Rail Ports as Nodal Gateways in the Sea – Land Connections and the Challenges of Sustainable Globalized Markets: The Case of Adriafer and the Port of Trieste

Giuseppe Borruso[1(✉)], Maurizio Cociancich[2], Andrea Gallo[1], Alice Scotti[2], Francesca Sinatra[1], Luca Toneatti[1], and Matteo Tredesini[2]

[1] University of Trieste, Via A.Valerio 4/1, 34127 Trieste (TS), Italy
giuseppe.borruso@deams.units.it, {andrea.gallo3, francesca.sinatra}@phd.units.it, luca.toneatti@dia.units.it
[2] Adriafer, Magazzino n.53 snc, Porto Franco Nuovo, 34127 Trieste, Italy
{mcociancich,ascotti,mtredesini}@adriafer.com

Abstract. In recent years rail ports gained a particular attention due to the environmental benefits connected to the freight movement by train of cargo embarked and disembarked from the sea leg. A modal shift from road to rail in fact is more and more considered important in reducing the logistic and transport carbon footprint, complying with the carbon reduction as well as a with many countries' regulations that limit their crossing by road freight transport to reduce the transport-related negative externalities. Countries as Austria and Switzerland in the European continent, in fact, have been introducing road limitations to lorries for years, incentivizing the modal shift and the quest for more sustainable transport.

Shunting and rail operators are key elements in such scenario, easing the sea-land connections and helping a port to enhance and extend its internal connections. The commitment towards the development of cleaner means and ways of fostering rail transport and reducing carbon footprint appears also relevant. On the other side, the reinforcement of rail connections can help also reducing both the road connections, but also allowing relying more on well-connected rail ports instead of choosing different port destinations. Until recent years, in fact, with reference to the European ranges, Northern range ports, although farther to Central Europe markets in terms of maritime distances, won a competition with Mediterranean (i.e., Tyrrenian and Adriatic) ports in attracting freight traffics, due to a higher level of efficiency and efficacy in freight movement and directing to inland destinations. The increase in efficiency of Mediterranean, and Adriatic ports in particular, due to their closer proximity to South-Eastern Asia – Mediterranean routes, the is however making the Mediterranean Ranges gain higher shares of freight movements and importance.

The paper is the result of the joint work of the authors. However, Giuseppe Borruso wrote Sects. 1 and 6, Maurizio Cociancich, Alice Scotti and Matteo Tredesini wrote the Sect. 4.2, Luca Toneatti wrote the Sect. 2.2, Francesca Sinatra wrote the Sect. 2.3 while Andrea Gallo wrote Sects. 2, 2.1, 3, 4.3, and 5. The Sect. 4.1 is the result of a joint effort between Andrea Gallo and Giuseppe Borruso.

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2023
O. Gervasi et al. (Eds.): ICCSA 2023 Workshops, LNCS 14110, pp. 425–441, 2023.
https://doi.org/10.1007/978-3-031-37123-3_30

Little knowledge, however, is still available in terms of the rail routes that can help in reinforcing the inland connections with the destination markets. Indeed, the dynamics of railway freight flows, the major service operators and the aspect related to the final destinations of goods are still poorly explained. Scopes of the present research is therefore that of trying to concretely observe and define the railway connections of the in such a way exploring the existing and potential routes that can be put into the system to increase a – sustainable - market potential and range.

Keywords: Rail Transport · Gateway Ports · Hinterland connection

1 Introduction

The recent changes occurred in intermodal transport and logistics have re-established a considerable importance of gateway ports in enhancing the global flow of goods, commodities and, more in general, value, over global and regional networks [1]. The globalization of supply chain has led to the need for a tight integration of the different logistic segments through their connecting nodes, in order to reduce delays in deliveries, at the same time minimizing warehouse stocks [2].

In time, this has led, first, to the development of the MTO, the Multimodal Transport Operator, a figure capable of managing the best combination of transport means and routes to optimize freight size, times and journeys, and, on the other side and as a consequence, a renewed interest for multi-scope transport nodes where logistics operations are more efficiently carried on [3]. In most recent years an interest towards a renewed interest in gateway nodes, gateway ports in particular, rose, together with the development of dry-ports and inland terminals, as privileged structures where non-strictly port operations are carried on, but, on the contrary, where warehousing, logistics and modal combinations are performed [4].

Rail transport is, in this sense, gaining a paramount importance on managing the medium-to-long range connections, after years of a role squeezed between the increased distances travelled by road transport on the short-to-medium range routes on one side, and maritime transport on the long-to-medium routes on the other side, after years of decline in market shares- this thanks to a growing interest towards intermodality and multimodality, the spreading of different forms of unitized transport, and, in particular, the tighter regulations and social acceptance leading towards forms of more sustainable transport. The transport sector witnessed the raise of an important attention towards environmental issues, particularly since the Nineties of the past century, after 1992 Rio Conference, and the consideration of negative externalities has become of paramount importance when evaluating transport performances [5].

When related to freight transport this led, particularly, to the need to think about alternative transport means along some routes, as, in the case of the European continent, those crossing the Alps and, also, states as Switzerland and Austria, very often just transit areas rather than destinations for traffic flows.

Such a process reinforced the importance of the railway network and operations servicing ports and port-regions and to connect farther port regions in global as well

as regional chained networks. The land leg of transport in fact has become more and more connected and vital in supporting the last mile of freight distribution, de facto supporting the maritime component in its geo-economical and geopolitical settings of the international supply chain connections. An increased competition has also risen among rail freight operators, allowing a real market to be set and increasing the choices available to operators in performing rail operations [2].

The widespread adoption of ICT has, nonetheless, increased the performance of operations, thanks to the digitalization of processes and administrative, custom and fiscal aspects, as well as tracking and tracing of many freight components, vehicles and means, thus allowing an increase of the optimization of transport in all of its components. This, however, still holds a drawback in understanding the spatial component and balances of transport systems, particularly in terms of understanding the spatial configuration of the final destinations of journeys and, therefore, goods and freights moved. The real configuration of the port and gateways' hinterlands, as well as a deep understanding of the main to-and-fro of the product categories still appears little known, if not just estimated. Similarly, the planning of the 'best route' or 'shortest path', in economical or in time terms, for freight still remains difficult, if compared to the tools and solutions available to passengers' transport, given a certain widespread lack of the real availability of suitable transport facilities and nodes, as well as suitable tracks for the different cargo and freight types.

In such a sense, there is a need to improve the analytical instruments and methods for tackling this issue and to perform better transport planning for an optimal and environmentally friendly logistic and transport performance.

2 Materials

This section focuses on the definition of the hinterland of a port, particularly considered from the rail system's point of view. This concept is particularly important for understanding the extent of the existing and, more interestingly, the foreseeable connections that can be set. The hinterland can be defined as the area surrounding a port that is directly influenced by the port's operations, in terms of both freight flows and economic activities, or, in similar terms, its port's catchment area. The hinterland of a port can varies in size, depending on factors such as the size of the port, the types of cargo handled, and the transportation infrastructure connecting the port to the surrounding regions. Its delimitation needs to analyze the economic characteristics and performances of the surrounding regions, including the most efficient and effective ways to move goods to and from the port, and the relationship with the port. A thorough identification of a port's hinterland is essential for effective transportation planning and for the sustainable growth and strategic development of the port and the surrounding regions. In the analysis of port hinterlands, however, it must be considered that information regarding the origin and final destination of different freight in transit is usually little known. This, together with the different transport dynamics such as intermediate rail yards, the train structure operations, and the different logistics operators operating the train, represent a system that is as complex as it is poorly identified.

This paragraph will address different considerations about the port's hinterland, the environmental consideration related to the railway transport and about the main

actors operating into the multimodal transport. The different aspects covered represent the useful methodological tools to be able to assess the potential drivers of strategic development for a rail port related to unreached markets or in strengthening certain strategic routes.

2.1 Rail Transport in the Dynamics of Intermodal Transport and Sea/Land Relationship

Transportation is an activity that by definition is articulated in its spatial dimension, thus combining various geographic and economic aspects [1]. Logistics infrastructure, nodes and networks play an extremely central role in space and form the basis of a complex spatial [6] system. The development of transport and logistics networks that are increasingly articulated and distributed in their spatial dimension sees the different transport systems integrated into the three geographical dimensions: global, regional and local [2]. The global dimension, in particular, reflects the dynamics of transportation systems on world trade, in which there are key nodes that take on the role of regional gateways (sea-land interfaces) or international hubs [4], which in turn are key nodes in relations at the regional and local scales. Therefore, gateways will find their geographic location in contexts characterized by a strong development of economic activity within their hinterland [7], assuming the role of logistics "clusters," linking maritime and land trade flows through the implementation of an infrastructure that is articulated from the waterfront areas to the inner port areas [8]. Given the current productive environment, articulated along extremely branched production chains, an efficient and well-structured transportation system is a factor of strategic importance, linking different modes of transport (maritime rail and road) and offering intermodal services for the distribution of goods [9].

The growth in global traffic has resulted in the reorganization of freight mobility processes between ports and their hinterlands, leading to rail transport playing a critical role in territorial distribution [10, 11]. This has created an opportunity for horizontal modal integration, with ports serving as modal shift hubs [1]. The gateway inner port areas have logistics infrastructure, such as dry ports or inland terminals, that work as distribution centers for goods in transit by different way of transport [12, 13]. The port function is expanding towards the hinterland and contributing to the creation of a regional distribution network through sea-road transport relationships, leading to a polycentric structure [14]. Rail connections with inland terminals have become crucial for the attractiveness of ports, as they provide benefits like reduced urban port traffic congestion [15], lower transportation costs, faster speed in ports, and lower environmental impact [16]. However, there are also downsides, such as the need for more detailed transportation planning, dependence on economies of scale, higher costs, and longer delivery times over short distances. Creating a well-developed hinterland based on rail connections has the potential to strengthen the maritime transfer segment, increase logistics efficiency, and produce a more sustainable global transport chain [17]. Intermodal rail-water transportation is recognized as one of the transportation methods of the future to be efficient, economical and environmentally friendly [18]. Gateway ports are increasingly becoming multimodal hubs in which rail transport is expected to play a strategic role [6]. Efficient rail operations and connections to and from ports, as well as within the port and directly

on the storage areas of the piers, are essential to maximize the use of rail as a sustainable transportation mode.

2.2 The Environmental Impact of the Rail Transportation System

The increasing attention to environmental problems brought to deepen the studies on the primary sources of the different pollutants and emissions to organize and define future actions that must be taken to reduce among others the carbon footprint of human activities. Among these sources, the transport sector plays a central role in CO_2 emissions [19, 20], with different contributions coming from different sectors: maritime, land and air. Every one of these sectors must cope with different challenges to reduce the CO_2 emissions, generated not only by the main engines. For example, cruise ships besides the emissions of the main power system, whose required power level represents the main obstacle, must also reduce the impact of the waste management system [21, 22]. Road transport development follows in each Country different strategies and timing: the European Union's efforts seem to highly push towards an electric conversion of all vehicles starting from the private ones, whilst other Nations have a more conservative approach. Road freight transport is the main responsible for carbon emissions among other transport [23] and several research investigate it, looking for viable innovations to reduce the carbon emission. Mulholland et al. exploit the International Agency's Mobility Model to evaluate temporary actions such as increasing vehicle efficiency, improving logistics, and shifting to less pollutant fuel [24].

In the rail sector, the evolution to zero emissions transport grid is far away from commercial availability, since the innovative technologies, which should substitute internal combustion engines, are not yet implemented and mature to be normally adopted [25]. Electric rail vehicles represent the most common technology to exploit for environmentally friendly and zero-emissions transport, but they need either the electrification of the net, which implies huge economic investment, or the adoption of new systems, such as fuel cells and storage batteries. Since worldwide only about one-quarter of rail lines are electrified [26], several research studied the integration between electrified lines and fuel cells technologies as a viable path to lower the CO_2 emissions: Fedele et al. highlight the role of onboard storage devices integration in rail vehicles to reduce CO_2 emissions, also if "rail is already an efficient and low-polluting transportation sector" [26]. Zenith et al. focused on the economic feasibility of railways electrification with overhead lines, hydrogen, and batteries, highlighting the relevant role played by the battery technology [26]. The research investigates the influence of the costs of the different systems/technologies, as well as the weight of the usage factor of the investigated path: fuel cell and battery technologies should be competitive within the next 10 years. Within this framework, the design process of innovative solutions in the rail sector must carefully consider the path to determine the actual power requirement and to size all the system components, such as batteries, fuel cells, and electric motors [28].

To assess the environmental performances of such integrated systems, which exploit overhead electrified lines and fuel cells, also the production procedure of the hydrogen must be evaluated, but the implementation of the system in a network with a fixed centre, like that used in port operations, allows to foresee good chances for green hydrogen to be exploited since the good storage logistics.

2.3 The Economical Actors Involved in Rail Freight Transport

Rail transport refers to vehicular traffic on guide tracks. Over the years, railways were the most common guideways, but recently thanks to technological developments, monorails and magnetic levitation trains are also available. [2].

A railway company is a public or private enterprise providing rail freight and/or passenger transportation services. Enterprises providing exclusively passenger transport services on metro, tram and/or light rail lines are excluded [29]. Moreover, besides railway companies are public or private they can also vary in size, scope and specialization.

Railway companies shall operate and maintain their trains, railway stations and the infrastructure they need to provide rail transport services. They can also offer support services such as ticket booking, passenger assistance and cargo management.

In many countries, the railway industry is regulated by the government to ensure passenger safety and quality of services. They must comply with government rules and regulations, such as those pertaining to the maintenance of rail infrastructure, the safety of passengers and workers, and the management of the environment.

Also, different railway enterprises can work together to offer integrated transport services, for example through infrastructure sharing agreements, or they can compete with each other to provide better and efficient transport services [30]. Railways companies can provide multimodal transportation services. A Multimodal transport takes place through the use of containers, semi-trailers, and others. Such transport methods are classified as secondary in order to distinguish them from primary ones such as lorry, wagon or ship.

In this scenario, it is possible to identify different stakeholders which are involved in rail transportation: multiservice transport operator (MTO) and logistic operator (LO) [31]. A multimodal transport operator is an intermediary that organises freight transport using multiple modes of transport, such as the combination of rail, road, sea and/or air transport. MTO coordinates all the transport of goods, dealing with all necessary logistics operations, such as loading and unloading of goods, temporary storage, shipping documentation and coordination of transport.

The definition of the Multiservice transport operator (MTO) is referred to the Geneva Convention of 1980 which indicates it as "a person who concludes a multimodal transport contract on his behalf or through the mediation of a third party and who does not act as the agent or agent of the sender or carriers involved in the multimodal transport operations and who assumes responsibility for the execution of the contract".

On the contrary, the role of the logistics operator has gained considerable importance in recent years. The cause is to be found in the exponential growth of e-commerce and in a supply chain whose management becomes increasingly complex. For these and other reasons, the companies often decide to outsource their own logistics. More specifically, LO are companies that supply logistic services to a third part, allowing therefore to other enterprises to outsource their own logistics. For this reason, they therefore rank among suppliers and end customers.

The LO, therefore, takes care of the management of the goods during all the logistic process, from the collection to the delivery. This type of logistics operator can offer

services such as goods storage, stock, order processing and labelling, transport coordination and shipment management. Also, they can work in synergy with an MTO, or can manage the logistics of a company independently.

The intermodal services are offered and managed by the MTO, while the LO manages and offers activities for the integrated distribution logistics. In conclusion, the logistics evolution produces a demand for services that guarantee the final delivery of the product left the production chain.

If the physical distribution is limited to the national area, LO may be sufficient. Instead if the supply chain is more complex, reaching or coming from/spread at least on a continental level, with the need for a mix of transport modes and additional services, it creates demand for a Multimodal Transport Operator (MTO) [30].

In both cases, the aim of these stakeholders is to ensure that goods are transported and managed efficiently and safely, reducing costs and improving the accuracy and timeliness of deliveries. Both of these players have revolutionised the rail sector, offering innovative and flexible solutions for freight and passenger management. Thanks to their presence, the railway sector is evolving towards greater efficiency and competitiveness, offering customers a more complete and high quality service.

3 Methods

The research presented here is aimed at gaining a better understanding of the actual pattern of land connections and relations originating from the port of Trieste and connecting it with the major logistic nodes and destinations within the European continent. As highlighted in the previous paragraphs, gaining such a knowledge would allow understanding the real routes followed by freights, allowing also a more detailed estimate of transport emissions and a comparison among different transport routes. Furthermore, by understanding the spatial pattern of production areas, demography and logistic infrastructure, would allow understanding the potential expansion of the market areas from the port itself and, therefore, the expansion of the hinterland itself.

To do that, we start from the standard procedure suggested for the exam of the hinterlands, adapting it to the present railway-based case study, and anticipating the results of the first part of the activity carried on within the research group. The traditional analysis to analyze the catchment area of a port follows different steps, implying:

- the identification of the primary transportation routes and modes used to move freight to and from the port, including road, rail, and waterways,
- an analysis of the cargo flows to and from the port, including the types of cargo, the origin and destination points, and the volumes and frequencies of shipments [2].

The abovementioned points need to be adapted and articulated according to a set of sub-steps, as.

- the analysis of the transport infrastructure surrounding the port, including highways, railways, and waterways,
- the identification of the areas that are directly or indirectly served by these transportation modes,

- the identification of the economic activities that are directly or indirectly influenced by the port's operations, such as manufacturing, warehousing, and distribution [13], both in the area around the port and in proximity of the destinations.
- use of GIS (Geographic Information System) tools and spatial analysis techniques to plot the catchment area of the port, based on the transportation routes, cargo flows and economic activities identified in the previous steps.

The methodology proposed for the port hinterland analysis can then be adapted to try to highlight the dynamics related to rail transport in relation to the catchment area of different port systems. For this reason, the methodology to be used for the rail hinterland analysis of a gateway will follow different steps in order to develop strategies and solutions that can maximize the benefits from the use of rail transportation for port logistics operations while minimizing their negative externalities on the environment and the surrounding communities as presented Table 1 (Table1) [32].

This table could be used as a guide for gathering data and analyzing the factors that contribute to defining the railway hinterland of a port. By completing each step and analyzing the data collected, a clearer picture of the port's catchment area can be developed, also taking advantage of the potential of different GIS software, which can be useful for planning and optimizing transportation and logistics operations. However, it should be noted that in this phase, the research will focus exclusively on the first step, namely the geographical mapping analysis of the main railway flows by origin and destination and part of the transport and logistic infrastructures on the territory.

4 The Case Study

4.1 The Port of Trieste as a Rail Port

The Port of Trieste, located at the Northern end of the Adriatic Sea, represents an extremely important logistical hub for intra-Mediterranean commercial flows and strategic exchange between Central-Western Europe and the Middle Easter, acting as an international port with most of its traffic spread over international routes. In 2022, it was the first Italian port for goods moved, with over 57 million tons of goods (65% of which were liquid bulk products, namely petroleum products). In recent years, the Port of Trieste has been experiencing a phase of growth and intensification of commercial flows, leveraging its traditional geographic advantages (both natural and anthropic), such as the seabed depth of approximately 18 m, the articulated railway network connected to the international hinterland of logistics hubs in Central and Eastern Europe, and the Free Port regime, which provides operational, administrative, financial, and commercial customs advantages [33, 34] both for what concerns the container handling and the Ro-Ro ferries [4]. The Port of Trieste plays an important hub function – with a transshipment share of 32% for pure container transport – as well as a continental gateway, with a significant component of traffic traveling by rail [8, 14]. The intermodal connections of the port of Trieste are represented by the international logistics hubs of Central and Eastern Europe through an efficient and capillary network of connections capable of catalyzing Eurasian traffic with the northern Adriatic ports as deepen presented later. Therefore, due to its strategic location, the port of Trieste is configured as an intermodal logistics platform

Table 1. Overview of the process of analysis of a catchment area of a port. Source: Personal Elaboration of the Authors [2, 18].

	Criteria	Data Collection	Analysis
Step 1: Spatial Analysis	Rail freight flows assessment	Analysis and mapping of the main known railway flows	Plot the different routes with origin and destination of freights on a map
	Geographic proximity	Identify all cities and logistics distribution center and hubs within a certain distance from the port (e.g. 100 km)	Plot the locations of each city/town and hubs on a map
	Designing railway infrastructure	Identify the railways connection from the port to other locations (highlighting any infrastructure constraints)	Plot the infrastructure on the same map as step 1
Step 2: Economic Analysis	Economic activity	Identify major industries and businesses in the area surrounding the port including the analysis of raw materials and semi-finished products used	Categorize the industries by sector and analyze their economical dimension
	Industries transportation need	Comparison between commodity categories handled in ports and demand in adjacent industrial districts	Observe whether there is a correspondence between rail traffic demand and economic activity, to understand their transportation need
Step 3: External Analysis	Competition	Identify other ports within the same geographic region	Analyze their strengths and weaknesses com-pared to the target port
	Logistics operator	Define the routes handled by the various logistics operators	Mapping the area of operation of different logistics operators
	Environmental factors	Identify potential environ-mental impacts of port operations on the surrounding area	Analyze potential mitigation measures

capable of catalyzing commercial flows between the Far East and Central and Eastern Europe [5].

4.2 From Port Shunting Activity Operator to Logistic Operator: The Case of Adriafer

Adriafer is a 100% owned subsidiary of the Port Network Authority of the Eastern Adriatic Sea specialising in the shunting and traction of railway convoys, both incoming and outgoing, within the Enlarged Port District of the Port of Trieste. As the Sole Manager

of railway shunting in the port area, Adriafer plays a vital role in the logistics chain centred on the Port, connecting the national railway network managed by RFI to the port terminals. Trieste, in fact, is the most important railway port in Southern Europe, equipped with 70 km of tracks serving all the piers and making it possible to compose trains directly at the terminals.

Adriafer's activity within the District and on the tracks of the railway stations (LDS), managed by RFI, has represented a real turning point for the entire Regional Logistics System, leading to an increase in the potential of the service that can be provided by trains and a reduction in the time required for rail transport, thus leading to a reduction in costs and transit times that have made Trieste a best practice for the modal transition from road to rail. During 2022, in fact, the number of trains moved was 9,536 from about 6,000 in 2015 within the District alone, a number that increases to over 11,000 trains if one widens the view to the port of Monfalcone (also under the control of the Trieste Port Authority), for a total of over 230 trains per week. The area of interest for the Regional Logistics System, it should be underlined, also extends outside the Free Port of Trieste, widening to the back-port areas of Aquilinia, Servola, up to the Italian-Slovenian border at Villa Opicina and the regional freight villages of Fernetti, Cervignano and Gorizia. It is precisely with a view to optimising the port network for the benefit of the various district operators that Adriafer has started to operate on the mainline on short-haul routes. Operations on these routes have been carried out since September 2017, the year in which the National Agency for Railway Safety (ANSFISA) granted the company the Single Safety Certificate to operate the first mainline trains, with the aim of creating a synergic system and improving the competitiveness of the Port System.

The Port of Trieste represents the link between the Mediterranean and the Adriatic Baltic European Corridors, as it is a strategic hub for the flow of goods between the markets of Central and Eastern Europe and the Mediterranean basin.

The rail services available from Trieste in fact reach, with different frequencies, Austria, Germany, Hungary, Croatia, Switzerland, Czech Republic, Poland, Luxembourg, Bosnia and Herzegovina and Slovakia. The Port of Trieste, in terms of freight flows handled by rail, is the first port in Italy and this is also perceived by the railway flows that depart from or arrive at the various port terminals every day. In terms of routes, the Port is connected by rail with 8 major Central European countries, creating a logistical network thanks to the infrastructural articulation with more than 31 different locations distributed throughout the Mitteleuropean region. The largest flows, also due to their geographical position, coincide with Germany, Austria and Italy itself. Every month from Trieste Campo Marzio approximately 42 convoys depart and just as many arrive, resulting in a constant flow of important monthly arrivals/departures, with frequencies of up to 13 convoys per week and 50 per month for the most popular routes.

Although the port of Trieste is the Italian port of call with the greatest international vocation, there have been recent pioneering experiences which have opened up new models for intermodal transport between the North-East and the Centre/South of Italy. This is the first service along the Adriatic railway line, initiated by Sangritana on behalf of Honda Industriale Italia to transport containers in inbound flow from Trieste to the Abruzzo freight village of Manoppello. Launched in January 2023, this new service represents a highly innovative choice because for the first time it extends the area of

influence of the port of Trieste as far as the Abruzzo region, and possibly even further, extending into central and southern Italy, an area previously perceived as distant from the Julian port of call.

4.3 Spatial Analysis: The Port of Trieste

The dynamics of commercial flows for the port of Trieste, observing how the share of traffic volumes managed by Northern European ports is the result of the combination of two fundamental factors [31]: the presence of productive districts in inner port areas and the attractiveness of these ports with respect to infrastructure and geographical components. However, it should be emphasized that port systems located in Northern Italy represent an extremely more efficient alternative for all oceanic connections coming from the Far East in transit through the Suez Canal [11]. By using the port of Trieste, four days of navigation (at an average speed of 20 knots/hour) and over 2200 miles of navigation [14] can be saved.

As outlined in the methodology, the aspects that will be prominently focused on in this analysis are those related to the spatial and territorial component: starting from the analysis of freight flows by rail, identifying the main logistics corridors for goods in transit, considering the railway infrastructure present in the territory, and the main distribution centers and logistics hubs in the study area.

The geographic location of the port of Trieste defines it like a gateway to access the markets of Central Europe for this port represents a significant strategic factor in the context of the environmental sustainability of logistics processes. Thanks to its strong international vocation, the port of Trieste channels large volumes of traffic towards the areas of Central-Eastern Europe (Bavaria, Austria, Slovakia, and the Czech Republic) [14].

The main railway connection for the port of Trieste could be summarized in the following table (Table 2), outlined by putting together a previous data collection from institutional sources (Port Authority of Trieste) to the data provided by directly from Adriafer.

Table 2. Summarize of the railway connection for the port of Trieste (Source: Adriafer, internal data given by the company)

National Routes		Distance (km)	International Routes		Distance (km)
IT	Ancona	506	DE	Karlsruhe	847
IT	Cervignano del Friuli	50	DE	Koln	1114
IT	Cremona	347	SI	Koper	78
IT	Milano	393	AT	Lambach	469

(*continued*)

Table 2. (*continued*)

National Routes		Distance (km)	International Routes		Distance (km)
IT	Padova	179	AT	Linz	269
IT	Manoppello	670	DE	Munchen	508
IT	Pordenone	126	DE	Nuremberg	664
IT	San Martino di Trecate	442	CZ	Ostrava	843
			CZ	Paskov	849
International Routes		Distance (km)			
LU	Bettembourg	1091	SI	Velenje	258
SK	Bratislava	616	AT	Villach	186
HU	Budapest	783	AT	Wels	488
DE	Burghausen	480	AT	Wien	554
HU	Csepel	598	AT	Wolfurt	673
DE	Duisburg	1183	CZ	Mosnov	820
SK	Dunajska	648	SK	Trnava	658
DE	Giengen	712			

However, although the main destinations and origins are known, the mapping and survey work on the analysis of the railway flows for the port of Trieste is still in progress. The proposed objective is to concretely define the catchment area for the port of Trieste.

The thematic cartography presented (Fig. 1) is divided into different layers, in which the main railway connections operated to and from the port of Trieste have been highlighted based on the data given directly by Adriafer company. The extensive railway infrastructure of Central and Eastern Europe is then pushed in evidence, together with the main network of intermodal rail terminals and hubs present in the investigated area. The information presented regarding the intermodal rail terminal network has been developed starting from the interactive map of the European Commission's TENtec, which highlights the main European logistics corridors, freight villages, inland ports and inland waterways (Fig. 2).

For the realization of the cartographic representation of the railway connections and logistic nodes so far highlighted, as well as for inserting the other elements of the analysis as previously mentioned in the 'methods', the research group agreed also to rely on an intermediate product, as a Google MyMaps project, useful, in the present stage, to work concurrently within the research group, gathering in a unique place all the data and information collected and elaborated and capable, once the project is fully implemented, to be used as a dissemination tool for allowing a more general public of users and operators to view and understand the layout of the overall hinterland, including, in its following steps, an evaluation of the flows as well as of the environmental aspects connected to the different routes and destinations.

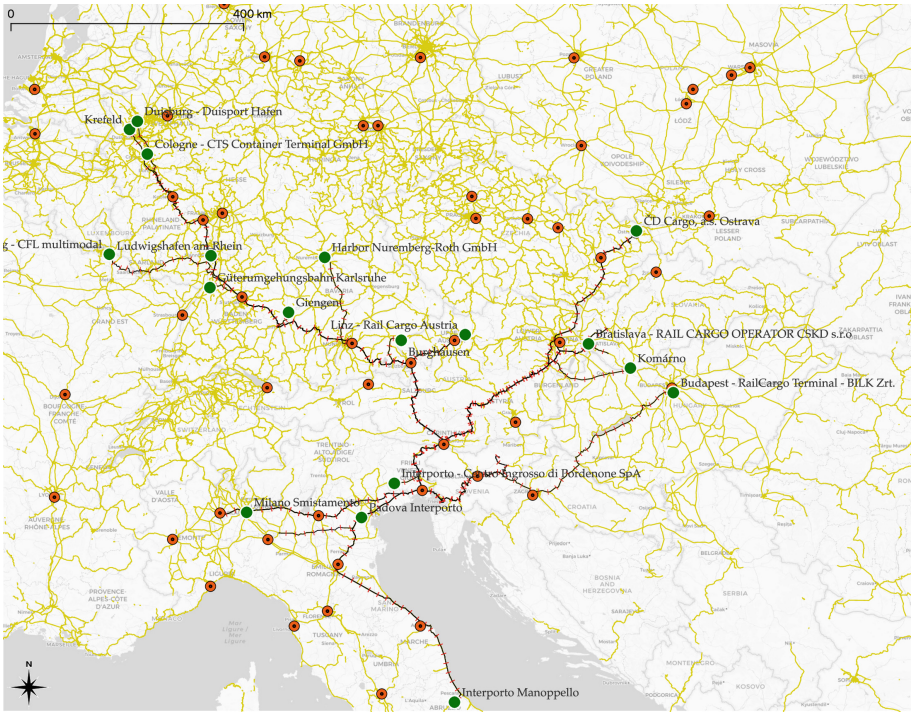

Fig. 1. Rail traffic routes to and from the Port of Trieste. Source: elaboration by A.Gallo from Adriafer internal data and TENtec interactive map[1].

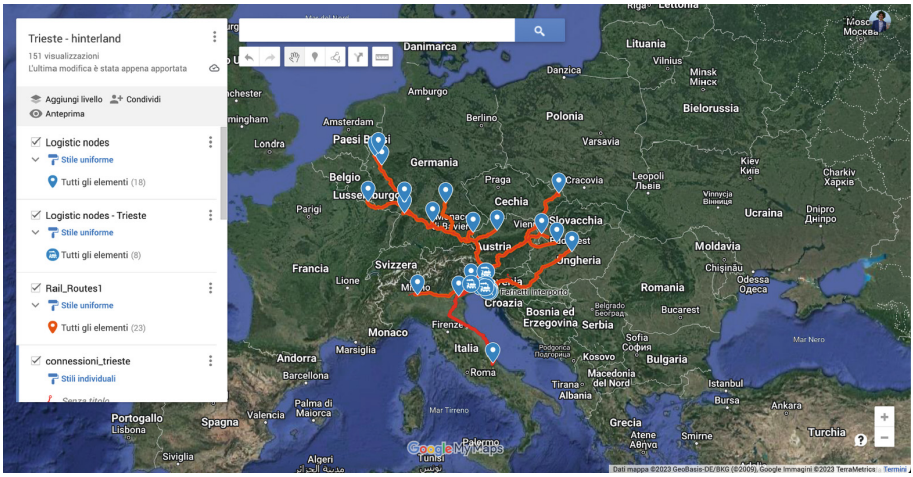

Fig. 2. Rail traffic routes to and from the Port of Trieste. Source: authors elaboration from Port Authority of Trieste, Adriafer, Desk research on main logistic nodes

[1] https://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/map/maps.html#Filter_page&ui-state=dialog consulted on 8/05/2023.

5 Results and Discussions

The analysis of a rail port hinterland is important to assess the effectiveness of the supply chain that connects the port to the production and consumption areas. Intermodal transport dynamics are fundamental components for the evaluation of the port hinterland, in linking together different modes of transport to move goods from one point to another, exploiting the strengths, in terms of costs and sustainability, of each mode of transport to optimize the logistics chain.

This contribution provides a general overview of the definition of a port hinterland with reference to railway connections, particularly in terms of the reconstruction of the rail links among the Port of Trieste and its major inland destinations. The joint analysis mode through a desk research coupled with direct collaboration with the railway shunting and handling company (Adriafer) has allowed the primary result of identifying the main areas served by the Port of Trieste, in an analytical manner, but especially through a cartographic representation. The first steps of the analysis so far carried out confirmed the characteristics of the Port of Trieste as an important hub in connecting the sea leg with an efficient railway system for the markets of Central and Eastern Europe. The port of Trieste has achieved significant success in recent years thanks to the strategic development of railway infrastructure. The routing of goods departing from the port of Trieste by train has also allowed greater efficiency in the handling of goods, significantly reducing road congestion and mitigating some of the negative externalities resulting from port activities. This has made the port of Trieste an important logistics hub for goods in transit between Europe and the Middle East. In this contribution, some key dynamics were therefore outlined regarding the role of gateways as main access routes to continental markets, also developing some reflections on the sustainability of freight transport and on the main market operators.

However, it is important to emphasize that this research has focused almost exclusively on the geographical aspects of evaluating the port hinterland. Therefore, this contribution represents a starting point for a thorough and careful study of the analysis of the port catchment area, which also takes into account the economic-productive dynamics of different areas, as well as urban, competitive and environmental aspects, these latter referred particularly to the modal shift towards more sustainable transport means as trains, and the perspective of energy supply. The next steps of the research as foreseen and theorized in this paper are not trivial, as it could appear in a world, as that of transport and logistics, dominated by an important modal integration and a growing importance of ICT in allowing a rapid exchange of information and travel document. Paradoxically, this is, at the same time, allowing little knowledge about the true connections and final destinations of goods, being the custom and tracing activities both spread over a set of different actors and located in different places as those directly involved by transport and logistics operations. As an example, while in the past and with the presence of borders customs operations were done in the transit, border nodes, recently these operations, and the related tracing, are recorded at destinations. Further actions are therefore needed to fill the information gaps so far highlighted in terms of the current pattern of destination nodes from the port of Trieste, as well as in terms of the possible expansion, given a more in depth knowledge of the major production areas.

6 Conclusions

Rail transport is living a renewed importance due to an unprecedented development of intermodalism, that is mainly regarding the integration of maritime and land transport, with particular reference to the role played by Ro-Ro ferries in moving semitrailers and similar unitized freight, and with reference to the port and dry port operations allowing assembling trains for transport over medium-to-long land destinations.

Although this principle is not new, its implementation and proficient operations have been only recently exploited and put in action. This appears particularly true in some gateway ports, as it is the case of Trieste, where the limited amount of space available on the seaside and on its proximity has forced port, freight and rail operators to optimize performances, realising intermodalism either directly on terminals or on port and dry port facilities.

This is enhancing performances both from the economical and environmental points of views, allowing to reduce considerably the number of lorries on roads and motorways. At the same time, the set-up of long and interconnected maritime – land routes allows reaching far destinations well routed into the European continent, de facto extending the international hinterland of the gateway port. Railway connections become therefore particularly important, particularly for an international port as the Port of Trieste, with its historical – and current – positioning as a gateway of Mediterranean and Asian flows on the seaside, and medium-to-long range railway connections well into the European continent. In the present we performed an initial survey of the existing railway connections among the port of Trieste and its major destinations, combining information coming from different research and business data, modelling them in a GIS environment and setting up a methodology for further elaborations of a proper rail hinterland, capable of being scaled and extended to other potential branches and destinations, as well as containing useful tools for evaluating the environmental impacts and benefits in a comparison with alternative transport modes. This can allow scholars and operators, including the main character in the realization of this modal shift revolution, as the local shunting company and rail operator (as Adriafer) to rely on a useful instrument to plan further actions aimed at improving connections, efficiency and environmental sustainability in logistics and transport.

References

1. Vallega, A.: Nodalità e centralità: relais tra teoria regionale e teoria dei trasporti. Studi Marittimi. **6**(19–20), 33–35 (1984)
2. Rodrigue, J.P.: The Geography of Transport System. Routledge, London and New York (2020)
3. Lupi, M., Pratelli, A., Giachetti, A., Farina, A.: Il trasporto ferroviario in Italia: una analisi dei collegamenti ferroviari di trasporto combinato—Rail freight transport in Italy: an analysis of combined transport connections. Ingegneria Ferroviaria **53**(3), 209–245 (2018)
4. Borruso, G.: Port-City relationship in the era of hybridization. A development model. J. Res. Didactics Geogr. **2**, 125–137 (2022)
5. Gallo, A.: The logistic carbon footprint: a dynamic calculation tool for an indicator of the sustainability of logistic processes with a case study on the Port of Trieste. In: Computational Science and Its Applications–ICCSA 2022 Workshops, pp. 109–123, Malaga, Spain, July 4–7, 2022, Proceedings. Springer International Publishing Part V, Cham (2022)

6. Mazzarino, M.: Geografia dell'innovazione logistica nel Nord-Est. EUT Edizioni Università di Trieste (2021)
7. Rodrigue, J.P., Notteboom, T.: Comparative North American and European gateway logistics: the regionalism of freight distribution. J. Transp. Geogr. **18**(4), 497–507 (2010)
8. Sellari, P.: Geopolitica dei trasporti. GLF Editori Laterza (2018)
9. Soriani Stefano: Riorganizzazione del ciclo di trasporto e spazi di influenza portuale. Dinamiche in atto e poste territoriali in gioco, in Salgaro Silvino (a cura di), Scritti in onore di Roberto Bernardi, Bologna, Patron Editore, pp. 165–177 (2006)
10. Vallega, A.: Geografia delle strategie marittime: dal mondo dei mercanti alla società transindustriale. Mursia, Milano (1997)
11. Tadini, M.: Intermodalità ferroviaria e assetto territoriale dei porti gateway: il caso di La Spezia. Rivista Geografica Italiana, CXXVIII **4**, 104–136 (2021)
12. Roso, V., Woxenius, J., Lumsden, K.: The dry port concept: connecting container seaports with the hinterland. J. Transp. Geogr. **17**(5), 338–345 (2009)
13. Notteboom, T.E., Rodrigue, J.P.: Port regionalization: towards a new phase in port development. Marit. Policy Manag. **32**(3), 297–313 (2005)
14. Tadini, M., Borruso, G.: Sea-rail intermodal transport in Italian gateway ports: a sustainable solution? The examples of La Spezia and Trieste. In: Gervasi, O., Murgante, B., Misra, S., Rocha, AMC, Garau, C. (eds), Computational Science and Its Applications – ICCSA Workshops 2022, LNCS, vol. 13381, pp. 156–172, Springer-Verlag, Berlin (2022)
15. Lam, J.S.L., Notteboom, T.: The greening of ports: a comparison of port management tools used by leading ports in Asia and Europe. Transp. Rev. **34**(2), 169–189 (2014)
16. Zhao, J., Zhu, X., Wang, L.: Study on scheme of outbound railway container organization in rail-water intermodal transportation. Sustainability **12**(4), 1519 (2020)
17. Woxenius, J., Bergqvist, R.: Comparing maritime containers and semi-trailers in the context of hinterland transport by rail. J. Transp. Geogr. **19**(4), 680–688 (2011)
18. Ignaccolo, M., Inturri, G., Giuffrida, N., Torrisi, V.: A sustainable framework for the analysis of port systems. Eur. Transp. **78**(8) (2020)
19. Wen, L., Song, Q.: Simulation study on carbon emission of China's freight system under the target of carbon peaking. Sci. Total Environ. **812**, 152600 (2022)
20. Yao, Z., Wang, Y., Liu, B., Zhao, B., Jiang, Y.: Fuel consumption and transportation emissions evaluation of mixed traffic flow with connected automated vehicles and human-driven vehicles on expressway. Energy **230**, 120766 (2021)
21. Toneatti, L., Deluca, C., Fraleoni-Morgera, A., Pozzetto, D.: Rationalization and optimization of waste management and treatment in modern cruise ships. Waste Manage. **118**, 209–218 (2020)
22. Toneatti, L., Deluca, C., Fraleoni Morgera, A., Piller, M., Pozzetto, D.: Waste to energy onboard cruise ships: a new paradigm for sustainable cruising. J. Mar. Sci. Eng. **10**(4), 480 (2022)
23. Breuer, J.L., Samsun, R.C., Stolten, D., Peters, R.: How to reduce the greenhouse gas emissions and air pollution caused by light and heavy duty vehicles with battery-electric, fuel cell-electric and catenary trucks. Environ. Int. **152**, 106474 (2021)
24. Mulholland, E., Teter, J., Cazzola, P., McDonald, Z., Gallachóir, B.P.Ó.: The long haul towards decarbonising road freight–A global assessment to 2050. Appl. Energy **216**, 678–693 (2018)
25. Stobnicki, P., Gallas, D.: Adoption of modern hydrogen technologies in rail transport. J. Ecol. Eng. **23**(3), 84–91 (2022)
26. Zenith, F., Isaac, R., Hoffrichter, A., Thomassen, M.S., Møller-Holst, S.: Techno-economic analysis of freight railway electrification by overhead line, hydrogen and batteries: case studies in Norway and USA. Proc. Inst. Mech. Eng. F J. Rail Rapid Transit **234**(7), 791–802 (2020)

27. Fedele, E., Iannuzzi, D., Del Pizzo, A.: Onboard energy storage in rail transport: review of real applications and techno-economic assessments. IET Electr. Syst. Transp. **11**(4), 279–309 (2021)
28. Fragiacomo, P., Piraino, F.: Fuel cell hybrid powertrains for use in Southern Italian railways. Int. J. Hydrogen Energy **44**(51), 27930–27946 (2019)
29. Glossario, TRASPORTO FERROVIARIO. ANNI 2004–2013, https://www.istat.it/it/files/2015/02/Glossario.pdf. Last accessed 11 Apr 2023
30. L'operatore in trasporto multimodale (MTO) e l'operatore logistico (LO), https://www.confetra.com/it/centrostudi/doc_pdf/quaderni_QUADERNO%20%20N.%2088.2.pdf. Last accessed 11 Apr 2023
31. Notteboom, T.: Concentration and the formation of multi-port gateway regions in the European container port system: an update. J. Transp. Geogr. **18**(4), 567–583 (2010)
32. Wilmsmeier, G., Monios, J.: Counterbalancing peripherality and concentration: an analysis of the UK container port system. Marit. Policy Manag. **40**(2), 116–132 (2013)
33. Roletto, G.: Il porto di Trieste. Zanichelli, Bologna (1941)
34. Borruso, G., Borruso, G.: Capitolo IX-Il Porto di Trieste: analisi del traffico, impatto economico e prospettive di sviluppo. In:Trasporto marittimo e sviluppo economico. Scenari internazionali, analisi del traffico e prospettive di crescita, pp. 235–273. Giannini Editore (2012)
35. Zhao, P., et al.: China's transportation sector carbon dioxide emissions efficiency and its influencing factors based on the EBM DEA model with undesirable outputs and spatial Durbin model. Energy **238**, 121934 (2022)