focus on tourism demand and the effects of the COVID-19 pandemic on travel patterns. Again, the analysis reveals that car travel is overwhelmingly dominant, especially among Italian tourists visiting Croatia. The COVID-19 pandemic significantly reduced cross-border travel, but demand is expected to recover. The study indicates that improving rail and public transport services could reduce car dependency but highlight infrastructure bottlenecks to be addressed in order to provide sustainable and attractive travel options.

As part of the Interreg Italy-Slovenia strategy a pilot project named ***CROSSMOBY***[5], consisting of an experimental railway connection between the Italian region of Friuli-Venezia Giulia (FVG) and Slovenia, was carried out with the goal of improving cross-border connectivity, promoting sustainable travel options, enhancing regional integration, and reducing car dependency. The report outlines a comprehensive monitoring approach, including both quantitative and qualitative analyses. Data collection involved passenger counts from September 2018 to December 2019, performance indicators such as punctuality rates, and a trilingual survey (Italian, Slovenian, English) distributed to the train users. The monitoring also included an environmental impact assessment comparing CO2 emissions from train versus car travel. The service recorded a steady increase in passenger numbers, totalling 31,218 passengers transported during the pilot project duration, with significant usage on weekends and during holidays, indicating

[3] "*Passenger Transport Demand Analysis*", Interreg Italy – Croatia – MIMOSA, 2021

[4] "*Quantitative analysis of the existing demand*", Interreg Italy – Croatia – MIMOSA, 2021

[5] "O.3.11.4 Report di Monitoraggio Finale", CROSSMOBY, 2021

strong tourism-related demand. The environmental analysis highlighted substantial carbon emission reductions compared to car travel. The findings also suggested potential for service expansion through partnerships with tour operators and targeted promotional efforts, especially focusing on young travellers (i.e. Under 30).

In the framework of Interreg Programmes, it is worth mentioning the ongoing Interreg Central Europe SUSTANCE project, led by the Executive Secretariat of the Central European Initiative (CEI), that thanks to the fruitful cooperation between Slovenian railways (SZPP) and Croatian railways (HZPP) launched an experimental direct train passenger service connecting daily (after more than 50 years in the period) the cities of Trieste (Villa Opicina) and Rijeka through Slovenia (Sezana, Divaca, Pivka). The service has been reactivated as a piloting initiative between 24 April 2024 and 30 September2024.

Finally, the ***Transport Development Strategy of the Republic of Slovenia Until 2030*** [6] [7] is an infrastructural planning document that provides detailed information on the planned developments of the Slovenian transportation networks, as well as the current and future estimates of travel demand across several modes. The strategy emphasizes the need to modernize and optimize Slovenia's rail network, enhancing connectivity and ensuring environmental sustainability. The Ljubljana–Zidani Most section and the Ljubljana–border with Italy sections are particularly vital due to their strategic role in linking key domestic and cross-border regions, and their potential to reduce road congestion and emissions.

A crucial feature of the study is that demand estimates are based on comprehensive transport modelling, incorporating socioeconomic data, historical travel patterns, and projected infrastructure improvements. The analysis considers both current demand and potential shifts from road to rail, driven by anticipated rail service enhancements. The modelling results indicate a significant potential increase in rail travel demand, especially in the Ljubljana–Zidani Most corridor, due to high population density and economic activity. Improvements in the Ljubljana–border with Italy section could boost international connectivity, though it requires strategic investment to realize this potential.

[6] "Transport Development Strategy of the Republic of Slovenia Until 2030", Ministry of Infrastructure – republic of Slovenia, 2015

[7] "Resolution on the National Programme for the Development of Transport in the Republic of Slovenia until 2030", Ministry of Infrastructure – republic of Slovenia, 2016

1.2 Collection of socioeconomic data in the study area

To evaluate the potential travel demand using the new rail service, the socioeconomic characteristics of the catchment areas[8] served by each station were gathered from different data sources and subsequently harmonized. Specifically, databases from EUROSTAT and the Statistical Office of the Republic of Serbia were used to collect information on the population and GDP generated in each NUTS 3 zone[9]. The collected data were then adjusted to ensure consistency and comparability across the dataset. This harmonization process was essential to create a unified and coherent data framework, allowing for a more accurate analysis of the potential demand and the **socioeconomic landscape** of the regions involved. The results of this data gathering process can be seen **Figure 4** and **Figure 5**, where population density and GDP per capita are respectively represented in the Adriatic-Ionian (AI) region[10].

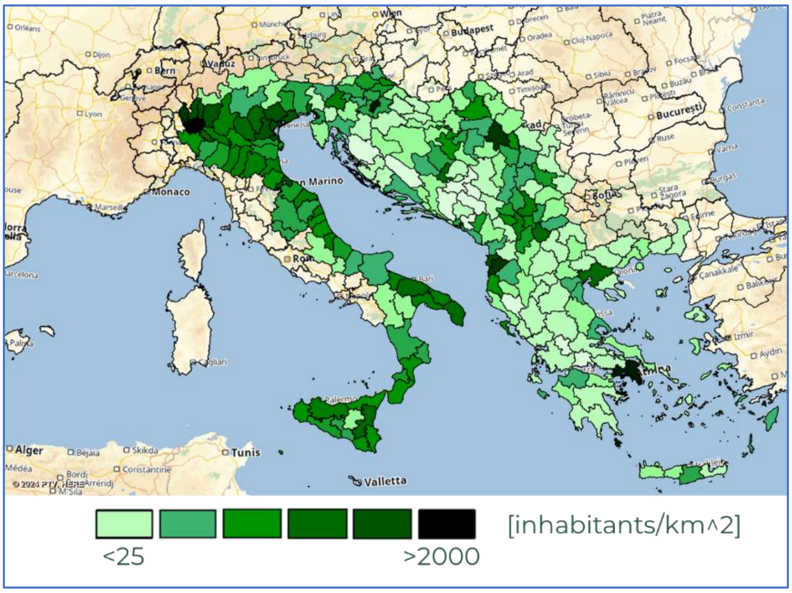

Figure 4 - Population density distribution in the Adriatic-Ionian (AI) Region

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[8] Catchment areas represent the areas reachable within a set travel time limit from a starting point. They are commonly used to represent the accessibility of said starting point or as a way to delimit the demand pool of a public transport station.

[9] NUTS3 zoning is roughly equivalent to the administrative unit of Italian provinces.

[10] The visualization of socioeconomic data is extended to the whole AI region in order to provide a more comprehensive overview of the differences and disparities that characterize it.

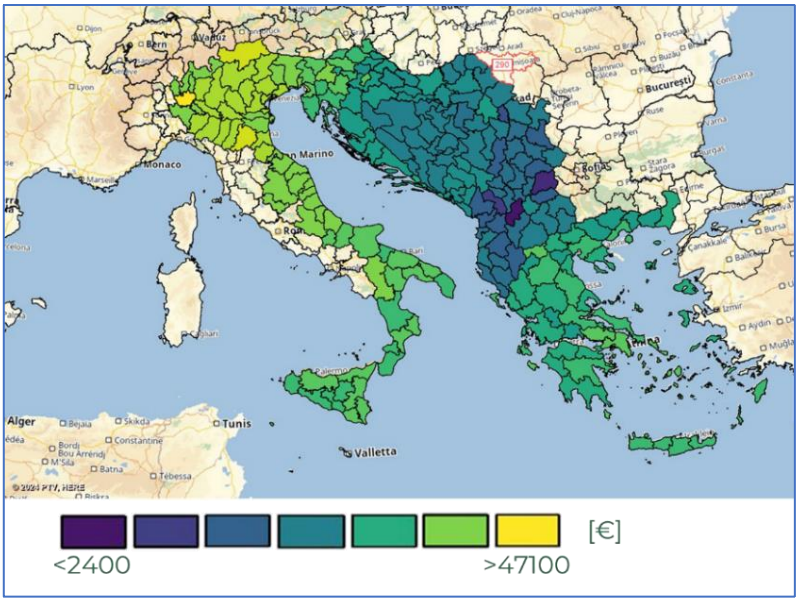

Figure 5 - GDP per capita distribution in the Adriatic-Ionian (AI) Region

At a first glance it can be clearly seen that the AI region features great disparities in wealth and population distribution. As expectable, the Italian and Slovenian regions are the wealthiest and most densely populated, while the southernmost provinces of the Western Balkans, with the exception for Greece, are characterized by the lowest GDP per capita. Furthermore, population distribution in the Western Balkans sees the countries' capitals as the most densely populated areas, while in Italy the distribution is more homogeneous, still highlighting great population agglomeration in great urban centres like Milan and Bologna.

1.3 Identification of the demand pools

The methodology for selecting the demand pools of the proposed rail service starts from the identification of the station served by the new line. The choice of the stations set allows for the consequent step of mapping each station's catchment areas that ultimately defines the relative demand pool. This procedure is instrumental to the estimate of the current and predicted demand for the service.

The **selection of stations** along the route is essentially guided by two criteria: population density and network effect. According to the first criterion, the service includes the three capital cities it passes through (Ljubljana, Zagreb, and Belgrade), the city of Trieste, and the city of Slavonski Brod in Croatia. Based on the second criterion, three locations are identified where stations serve as highly central nodes within national and international railway networks: Pivka and Zidani Most in Slovenia, and Vinkovci in Croatia. This set of **eight stations** ensures the generation and attraction of passenger flows, given the established connections between urban centers, while also capturing and channelling flows along other railway routes, thus leveraging and promoting rail interconnectivity in the region.

Subsequently, using the commercial software *PTV Visum*, it was possible to map the catchment areas for each selected station (**Figure 6**). Specifically, the catchment areas were determined based on the road network graph, setting a **driving time of 45 minutes** under free-flow conditions. The choice of a 45-minute driving time threshold is justified by the fact that it represents a realistic maximum time for accessing a long-distance rail service such as the one under consideration.

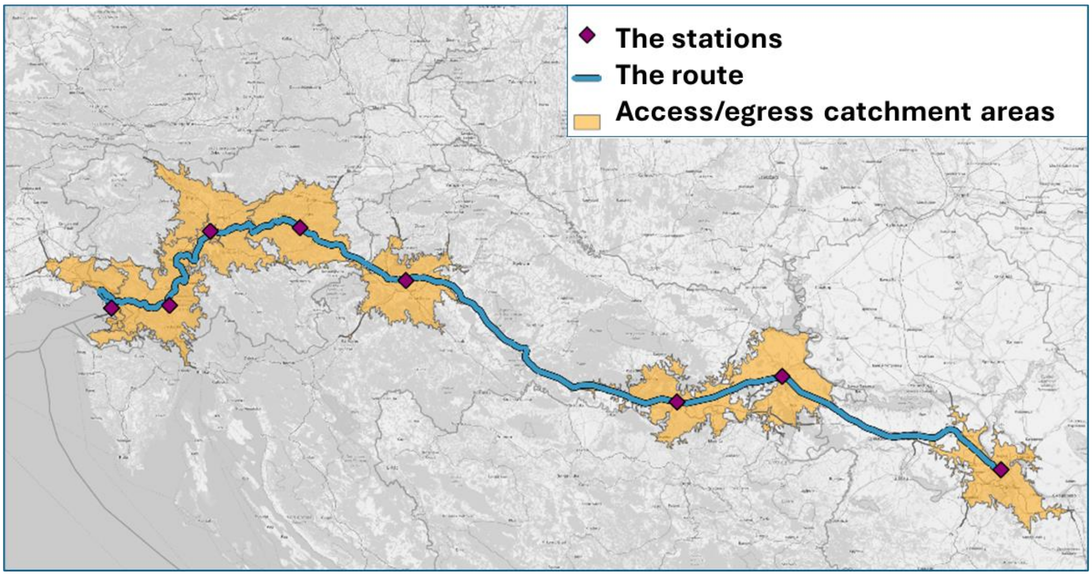

Figure 6 - The catchment areas of the chosen stations along the route

Finally, the NUTS3 zones intersecting with the catchment areas are selected, allowing to **extract the demand pool of each station** of the line (**Figure 7**).

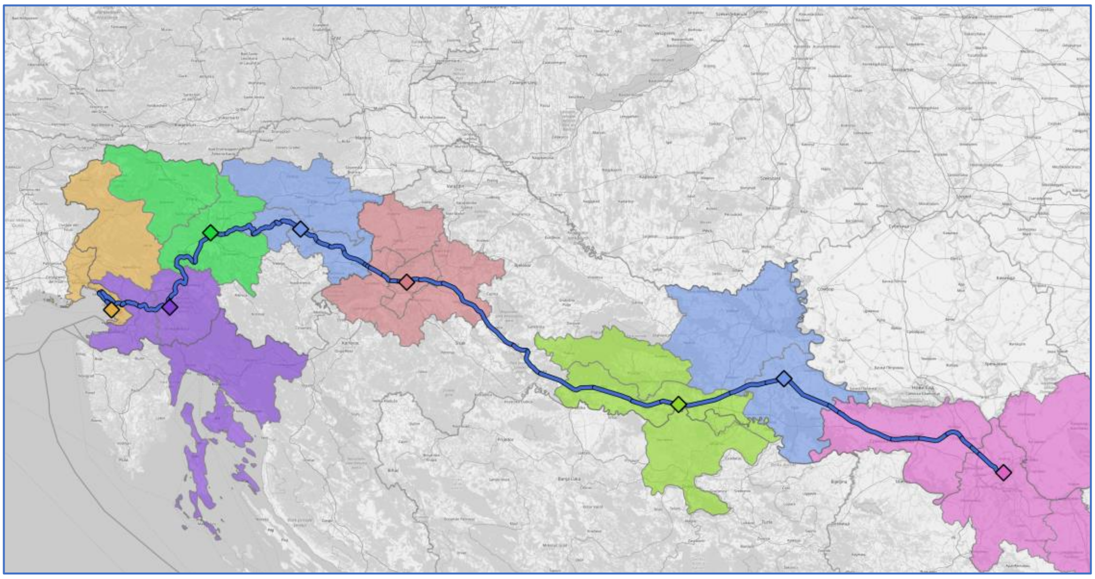

Figure 7 - The demand pool of the stations of the line (each colour corresponds to a rail station and its corresponding demand pool)

The overall demand pool encompasses a total of **6.63 million people**, generating a combined **GDP of €93.8 billion**. The most populous portion is the one associated to the station of Belgrade, with a total of 2.45 million people (37% of the total), while the wealthiest one is in Slovenia, contributing €31.8 billion (34% of the total).

1.4 Estimate of current and potential demand

The identified socioeconomic data was integrated with transport data from the **EUSAIR Master Plan of Transportation** (2021) to provide an estimation of the current transport demand across three distinct modes: private car, train, and long-distance bus. Some adjustments were made to the demand estimates, including modifications to reflect cross-border demand changes resulting from the impact of the COVID 19 global pandemic of 2019–2021 and the harmonization of all input data to a common base year. Ultimately, calibration of the results was achieved through the utilisation of road and rail traffic counts.

The estimation results indicate that the demand for rail transport (**Table 1**) is relatively insignificant in the study area, particularly in comparison to car and bus transport. The average **rail modal share is found to be 1.8 percent**, which corresponds to approximately **1.5 million passenger trips per year**. Additionally, as anticipated, the data indicates a clear predominance of domestic trips over international trips, which further substantiates the conclusion that demand is predominantly regional in nature.

The international origin-destination (OD) pair with the highest rail modal share is the one between Vinkovci and Belgrade, with a share of approximately 3.8 percent. The proximity of the two cities and Belgrade's status as Serbia's primary urban centre and demand attraction hub provide a rationale for this outcome. The OD pair with the highest number of passengers is Ljubljana-Zidani Most, with approximately 293,000 passengers per year

International trips account for approximately 260,000 passengers per year, representing 17% of the total demand. with a peak between Ljubljana and Trieste with 87,500 passengers per year.

Table 1 - The current origin-destination (OD) railway demand matrix. The values express the travel demand between origins (rows) and destinations (columns) in thousands of passengers per year

	TRIESTE	Pivka	LJUBLJANA	Zidani Most	ZAGREB	Slavonski Brod	Vinkovci	BELGRADE
TRIESTE	-	21	88	11	-	-	-	-
Pivka	21	-	111	15	-	-	-	-
LJUBLJANA	88	111	-	294	1	-	-	-
Zidani Most	11	15	294	-	3	-	-	-
ZAGREB	-	-	1	3	-	62	36	-
Slavonski Brod	-	-	-	-	62	-	113	-
Vinkovci	-	-	-	-	2	113	-	4
BELGRADE	-	-	-	-	-	-	4	-

The consequent step consisted in estimating the level of the **potential railway demand** following the opening of the service and the infrastructural interventions that are expected to provide a critical upgrade in efficiency and reliability of railway services running along the route (further analysed in chapter 4.1). This evolution is expected to make railway services generally more attractive, as a primary result of the availability of **more competitive travel times** (**Table 2**).

Table 2 - Estimated travel times following the opening of the service and the infrastructural upgrades planned along the route

	TRIESTE	LJUBLJANA	ZAGREB	BELGRADE
TRIESTE		2h	3h 50min	10h
LJUBLJANA	2h		1h 50min	8h
ZAGREB	3h 50min	1h 50min		6h 15min
BELGRADE	10h	8h	6h 15 min	

Therefore, using direct and cross elasticity values[11], an estimate of the amount of demand that will be shifted from car and bus to rail (i.e. **modal shift**) was obtained, as well as the additional demand for the new service generated by the introduction of the service (i.e. **induced demand**). Overall, total rail demand is estimated to increase by +234% (reaching a total of 4.98 million passengers per year[12]). Globally, a modal shift of about **+4%** to railway services is expected, while locally, the largest modal shift is on the ODs that include Belgrade (the Vinkovci-Belgrade pair gains a share of +13%, reaching a total share of 17%), while for the other OD pairs the change in share is between +2% and +7%.

Table 3 shows the increase in railway demand (in thousands of passengers per year) for each OD pair estimated from the attractivity increase of the railway mode in the

[11] "*A study on the elasticity of long-range travel demand for passenger transport*", P. Coppola, A. Cartenì, European Transport / European Transport, VII, 19, 32-42, 2001.

[12] The high demand value is given by the fact that the Ljubljana - Zidani Most pair is currently very strong, accounting alone for 39% of the total demand. The two stops are at a relatively short distances from each other (about 1 hour by train), both serve very large population catchments generating daily commuting trips, and Zidani Most is a crossroads station between the route under consideration and the Ljubljana - Maribor - Graz - Vienna route. Thus, the opening of the new service will further increase the demand of an attractive connection, already high in volume, between two large demand pools. This traffic value is in line with the forecasts of the Strategic Infrastructure Development Plan of the Republic of Slovenia presented in section 1.1.

study area. The proposed service shows a great potential in enhancing cross-border connectivity, as can be seen, for instance, from the sharp increase in passenger flows from Trieste and the Slovenian cities.

Table 3 - Estimated railway demand change following the increase in the service's attractiveness. The values express the travel demand change between origins (rows) and destinations (columns) in thousands of passengers per year

	TRIESTE	Pivka	LJUBLJANA	Zidani Most	ZAGREB	Slavonski Brod	Vinkovci	BELGRADE
TRIESTE	-	+224	+363	+40	+6	-	-	-
Pivka	+224	-	+178	+36	+1	-	-	-
LJUBLJANA	+363	+178	-	+606	+5	-	-	+1
Zidani Most	+40	+36	+606	-	+8	-	-	-
ZAGREB	+6	+1	+5	+8	-	+144	+85	+2
Slavonski Brod	-	-	-	-	+144	-	+63	+1
Vinkovci	-	-	-	-	+8	+63	-	+18
BELGRADE	-	-	+1	-	+2	+1	+18	-

Furthermore, it is possible to conclude that the proposed service has the potential to provide positive environmental effects, as it is estimated that there will be around **1.8 million less trips by car** in the study area. The environmental implications of such phenomenon will be further discussed in section 4.3.

2 INFRASTRUCTURAL SUPPLY ANALYSIS

The analysis of the infrastructural status aims to highlight, in the first place, the diversity in railway infrastructural supply among the countries involved and, secondly, to shed light on the most critical sections of the route under consideration (those that may undermine, from a capacity availability point of view, the planning and execution of the service), in order to suggest possible recommendations for service operations.

2.1 Overview of the current state of the infrastructure

The Trieste - Ljubljana - Zagreb - Belgrade route extends a total of about **683km** across four countries, all of which, apart from Serbia, belong to the EU. **Figure 8**, shows that most of the route's extension is concentrated in Slovenia and Croatia. As previously discussed in the introduction, the route fits into the European context by being part of the **Core TEN-T network** in its entirety.

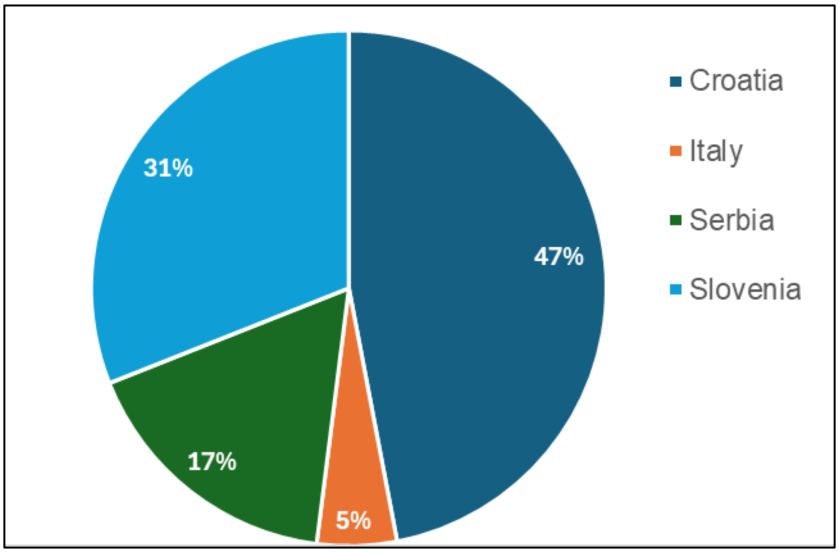

Figure 8 - Share of the route's extension over each country

By cross-referencing transport supply data from the EUSAIR master plan of Transportation[13] with Openrailwaymap[14] data, it is possible to outline the current state of the infrastructure in the different countries along the route. As can be observed in **Figure 9**, there are **3 different signaling systems** (SCMT. ETCS and INDUSI/PZB), **2 different electrification systems** (3kV and 25kV) and, finally, one section (Dugo Selo - Novska) with a single track.

[13] "EUSAIR Transport MasterPlan Volume 5 Rail Transport and related Intermodality", 2021

[14] https://www.openrailwaymap.org/

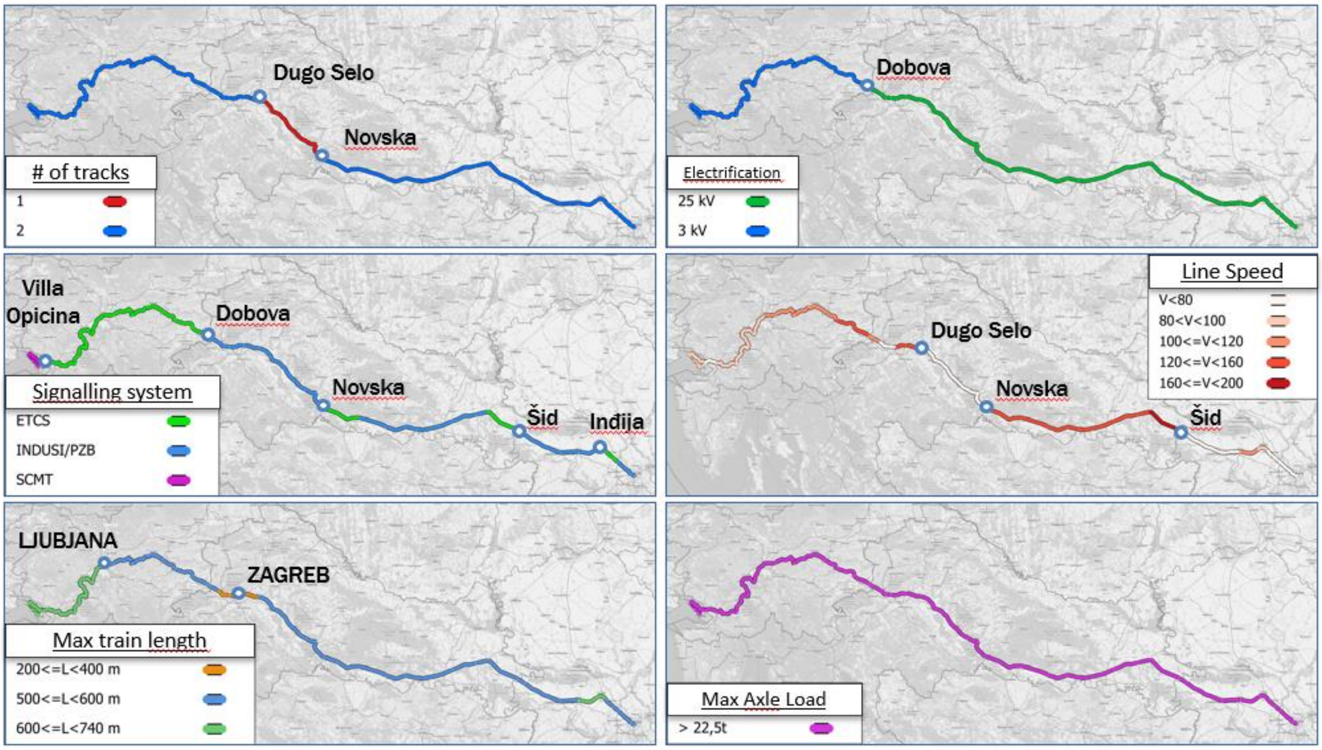

Figure 9 – Characterization of the railway route based on different attributes

Such diversified infrastructure poses a great risk on the provision of a reliable and attractive passenger railway service for two main reasons: **interoperability issues** and **capacity constraints**. In fact, the presence of 3 signalling systems and 2 electrification voltages implies the need of utilizing interoperable rolling stock in order to run the service. Moreover, interoperability does not only increase the complexity of service planning and operations but also increases the risk of operational disruptions, as the presence of different and independent elements in the systems makes it more exposed to interruptions of service. On the other hand, capacity constraints, or infrastructural bottlenecks, are represented by those sections where the route allows a lower number of running trains. Bottlenecks are usually identifiable in single-track sections or in low-speed sections, where for example the geometry of the line or specific types of signalling system or electrification voltage switches limit the maximum speed deliverable by the train.

Again, these two highlighted criticalities can pose a great risk for the proper provision of a reliable and attractive service along the Trieste – Ljubljana – Zagreb-

Belgrade route, as such, they ought to be discussed in order to frame them and to assess their potential for resolution in the context of future development plans.

2.2 Identification of infrastructural bottlenecks

The identification of infrastructural bottlenecks is performed with the goal of identifying the most critical sections of the line, those that could potentially limit the provision of a reliable service, so to later understand whether the national development plans are in line in addressing and resolving these criticalities. Furthermore, pinpointing critical sections is instrumental for assessing current and estimated railway travel times which, as seen in chapter 1, are a key input in assessing current and future demand for railway travel in the region.

The methodological approach for the identification of bottlenecks is based on a multi-criteria assessment of the infrastructure's characteristics. The more a route section features elements that contribute to capacity constraints (i.e. single-track sections, change in signalling systems, change in voltage tensions, line speed reduction, etc.) the higher the **risk for a bottleneck** to be present in that section. The analysis is carried out in both directions.

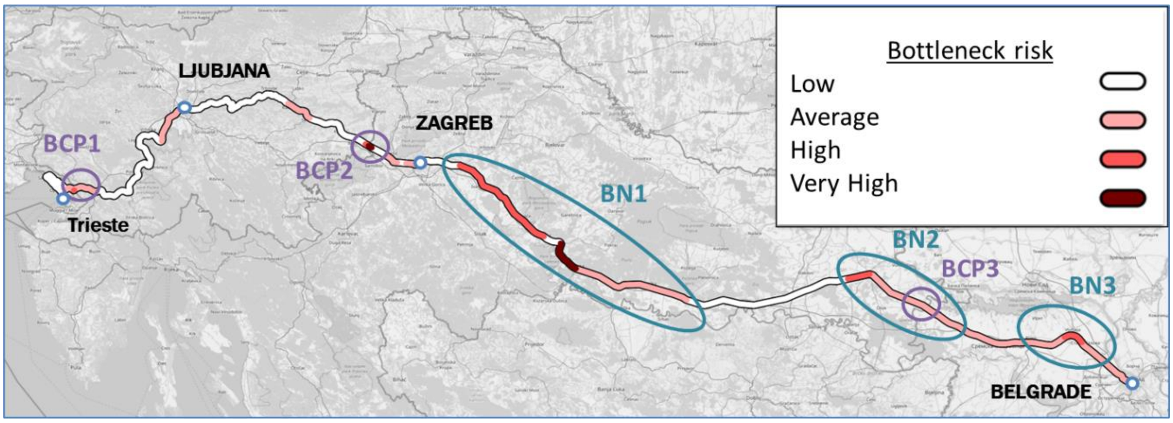

Figure 10 - Bottlenecks risk along the route

Figure 10 shows the results of the analysis conducted on bottleneck risk assessment along the route. The results highlight several critical sections, such as:

- **Italy - Slovenia border (BCP1)**: change of signalling system (from SCMT to ETCS) and track curvature radii limit speed to 50 km/h;
- **Slovenia - Croatia border (BCP2)**: change of signalling system (from ETCS to INDUSI/PZB) and voltage from 3kV to 25kV at the Dobova station facility limit speed to 30 km/h, even for passing trains;
- **Dugo Selo - Novska - Batrina (BN1)**: the section is characterized by the presence of a **single-track** section and alternating INDUSI/PZB and ETCS signalling systems. Speed is limited between 40 and 70 km/h;
- **Ivankovo - Tovarnik (BN2)** and **Croatia - Serbia border (BCP3)**: as with the BN1 bottleneck, there is alternation between the two signalling systems, as well as very limited speeds at the Vinkovci urban node.
- **Belgrade - Stara Pazova - Šid (BN3)**: the alternation between signalling systems and the low level of maintenance have caused line speeds to be limited to a maximum of 50 km/h in some sections.

As expectable the most critical sections are the **Border-Crossing Points (BCPs)**, as well as the **Dugo Selo – Novska section**, the only single-track section of the whole route. Thus, for the purpose of increasing the attractiveness of railway services over the route, as well as promoting cross-border connectivity, it is necessary that infrastructure development plans address these criticalities.

It is also worth mentioning that, in addition to infrastructure limitations, there are also capacity constraints along the route due to track occupancy by **freight trains**, whose demand in the region is increasing.

2.3 Identification of rolling stock criticalities

As introduced in the previous sections, a key obstacle for the delivery of attractive cross-border railway services is the issue of interoperability. The diversity in the route's signalling and electrification systems implies that the service should be implemented with a train towed by a **multi-voltage, multi-system locomotive** in order to ensure interoperability and, given the few stops and long distances, greater economies of scale and energy efficiency than an Electric Multiple Unit (EMU) train. In addition, the organization of convoys with a locomotive allows for increased resilience of the service in the event of a breakdown, as locomotive replacements can be done to continue service.

3 TRANSPORT SERVICE SUPPLY ANALYSIS

In this section the study analyses the current availability of transportation services along the route, with the purpose of highlighting how railway service place themselves in the market with respect to the competition represented by other modes of collective transportation. Additionally, railway services are simulated, so to analyse the level of accessibility that they are able to provide the user with. The simulations are performed on currently available railway services and on the proposed long-distance Trieste to Belgrade service, in the conditions of upgraded infrastructure, whose development plans are introduced in subsequent chapter 4.

The information is extracted from common trip-planning websites (i.e. *Trainline, Rome2Rio*), as well as from the transport operators' websites (i.e. *Trenitalia, ÖBB, Slovenske Zeleznice, Hrvatske željeznice, Železnice Srbije, FlixBus, BlaBlaCar, GoOpti)* and the accessibility simulations are run on a macro national transportation model built on the commercial software *PTV Visum* for transportation simulation.

3.1 Available railways services along the route

Cross-border passenger rail services along the route (**Figure 11**) are currently **limited** (June 2024) to connecting some major cities along the corridor, specifically the Trieste-Ljubljana service, operated by *Trenitalia* and *ÖBB*, and the Ljubljana-Zagreb connection, operated by the Slovenian (*SŽ*) and Croatian (*HŽPP*) railways. Connections between Belgrade and the rest of the corridor, namely Zagreb, were suspended in 2020 due to COVID-19 and have not yet resumed.

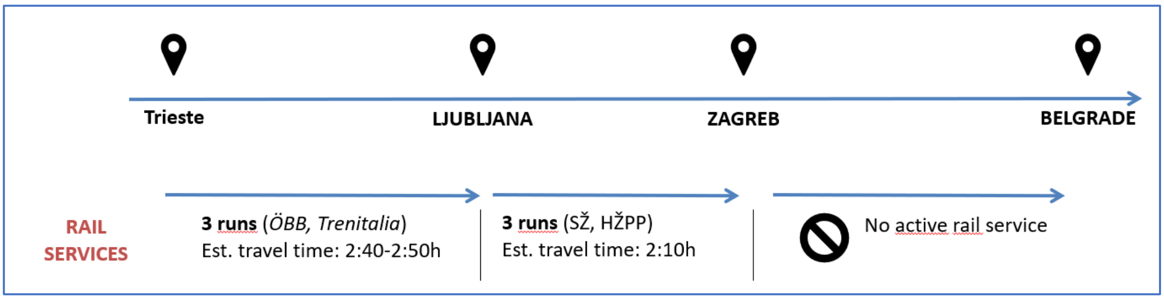

Figure 11 - Railway services along the route (from West to East; the same number of daily runs and the same travel times are available in the opposite direction)

3.2 Other transport services along the route

The analysis of other collective transportation services along the route shows the presence of a relatively frequent long-distance bus service (operated by international operators such as *Flixbus* and *BlaBlaCar Bus*), which provide shorter travel times (e.g. a bus from Trieste to Ljubljana takes 1h to 1h20min less than the train) or cover connections that would otherwise be non-existent with the train (i.e. Zagreb-Belgrade). In addition, there are other mass transit services operating in the study area. As an example, *GoOpti* provides an on-demand shuttle service designed to connect airports in the area with major population centers.

The performances of the available cross-border rail services are constrained by the state of the infrastructure, forcing lower speeds, thus making **rail travel times less competitive than the private car and bus services**. Furthermore, the rich supply of alternative modes of transportation represents a very competitive mix: the user has at his or her disposal long-distance bus services with often more advantageous travel times and fares. This fact inevitably highlights the necessity to design faster and more frequent railway services in order to be a more attractive and cost-effective solution than the others.

3.3 Accessibility analysis

By means of a commercial simulation software (i.e. *PTV Visum*), simulations on the level of accessibility deliverable by the current and planned supply of railway services is performed. Precisely, in the first place, railway catchment areas from available services are calculated in order to highlight the current (***AS IS***) level of railway accessibility to the main urban centres of the line (Trieste, Ljubljana, Zagreb and Belgrade), then both the planned infrastructural upgrades (whose detailed plans will be introduced in the following chapter) and service operations are run into the simulation software, with the purpose of extracting the travel time reductions achievable by the combined effect of the two (***TO BE***).

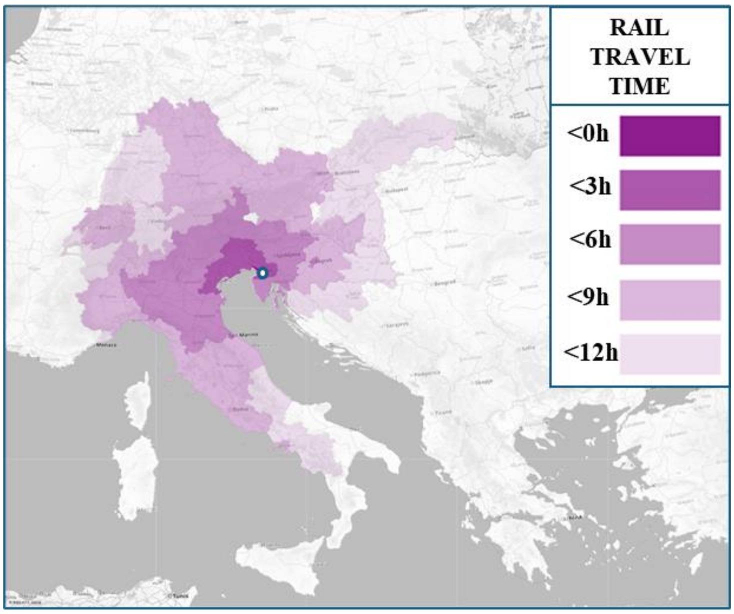

Figure 12 – Current levels of railway accessibility from Trieste (AS IS)

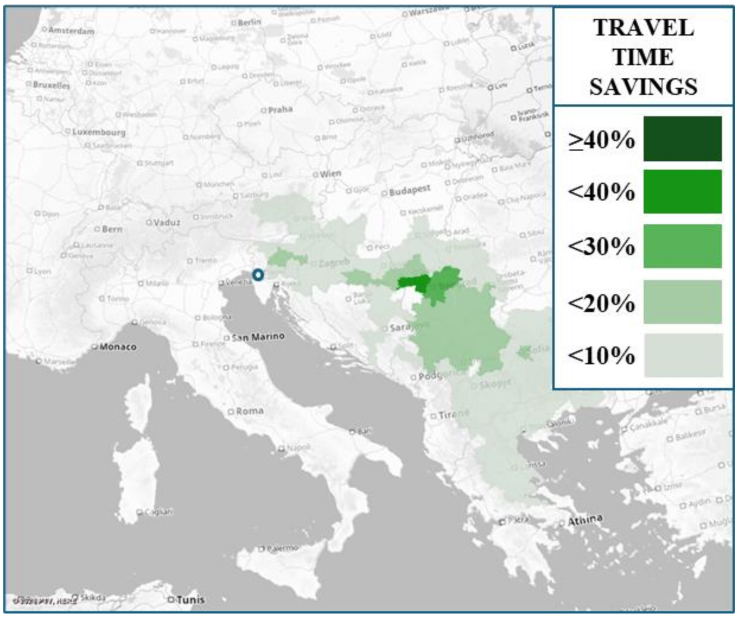

Figure 13 - Estimated railway travel time reductions from Trieste following planned infrastructural investments and the opening of the proposed service (TO BE)

At the current state (**Figure 12**), **Trieste** is experiencing relatively high levels of railway accessibility compared to the other main urban centres of the study area. Towards the West, Trieste is well connected to the rest of the Northern Italy, especially with Veneto, Lombardy and the Emilia-Romagna regions thanks to the availability of **high-speed railway services**. Rome and Naples are reachable via high-speed rail too within a reasonable yet higher travel time. On the other hand, for what concerns cross-border connectivity, the city of Trieste displays good accessibility levels with respect to Switzerland, South Germany, Slovenia and Zagreb. Serbia, and the rest of the Western Balkans' territory remains inaccessible by rail. The infrastructural and service upgrades along the Trieste – Ljubljana – Zagreb – Belgrade line have in fact the potential to reconnect the city of Trieste with this portion of the Balkan Peninsula (**Figure 13**): said development is estimated to greatly improve achievable mobility in the area by rail, allowing for faster connections to the capital cities along the line. Strong accessibility improvements are indeed predicted for what concerns the connections with Ljubljana, Zagreb and Belgrade. Additionally, the route's boosting will allow for faster connections even with the rest of Serbia, Macedonia and northern Greece.

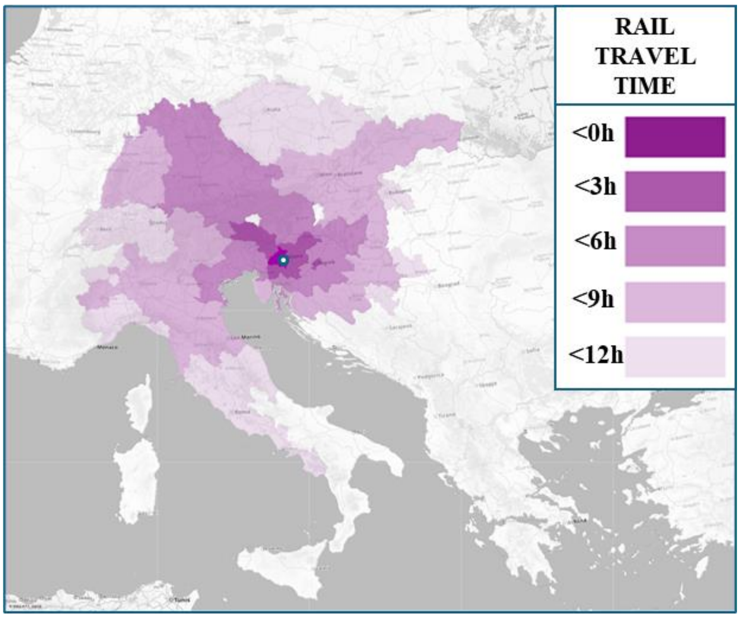

Figure 14 - Current levels of railway accessibility from Ljubljana (AS IS)

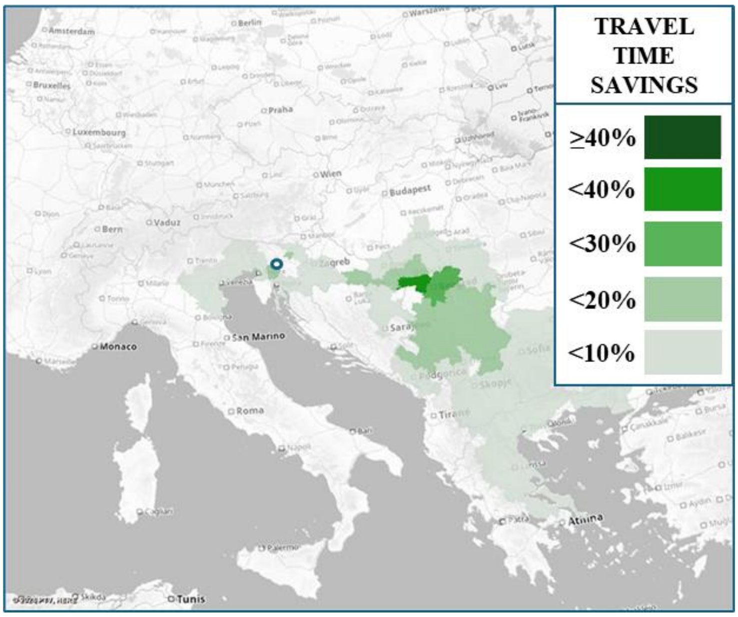

Figure 15 - Estimated railway travel time reductions from Ljubljana following planned infrastructural investments and the opening of the proposed service (TO BE)

The city of **Ljubljana** is situated in a **strategic crossroad location** between the Western Balkans, Central Europe, the Alps and Italy. The benefit of this positioning is also reflected in railway accessibility levels (**Figure 14**), as the city shows a great degree of potential mobility by train in these areas. In fact, from Ljubljana it is possible to access Northern Italy with relative ease, as well as travelling across Slovenia and western inland Croatia. Indeed, railway connections between the two capitals, as discussed in the previous sections, take only about 2 hours. Additionally, travelling to southern Germany, Hungary and Austria is relatively manageable. A different picture emerges when analyzing cross-border connections to the rest of the Western Balkans, as Serbia, Bosnia and Montenegro are not deemed accessible from the territory of Ljubljana. Though, the analysis shows that infrastructural development in the area might bring great benefits to railway accessibility to and from the city (**Figure 15**). As per the city of Trieste, the speeding-up of the route would induce shorter travel times to reach Zagreb, Belgrade and the rest of the Western Balkans. Moreover, facilitating cross-border connections with Italy may foster accessibility improvements to the North-East of the country.

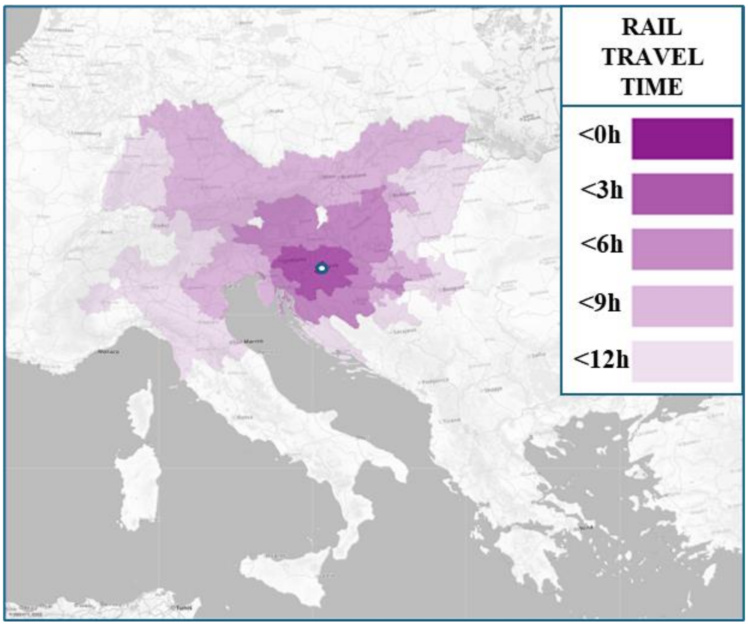

Figure 16 - Current levels of railway accessibility from Zagreb (AS IS)

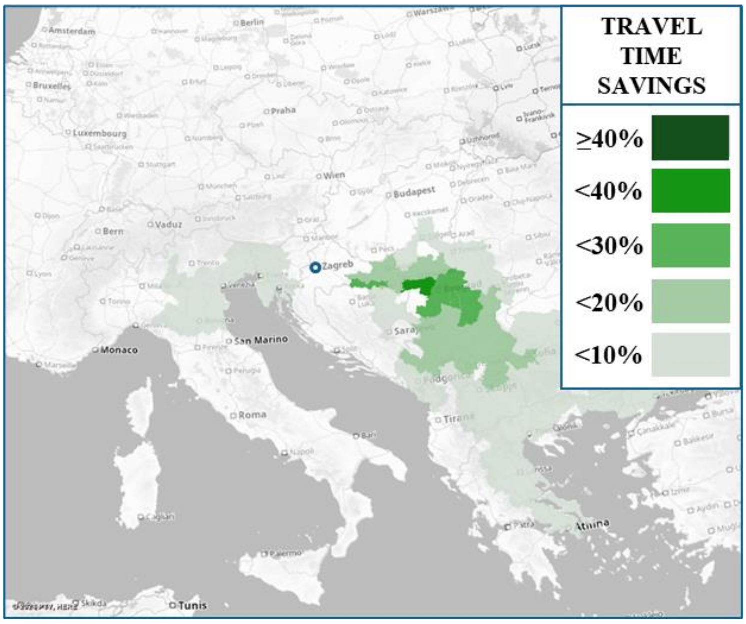

Figure 17 - Estimated railway travel time reductions from Zagreb following planned infrastructural investments and the opening of the proposed service (TO BE)

The accessibility analysis on the city of **Zagreb** (**Figure 16**) highlights a great degree of railway mobility inside the country and towards Slovenia. The two countries (and capitals), being relatively close to each other, benefit from their geographical location when it comes to transport connectivity. Accessibility to Italy is hindered by the considerable distance between Zagreb and Trieste, yet it still remains higher compared to accessibility to Serbia. On the other hand, cross-border connections to Hungary and Austria are relatively attractive, considering that relatively short distance between with the two countries. A noteworthy remark should be done when analysing railway accessibility inside the Croatian boundaries: the **Dugo Selo – Novska section** of the national railway network, with its low permissible speed, reveals itself as a substantial obstacle in connecting the country's capital to the eastern part of Croatia. Again, infrastructural development (**Figure 17**) is shown to have a potential for improving this critical section of the route, allowing for faster connections between Zagreb, the rest of the country, Serbia and the Western Balkans.

Belgrade, when compared to the other urban centres of the studied route, finds itself more isolated at the regional scale (**Figure 18**). The catchment area drawn on the Serbian capital highlights how the cross-border connectivity is hindered, and accessibility remains limited to the national scale (with the only exception of the connection with Bar, Montenegro). This fact is easily explainable by the fact that several development projects from the Serbian Railways, specifically targeted at addressing this issue, are currently undergoing, thus the infrastructure is closed temporarily closed to traffic. For instance, the modernization works of the **Belgrade – Budapest line** are being carried out at the time of development of this study (June 2024)[15], precisely in the Novi Sad – Subotica section[16], and are expected to be completed in the upcoming months. The opening of the line will greatly enhance railway accessibility within the national borders, as well as with the neighbouring Hungary. Furthermore, modernization works are planned to start in 2025 on the **Belgrade – Niš railway line** [17], allowing, once complete, for faster travel across the country as well as to Bulgaria and North Macedonia. Though development perspectives for Serbian railway networks look promising, in terms of potential for accessibility improvements, the current state of the infrastructure looks suboptimal, especially when

[15] https://hungarytoday.hu/traffic-on-the-serbian-section-of-the-budapest-belgrade-railway-line-to-start-in-november

[16] https://www.serbianmonitor.com/en/train-from-belgrade-to-the-hungarian-border-in-76-minutes-by-the-year-end/

[17] https://seenews.com/news/serbia-to-start-belgrade-nis-railway-overhaul-in-2025-1245309

taking into consideration cross-border connectivity with Croatia (as highlighted in section 2.2). This issue is also already addressed for by the national government, as it will be shown in the next chapter. Indeed, the development and upgrading of the railway line from Belgrade to the Croatian border, together with all the other development plans along the route will allow for the achievement of great accessibility improvement for the city of Belgrade. Specifically, as shown in **Figure 19**, said upgrade will determine a substantial reduction in travel times between the Serbian capital and the other cities along the route, greatly enhancing the possibility to access the capital cities of the other countries, as well as Trieste. Minor, yet significant, accessibility improvements will naturally be reflected on territories beyond the Trieste – Ljubljana – Zagreb – Belgrade route, such as the Italian peninsula, Austria and Central Europe.

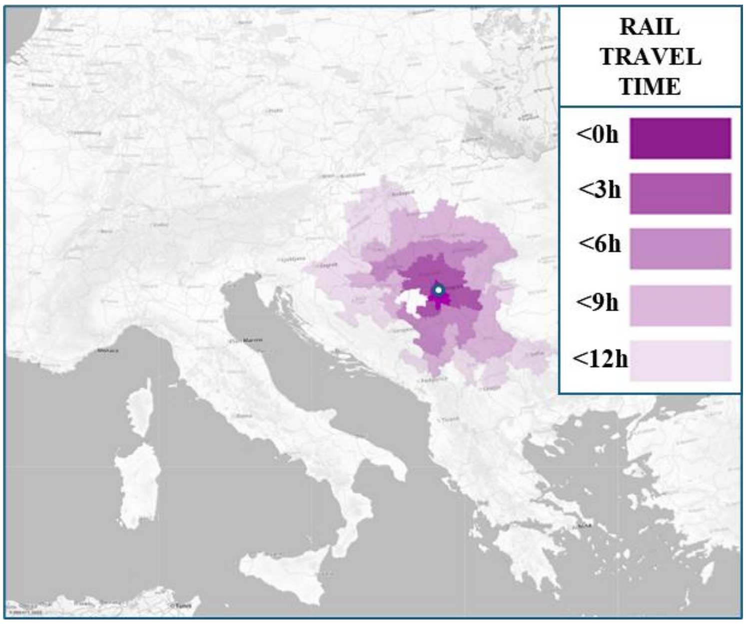

Figure 18 - Current levels of railway accessibility from Belgrade (AS IS)

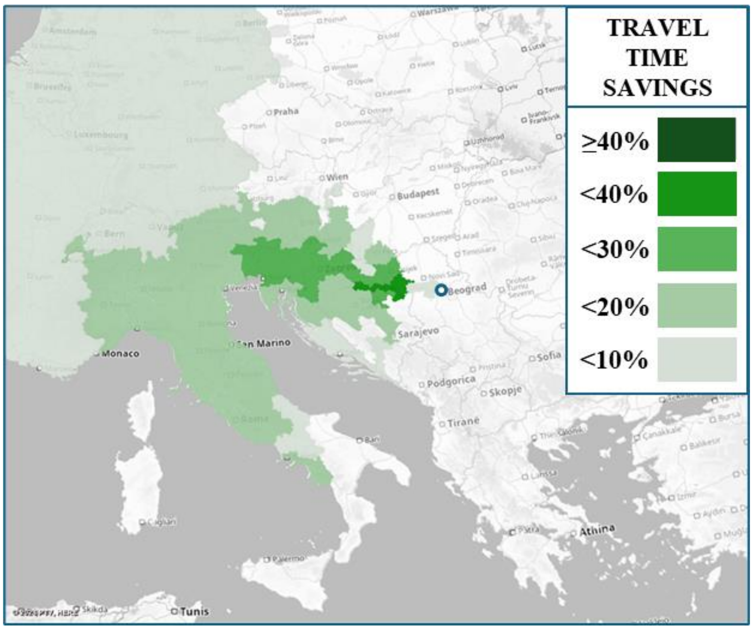

Figure 19 - Estimated railway travel time reductions from Belgrade following planned infrastructural investments and the opening of the proposed service (TO BE)

4 DEVELOPMENT OPPORTUNITIES

As introduced in the previous chapter, development projects are planned along the route and show a great potential for enhancing national and cross-border accessibility of the main urban centres. In this chapter, these plans will be further discussed in order to conclude whether the infrastructural criticalities highlighted in chapter 2 (i.e. capacity constraints and interoperability issues) are to be addressed for. Furthermore, additional indications for connectivity enhancement are provided, as well as an estimate of the positive environmental impacts arising from the modal shift of the demand for transportation in the area from polluting modes, such as the car, to the railway.

4.1 Analysis of planned investments

By taking into consideration national and supranational infrastructure development plans [18] [19] [20] [21] [22] [23], together with the business and/or strategic plans of national rail infrastructure operators and managers [24] [25], it is possible to get an overview of planned interventions along the Trieste – Ljubljana – Zagreb – Belgrade route.

These are the main planned project interventions:

- In **Italy**, *RFI* plans to phase out the SCMT and in favor of ETCS by 2029 in the **Trieste Centrale - Villa Opicina section**. In addition, localized velocity and capacity enhancements are planned.
- In **Slovenia**, interventions are planned to upgrade and adapt the infrastructure to the standards of the Core TEN-T network between Divaca and Sezana, between Koper and Ljubljana, and between Zidani Most and Dobova. Some projects are in the executive/final design phase, while others have seen the completion of some of the relevant functional lots. In addition, Slovenian Railways (*Slovenske železnice*) is planning to expand Ljubljana's main station in order to increase its capacity and induce more railway traffic.
- In **Croatia**, the national infrastructural manager (*HŽ Infrastruktura*) is planning to deploy the second track and upgrade the **Dugo Selo - Novska section**, which, as already seen, probably represents the most critical section of the entire route. Works are scheduled for completion in **2028**. Additionally, there are also

[18] "EUSAIR Master Plan of Transport - Volume 5 Rail Transport and related Intermodality", 2021

[19] "*Annual Progress Report 2022*", Western Balkans Investment Framework (WBIF), 2023

[20] "Transport Development Strategy of the Republic of Slovenia Until 2030", Ministry of Infrastructure – Republic of Slovenia, 2017

[21] "Resolution on the National Programme for the Development of Transport in the Republic of Slovenia until 2030", Ministry of Infrastructure – Republic of Slovenia, 2016

[22] "*Network Statement 2025*", INFRASTRUCTURE OF SERBIAN RAILWAYS JSC, 2024

[23] "krajsamo razdalje - *Finančna perspektiva 2021–2027*", Ministry of Infrastructure – Republic of Slovenia

[24] "*Il Piano commerciale 2024 -2028*", Rete Ferroviaria Italiana S.p.a., 2024

[25] "Our EU Projects", HŽ Infrastruktura

plans in place to upgrade Okucani – Vinkovci section (for which the feasibility assessment is scheduled to be completed by the end of 2024), and to enhance capacity and modernize the Zagreb railway node.

- In **Serbia**, along the Belgrade-Sid section, extraordinary maintenance and technological upgrades are planned, partially completed between Belgrade and Stara Pazova, with completion scheduled for 2028.

In conclusion, it can be stated that, from a preliminary analysis, **all bottlenecks identified in the transportation supply analysis** (see chapter 2) **are being addressed**.

It is necessary to emphasize that, during the implementation phase, these interventions are expected to have an impact the infrastructure's capacity and, consequently, on the service provided. This factor could be particularly critical in the Dugo Selo–Novska section, where the presence of a single track will likely require rerouting the service along parallel lines, inevitably increasing travel times.

Despite the initial drawbacks associated to the construction works, the infrastructural development will provide substantial improvements in the networks' performances: **travel times savings** (**Table 2**), for instance, will allow for improved accessibility and enhanced cross-border connectivity across the Western Balkans, as shown in the previous chapter. Additionally, **capacity is expected to increase** along the whole route, allowing for the resolution of critical infrastructural bottlenecks; among them, the Dugo Selo – Novska section doubling will certainly represent the greatest positive differential in the route's capacity.

Lastly, the deployment of the ERTMS signalling system is expected to solve major **interoperability** concerns for cross-border railway services. In fact, the presence of a standardized system is expected to produce several benefits to the route's operations: first, the organization of the service is not going to be strictly bound to a multi-system locomotive, second, ERTMS allows for higher capacities on railway links, compared to outdated national signalling systems, thus creating a potential for higher traffic.

Table 2 - Estimated travel times following the opening of the service and the infrastructural upgrades planned along the route

	TRIESTE	LJUBLJANA	ZAGREB	BELGRADE
TRIESTE		2h	3h 50min	10h
LJUBLJANA	2h		1h 50min	8h
ZAGREB	3h 50min	1h 50min		6h 15min
BELGRADE	10h	8h	6h 15 min	

4.2 Possible solutions for rail connectivity improvement

The analysis presented above highlights how infrastructural development of the railway infrastructure is going in the right direction of solving critical bottlenecks and deploying a standardized signalling system, granting interoperability of rolling stock for cross-border services. Other than pursuing these development plans as intended, cross-border services that can improve rail connectivity improvements, foster economic activity and exchanges, must be supported by **proper cooperation and coordination** between the involved stakeholders. Specifically, it is crucial for the proposed service's success that national infrastructural managers and railway operators define a common vision, as well as objectives and a roadmap not only for the implementation of the proposed service, but also for the further development of cross-border solutions. Synergies between the involved players is essential to foster proper service plannings as well as funding. Since the service along the route would improve regional accessibility, and foster economic cooperation across borders, it could qualify for public funding under the **Public Service Obligations (PSOs)**, subject to approval from participating countries (see Regulation 1370/2007 and point 2.1.3 of the the relevant interpretative guidelines [26]).

[26] COMMISSION NOTICE on interpretative guidelines concerning Regulation (EC) No 1370/2007 on public passenger transport services by rail and by road (2023/C 222/01) - https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023XC0626(01)

4.3 Expected environmental impacts

As previously discussed in chapter 1, the launch of passenger rail service between Trieste and Belgrade may generate a modal shift phenomenon in local demand from road transport (cars and buses) to rail. Additionally, due to the increased attractiveness of the service (i.e. the so-called phenomenon of induced demand), it is estimated that there will be a simultaneous generation of new rail demand from users who previously did not travel. The overall effect leads, in the first case, to a reduction in global emissions due to the shift in demand from road modes, which are more polluting than rail, and in the second case, to an increase in global emissions caused by the newly generated trips.

By means of emission factors, it is possible to estimate the impact of the aforementioned dual effect. Specifically, the modal shift of car demand to rail results in a reduction of global CO2eq emission[27]s of approximately 54.11 kt per year. The shift of long-distance bus passenger demand results in a smaller reduction of 2.49 kt per year. Simultaneously, the induced demand on the new rail service will contribute to a relatively minimal increase in emissions of 0.95 kt per year. In fact, it clearly arises that this latter negative contribution is largely offset by the positive effect of the modal shift from road transport. Therefore, overall, the opening of the service in question is estimated to contribute to a reduction in global transport-related emissions in the region of **55.66 kt of CO2 equivalent per year**. This emission reduction is equivalent to avoiding about **1.8 million trips by car per year** in the study area.

[27] CO2 equivalent (CO2eq) is a measure that expresses the global warming potential (GWP) of emitting a given quantity of greenhouse gases into the atmosphere, relative to the GWP of CO2 (for example, the emission of one kg of methane has a global warming impact equivalent to the emission of 28 kg of CO2). It is a measure used to aggregate and standardize the GWP from the emission of a heterogeneous mix of greenhouse gases.

5 PRELIMINARY INDICATIONS ON THE SERVICE OPERATING MODEL

Based on the estimated demand discussed in the chapter 1, it is possible to hypothesize an operating model for the railway line that meets this demand, within the constraints of cost-effectiveness and service feasibility.

The methodology applied for the service model definition involves using an **optimization model** for weekly train pairs, which provide passenger capacity for each OD pair, with the aim of **minimizing operating costs** while **maximizing train occupancy** (**Figure 20**). In other words, the objective function of the line configuration optimization algorithm consists of the sum of the operating costs of each line and the lost revenue for the operator due to any unmet demand. The model takes in input the estimated demand following the opening of the service, as well as rolling stock and infrastructure characteristics. Multiple line configurations are considered, for example: from Trieste to Belgrade (all stops), from Trieste to Belgrade (urban centers only), from Ljubljana to Belgrade (all stops), and so on.

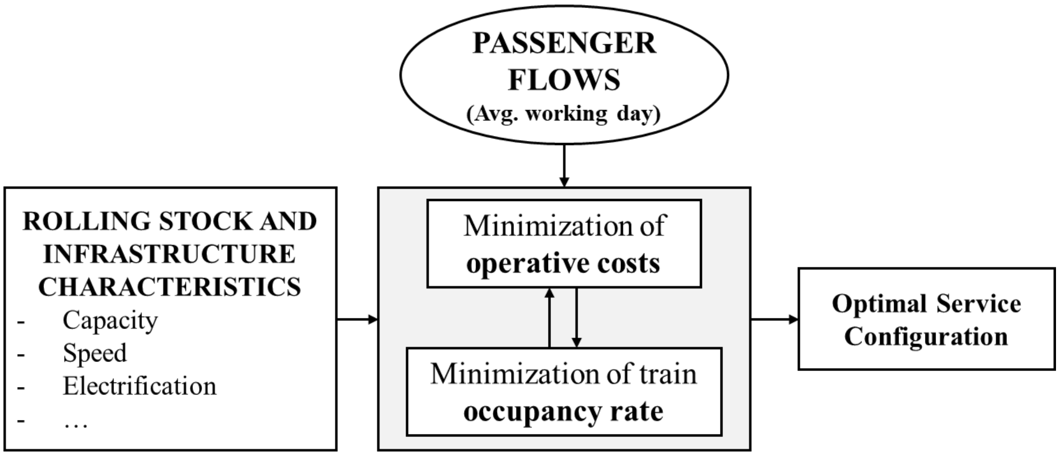

Figure 20 - The optimization model for the service operating model configuration

The results of the optimization model indicate that the most optimal configuration consists of providing **9 daily train pairs**, 6 of which run between Trieste and Zagreb and 3 as between Trieste and Belgrade. As expected, the model adapts to the demand, which is highest on the segment between Trieste and Zagreb. It is estimated that Full operations would require a fleet of **11-14 trains**, delivering approximately **51,000 train-km per week**.

A **phased rollout** recommendation would suggest to initially start operating six daily train pairs between Trieste and Zagreb, with infrastructure upgrades expected to be completed by 2027. Once the Dugo Selo–Novska section is modernized by 2029, the service can extend to Belgrade with three additional daily pairs. However, infrastructure interventions may lead to longer travel times because of construction works, which could reduce the service's attractiveness compared to other modes of transport. Thus, **the service model should be adjusted** based on infrastructure conditions and actual passenger traffic. In the early phases, it is advised to limit the service to Zagreb for better economic sustainability and to gather data to adjust the service accordingly.

Furthermore, given the characteristics of the infrastructure, as discussed in chapter 2.4, it is suggested to organize the service with a train hauled by a multi-voltage and multi-system locomotive to ensure interoperability and, given the few stops and long distances, greater economic and energy efficiency compared to an Electric Multiple Unit (EMU) train. Additionally, using a locomotive-hauled configuration increases service resilience in case of breakdowns, as it allows for replacing the locomotive to continue the service.

CONCLUSIONS

The study examines potential demand and infrastructure requirements for a new rail service along the **Trieste-Ljubljana-Zagreb-Belgrade route**, spanning approximately 680 km across four Countries (Italy, Slovenia, Croatia, Serbia). The study highlights **significant infrastructure issues**, such as single-track sections (i.e. the Dugo Selo – Novska section in Croatia) and heterogeneous signalling and electrification systems, which could limit service capacity and cause delays, simultaneously posing a significant challenge in terms of rolling stock interoperability.

The demand estimation is based on socioeconomic data and considers a catchment area of approximately 6.63 million people. **Current railway demand is limited**, with a predominance of car and bus transport. In fact, international trips account for approximately 260,000 passengers per year, representing 17% of the total demand, with a peak between Ljubljana and -Trieste, with 87,500 passengers per year. A substantial increase is estimated following the opening of the new service and the infrastructural upgrades as planned by national strategic development plans. This dual effect is projected to induce a **4% modal shift** from cars and buses to rail. Additionally, the analyses show that the modal shift phenomenon may lead to a significant reduction in CO_2 emissions, positively impacting the environment.

Based on an optimization network design model aiming at minimizing operational costs and maximizing train occupancy, **9 daily train pairs** (i.e. 6 pairs between Trieste and Zagreb and 3 between Trieste and Belgrade) have been identified as an optimal solution: to be progressively implemented based on on-going infrastructure achievements.

The analyses proves that the launch of the cross-border rail service along the route represents a significant **opportunity for decarbonizing long-distance transport** while simultaneously improving the accessibility of the areas it traverses. This service would **promote economic and social cooperation**, as well as **cohesion and connectivity** in the region. It is worth mentioning that the service, given its underlined potential benefits, could qualify for public funding under the **Public Service Obligations (PSOs)**, subject to approval from participating countries (see Regulation 1370/2007 and the relevant point 2.1.3 of the interpretative guidelines).

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