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Logistics chain responsiveness to war impacts: A case study in North Adriatic Region

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ABSTRACT

The Russian-Ukraine conflict outbreak abruptly interrupted the sea-road intermodal service which provided some metal companies in the Italian region of Friuli Venezia Giulia with semi-finished steel products coming from the Ukrainian port of Mariupol. Those companies were then forced to find an alternative supply source to feed their production system, which entailed the arrival of oceanic vessels with a greater cargo load, but at a lower frequency. Such changes implied significant consequences both on the maritime and the land side and requested the employment of trucks, train and barges to transfer the increased volume of goods. Moreover, those variations generated additional costs for all the involved operators, threating the survivability of the whole supply chain and, thus, of an important share of the regional economy. In this paper, a methodology combining process modelling and quantitative analysis has been applied, first, to gain an in-depth understanding of the case study and then, to suggest modifications to existing policies. Such investigation techniques enabled, on one hand, to identify process bottlenecks and, on the other hand, to examine infrastructural and financial consequences for each considered transport mode. Results revealed the need of adjusting the current strategic vision especially with reference to the development of the infrastructural networks, the introduction of incentive schemes and the availability of skilled people operating in logistics. The proposed lines of action are meant to foster the resilience of the analysed supply chain at economic, environmental and social level.

1. Introduction

Together with the Covid-19 pandemic, the current Russia-Ukraine conflict represents one of the biggest disruptions of the recent past (Simmons et al., 2022), calling the whole world to face new challenges, even though under different perspectives (Zhang and Gao, 2022). As a consequence of this latest disruption, global economy was further severely impacted, just when many countries were still trying to recover from the financial losses due to the pandemic. The negative effects of the conflict have been mainly recorded in commodity markets, weakening regional and global growth and, therefore, undermining future economic prospects. Russia and Ukraine are large exporters of some key commodities, like energy, grains, fertilisers, and metals, which are the upstream inputs of several industries, such as food, construction, petrochemicals and transport (World Bank Group, 2022; National Institute of Economic and Social Research, 2022). In this regard, the strong interconnectedness resulting from the specialisation process of the nodes and edges of the global production network often induces a cascading transmission of possible shocks also beyond the country in which the disruption originates (Guan et al., 2020). Similarly to the spillover effects caused by the Covid-19 pandemic, the war between Russia and Ukraine hit commercial relationships at the international level, entailing geopolitical tensions which are likely to affect supply chain logistics and trading corridors in the long term (World Bank Group, 2022; Braun et al., 2022). Trade connectivity of the two conflicting countries has been remarkably constrained, on one side, by the blockage or occupation of Ukraine's Black Sea ports and, on the other side, by sanctions imposed to Russia, implying significant traffic shortages and, thus, price hikes for exported goods (Ruta, 2022). Proof of that, ocean shipping, together with railways, have been the most affected transport modes (Schiffling and Valantasis Kanellos, 2022), which forced a re-routing of commercial routes to avoid emerging transport bottlenecks. Especially in the former case, modifications in traditional operations have led to a lengthening of journey times and an increase in costs (Monika, 2022; Guenette et al., 2022; Fernandes et al., 2023), which influenced the provision schedule and the price of

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products at the final destination.

One of the most important manufacturing sectors of Ukraine's exports is related to iron ore and iron products, some metals, and semi-finished metal products, which used to feed the value chains of different European countries. The critical dependency from such Ukrainian inputs have placed European markets in a quite vulnerable condition, due to which firms need to re-assess security-related risks given by a potential fragmentation of the trade and investment system (Ruta, 2022).

In respect of such context, the case study reported in this paper concerns the disturbances occurred at the supply chain of some rolling mills settled in the northeast of Italy, which, prior to the invasion, used to stock up with semi-finished products from Mariupol via a sea-road intermodal service. Notably, transport implications are discussed in the light of the countermeasures which the engaged companies needed to undertake for the provision of steel slabs after the stoppage of shipping services from the port of Mariupol. Dramatic changes have been registered in every node of the examined supply chain, not only regarding maritime operations but also landside ones, in terms of both infrastructural capacity and human resources. Indeed, variations in traffic volumes and timings related to the main freight transfer has required the rearrangement of logistics processes at the involved North Adriatic ports, with significant repercussions on the production system at plants. The reason for such application is the great relevance of the steel sector in the Friuli Venezia Giulia region, and in particular in the Aussa-Corno area where the analysed rolling mills are located: these latter operate on average an annual volume of steel slabs which equals to 1.6 million tons, giving employment to more than 500 people, with an annual production value of about 1.2–1.3 billion Euros and equally worth satellite activities. Slabs coming from Mariupol represented almost 80% of the total amount of steel products processed by the four examined Aussa-Corno rolling mills, which transformed them into plates for the construction and railways industries (Agenzia Imprenditoriale Operatori Marittimi – Trieste, 2022). With reference to Fig. 1, the transport facilities accommodating the traffic flows under investigation are, on the seaside, the Port of Monfalcone and Porto Nogaro while, on the landside, the national and local road junctions and railway lines connecting those two ports with the rolling mills.

Transport processes of the considered supply chain have been represented at different level of detail using the Business Process Model and Notation (BPMN) standard, developed by the Object Management Group (Object Management Group, 2022), in order to analyse the previous and current scenarios and to identify possible bottlenecks regarding infrastructural and operational aspects. Processes have been graphically displayed according to the various actors responsible for the different phases of the supply chain and to the corresponding transport mode used to perform activities. Subsequently, a quantitative analysis has been carried out to determine the differences in terms of loads, costs and timings in various operational scenarios.

The paper aims at highlighting the transport policy implications generated by the Russia-Ukraine conflict on the steel industry related to the specific reported case study, giving insights on the infrastructural, economic and ancillary lines of action necessary to ensure the operation of the logistics system. Indeed, unlike scientific contributions dealing with models to simulate the components of transport systems, referred to as Transport System Models (Ben-Akiva and Lerman, 1985; Ortuzar and Willumsen, 2001; Cascetta, 2009), this paper underlines the adjustments which should be made to the considered supply chain to cope

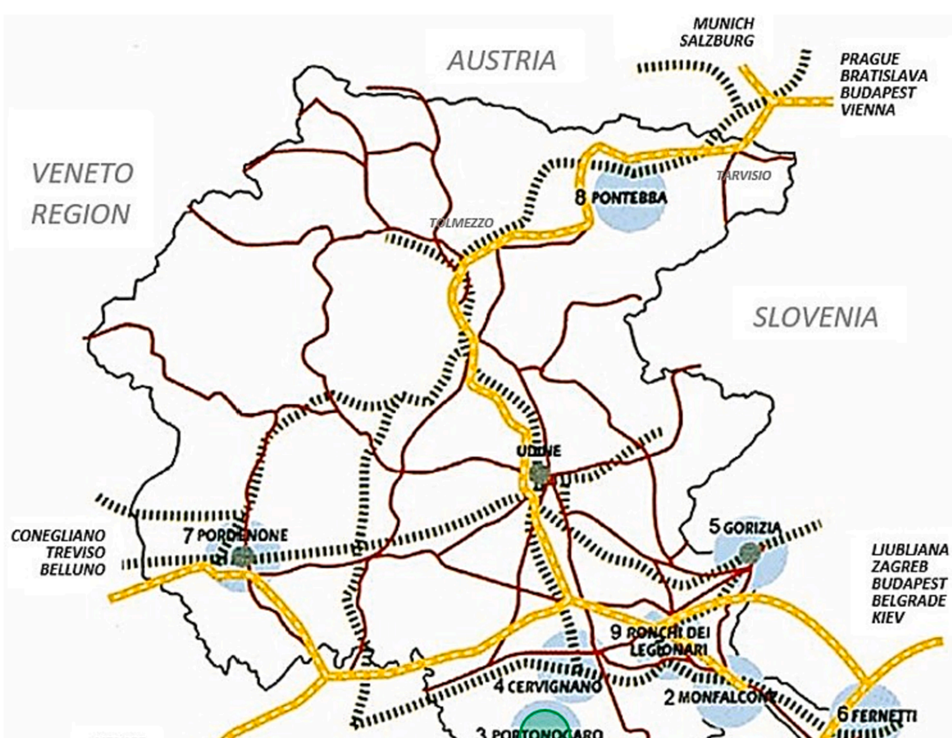

Fig. 1. Transport nodes and edges of the Friuli Venezia Giulia Region (Regione Autonoma Friuli Venezia Giulia, 2011).

with the impacts of the war and, consequently, the prompt revision to be implemented on existing investment policies. Rather than concentrating on modelling transport offer and demand, the paper actually focuses on the analysis of such disruption on previous strategic directions, in order to point out the emerging priorities for the overall sustainability of the examined supply chain. In this regard, the performed qualitative and quantitative analyses not only revealed transport needs to assist the disruption recovery, but also gave insights on possible opportunities for growth.

The paper is structured as follows. The second section includes a literature review of research studies concerning, on one hand, the analysis of war impacts on diverse sectors, and, on the other hand, the modelling of freight transport processes based on the BPMN standard. In the third section, the methodology adopted in the paper is described, underlining the main features of the employed modelling technique and its contribution in supporting the comprehension of processes, especially in multi-actor contexts. The fourth section illustrates the investigated case study, encompassing an explanation of the current and alternative scenarios represented in the developed BPMN models, in order to stress variations caused by the war in the supply chain with a reference to traffic flows, costs and timings of transport operations. The results obtained by the performed modelling activities are discussed in the fifth section in terms of infrastructural, operational and economic consequences, and finally, conclusions on possible strategies are drawn, suggesting the transferability of the applied methodology to further industries affected by the conflict.

2. Literature review

As anticipated, the strong interconnection among production network nodes makes the whole supply chain very sensitive to possible disruptions, which propagate creating an adverse ripple effect. The key role for such connectivity is played by transport, which therefore constitute the main driver affecting the responsiveness, efficiency and performance of supply chains. Given the increasing dynamics and complexity of the modern transport system, a variety of disruption risks can impact supply chains not only individually but also simultaneously, challenging scientists in their identification, analysis of consequences and in the definition of reduction strategies (Ghadge et al., 2022; Paul et al., 2020; Stažnik et al., 2017). As synthesized in the review included in (Shekarian and Mellat Paras, 2021), different categorizations of disruption risks for supply chains have been proposed in literature among which the following three are highlighted:

1) Micro risks and macro risks (Ho et al., 2015);
2) Disruption risks and operational risks (Kleindorfer and Saad, 2005; Tang, 2006);
3) Risks internal to the firm, risks external to the firm but internal to the supply chain network and risks external to the network (Christopher and Peck, 2004).

Reason for such selection is that the mentioned categorizations have been adopted in further research studies to explicitly consider war in the list of risks which can potentially unsettle supply chains. Indeed, war falls respectively into the category of macro risks (Ho et al., 2015), disruption risks (Chopra and Sodhi, 2004; Tummala and Schoenherr, 2011) and risks external to the network (Shekarian and Mellat Paras, 2021).

In the context of scientific contributions dealing with disruptions, the response of affected systems is commonly associated to the notion of resilience, which, as proposed in (Fiksel, 2006), is defined as "*the capability to survive, adapt, and grow in the face of turbulent change*". More in detail, in (Pettit et al., 2010) the authors suggest measuring the adherence of systems to such concept as a balance state of capability factors and vulnerability factors, in which the former should assist the system in coping with the latter.

Bearing in mind that, at the time of writing this paper, the Russia-Ukraine war can be still considered a relatively recent event, it appears that most of the available scientific contributions concerning such conflict are related to its economic impacts on global trade and, notably, on the primary supply chains involving the two countries. Indeed, to the authors' knowledge, the existing and yet not very wide literature analyses the topic according to a financial and social perspective, underlining the most evident consequences of the war and questioning its long-term effects. For instance, the study reported in (Braun et al., 2022) concentrates the attention on the extent to which third nations depend on import products from Russia and Ukraine, identifying the most relevant exported goods. The study is based on trade data as a measure to evaluate the nations' exposure to the conflicting economies, also considering the relative substitutability of imports. Researchers of (Mbah and Wasum, 2022) propose a review of the economic impact of the Russia-Ukraine crisis on some of the countries which have imposed financial sanctions on Russia, i.e., the USA, Canada, UK and Europe, remarking the vital need for policymakers to define alternative strategies in case Russia reacts by limiting its export of essential global commodities. The rise of inflation is indicated as the major financial concern in many studies, like for example (National Institute of Economic and Social Research, 2022; Guenette et al., 2022), representing the expected consequence of the rise in energy, commodity and food prices. In this regard, the authors of (Ozili, 2022) point out that higher prices of imported goods are motivated also by possible difficulties and delays in processing cross-border freight, since border officials usually prioritise the completion of procedures dedicated to refugees. Other than a description of implications for global business, the investigations included in (Markus, 2022) stress the long-lasting repercussions of the invasion specifically on the Russian economy, which consist in lower foreign investment and trade in the future, and, thus, a more pronounced de-globalization. Finally, the economic implications of the war in developing countries are captured in (Raga and Pettinotti, 2022; Ali et al., 2022), respectively in terms of the vulnerability of low- and medium-income countries and of the war impacts on the African continent, shedding light on the urgence of defining adequate resilience policies to cope with further external imbalances.

As far as war shock propagation is concerned, the authors of (Korovkin and Makarin, 2011) analyse such phenomenon with respect to a more detailed scale, rather than to macroeconomic effects, adopting the perspective of firms in relation to production networks. Although the study refers to a previous war involving the current conflicting context, i.e., the Donbas War and the annexation of Crimea, evidence obtained with regard to disruptions on the production network and, in turn, on firm performances can be valid also at present. Using a difference-in-differences framework, the authors of (Korovkin and Makarin, 2011) assess the war shock propagation at two diverse levels: on a shorter extent, the first-degree effect occurring on interfirm shipments between the conflicting and non-conflicting areas, and, on a wider range, the second-degree effect encompassing interfirm relations between partners outside the conflicting areas in which, prior to the conflict, one of them relied on a trading partner settled in conflicting areas. Alterations on firms located not in the immediate vicinity of the certain shock are classified according to three scenarios, which differ in either the status of the production network structure or of the demand and supply of firms. Among these latter, the one considering the readjustment of firms by finding alternative buyers and suppliers to form a new production network equilibrium corresponds to the condition of the rolling mills examined in the case study of this paper.

Regarding the modelling technique proposed in this paper, the literature review has been concentrated on previous scientific contributions applying the BPMN standard in the transport sector, and more specifically in intermodal freight transport and logistics. BPMN modelling relates to the discipline of Business Process Management (BPM), which is defined as "a systemic approach to analyse, improve, control and manage processes with the aim of improving the quality of products and services" (Elzinga et al., 1995). The act of redesigning business processes can entail radical or modest variations of current business processes, taking the name of, respectively, Business Process Reengineering or Business Process Improvement, with the major goal of enhancing productivity and reducing costs (Stajniak and Guszczak, 2011; Hammer, 1990). For this reason, companies have become more and more interested in using BPM, like observed in surveys reported in (Capgemini, 2012; Dumitriu, 2018), turning it into a common practice. Indeed, in analogy with the industrial field, BPM has been applied to a variety of other sectors, like, for example, the transport one, which shows great affinity with the former when dealing with the management of complex systems. Given the examined multi-actor context, attention has been paid to research studies capturing the interaction among the stakeholders involved in processes, which constitutes one of the main factors influencing their complexity. For example, in (Elbert and Pontow, 2013) business processes and information flows referring to incoming container traffic via the port of Hamburg have been modelled using the BPMN standard, with the aim of detecting possible data exchange deficiencies on significant junctures of the transport chain which can compromise the efficiency in the utilisation of existing infrastructure. Another application of the BPMN standard to examine information flows in a seaport is reported in (Bisogno et al., 2015), in which such modelling technique has been adopted to investigate the relationships among the local actors of the port network in an existing and potential scenario, in order to improve the coordination of operations. Besides, railway processes in the Port of Trieste, Italy, have been deeply analysed in terms of both transport operations and administrative procedures in (Campagna et al., 2020; Caramuta et al., 2021; Caramuta et al., 2021), in which BPMN modelling has been integrated with further techniques with the common goal of enhancing freight movements. Notably, the created BPMN models have been combined, respectively, with a capacity analysis, with a multi-criteria evaluation method, and with a simulation and optimization procedure, enabling the identification of organisational, infrastructural and operational lines of action to increase the port railway capacity and, thus, port competitiveness. In (Fahima et al., 2021), the BPMN standard has been used to display the operational processes of a part of a logistics chain according to a new vision for global freight transport and logistics, which is called the Physical Internet (PI). The model visualizes activities and information exchanges accounted for the reconsolidation of shipments from a port terminal to a consignee in the innovative context of PI ports, which entails dynamic and real-time factors. The BPMN modelling has been functional to the definition of the requirements of the necessary information systems, in particular with reference to ports' track-and-trace capability. The authors propose a specific information architecture enabling to integrate data on PI port containers with the wider supply chain, thanks to an open interface platform among various actors. The validity of the suggested solution has been tested in Teesport, England, United Kingdom. Finally, the BPMN notation has been employed in (Kasher et al., 2022) with the analogous objective of eliciting the information requirements related to a transport logistics forwarding process. Such modelling activity represents the first step of the proposed systematic procedure aimed at choosing suitable digitization technologies, which is then combined with a multi-criteria decision analysis based on process-related selection criteria.

Overall, the literature review seems to reveal a lack in research studies concerning specifically the practical transport implications of the Russia-Ukraine invasion, which represents the main focus of this paper. Indeed, the objective of the paper exceeds a high-level description of war disruptions on transport networks, since it consists of a more precise and quantitative analysis of the conflict shock propagation in the previous and current scenario, not only with respect to maritime and landside facilities but also to the operational requirements for transport service providers and steel plants.

3. Methodology

The methodology adopted in this paper consists in the application of the BPMN modelling technique to the transport sector, which has enabled a punctual analysis of processes at hand in order to identify possible bottlenecks and envision improvements. BPMN is the *de facto* modelling standard used to visualise business processes and it is characterised by an intuitive and expressive look based on a series of specific graphical elements. Business processes are represented in the form of flowcharts which display primary process features like tasks (activities), gateways (decision points), events and subprocesses, which are connected to one another by sequence flows. Process elements are included in pools which are functional to the organisation of represented elements, especially when they are divided into lanes to distinguish the responsibilities among the diverse actors involved in the process. Besides, elements called data objects can be included in business process models to provide information regarding the requirements needed to perform activities or their produced results. The BPMN modelling technique and notation is meant to support the readability and understandability of business process flows according to an activity perspective and it permits an effective examination of processes thanks to peculiar characteristics, like scalability and enactability. As indicated in (Leopold et al., 2015), quality issues in developing BPMN models are related principally to three categories of features, i.e., structure, layout and labelling, for which useful recommendations are suggested in (Silver, 2011). Fig. 2 illustrates some of the basic BPMN elements, which can be further declined into more case-specific ones. In practical terms, BPMN models for the case study presented in this paper have been created by means of the online editor Cardanit, developed by the company ESTECO S.p.A. (ESTECO S.p.A., 2022).

In addition, BPMN is able to combine the graphical representation with a rigorous XML encoding of processes, since it translates every graphical element into the corresponding XML one. The resulting execution code also encompasses some hidden attributes, which support process simulation with technical details without compromising model readability. Indeed, even though in this paper the use of the BPMN modelling is meant to address an in-depth understanding of the examined processes and, thus, the identification of possible criticalities and alternative scenarios, the quantification of parameters included in the model would enable the actual execution of processes, in line with the BPM approach.

BPMN has been adopted to approach the case study presented in this paper benefitting from its versatility to model different kinds of processes to investigate previous and current scenarios. Given the contribution of aspects such as the operating system, the cultural context, regulations, and operational policies, in the definition of the process environment (Caceres et al., 2015), context-sensitive models have been built reflecting the properties of the examined transport operations. The representation of these latter has been facilitated by stakeholders' engagement, information resources and modelers' expertise (Bandara et al., 2015). Indeed, on-field visits and technical meetings with operators related to the transport modes considered in process models have been performed to gather information on activities, traffic volumes, economic aspects and timings. Moreover, whenever possible, official data have been used. As anticipated, the BPMN models created for this paper have constituted the starting point for further analyses regarding the actual transport implications caused by the Russia-Ukraine conflict, with respect to the pre-war infrastructural and operational configuration. In this regard, collected data has been then used to feed a quantitative analysis of the logistics chain referring to different scenarios.

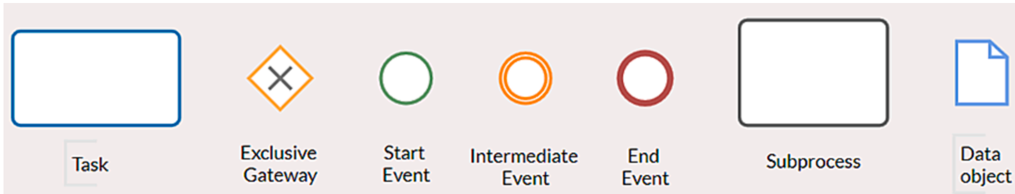

Fig. 2. Some of the main BPMN graphical elements (ESTECO S.p.A., 2022).

4. Case study

4.1. Analysis of transport processes

The supply chain analysed in the selected case study refers to the transfer of steel slabs from the port of Mariupol to four rolling mills located in the Friuli Venezia Giulia region, Italy, following the route reported in Fig. 3. Prior to the war, such maritime service was performed on a weekly basis and consisted in the shipping of 10,000 tons of freight. As illustrated in the BPMN model of Fig. 4, ships first moored at a specific quay of the port of Monfalcone characterised by a water depth of 9,7 m, which proved to be suitable for the employed vessels. At that location, half of the cargo was discharged in order to lighten the vessels and, thus, to allow them to continue their journey towards Porto Nogaro, which is the closest port to the rolling mills in the Aussa-Corno area. This operation was strictly necessary because Porto Nogaro presents a lower water depth with respect to the port of Monfalcone. Once arrived at Porto Nogaro, ships were unloaded in the proximity of rolling mills in case these latter possess a dedicated dock, otherwise steel slabs were unloaded at Porto Nogaro and transferred by truck to the respective rolling mill, just like the remaining half of the cargo previously unloaded at the port of Monfalcone.

After the outbreak of the Russia-Ukraine conflict, and the consequent stoppage of operations at the port of Mariupol, the rolling mills under investigation were forced to find a different supply source of steel slabs, which provoked a significant disruption in the whole supply chain. Indeed, nowadays traffic flows originate from countries like Brazil and India, employing bigger vessels with a lower arrival frequency and transferring a larger amount of semi-finished products, up to 60,000 tons. This change in the type of transport means, in the time schedule of vessels arrivals and in the volume of transferred goods translated into a severe supply shock, which required the rearrangement of transport operations under different perspectives. As reported in the BPMN model of Fig. 5, an alternative configuration to the pre-war scenario has been implemented, also considering the use of trains and barges to transfer part of the amount of steel slabs unloaded at the port of Monfalcone. The need of employing further transport modes has been motivated by infrastructural reasons, both on the maritime and land side. Railway services have been introduced to dispatch more quickly the greater quantity of unloaded goods (up to 2100 tons/train), alleviating road traffic, while employing barges turned out to be essential to perform sea transfers because of the limited width and water depth of Porto Nogaro, which do not allow the accommodation of such big vessels. Barges, carrying up to 5000 tons/trip, are needed also to reduce the total land side traffic. Just like in the pre-war scenario, the road mode is still valid to transfer the remaining volume of goods.

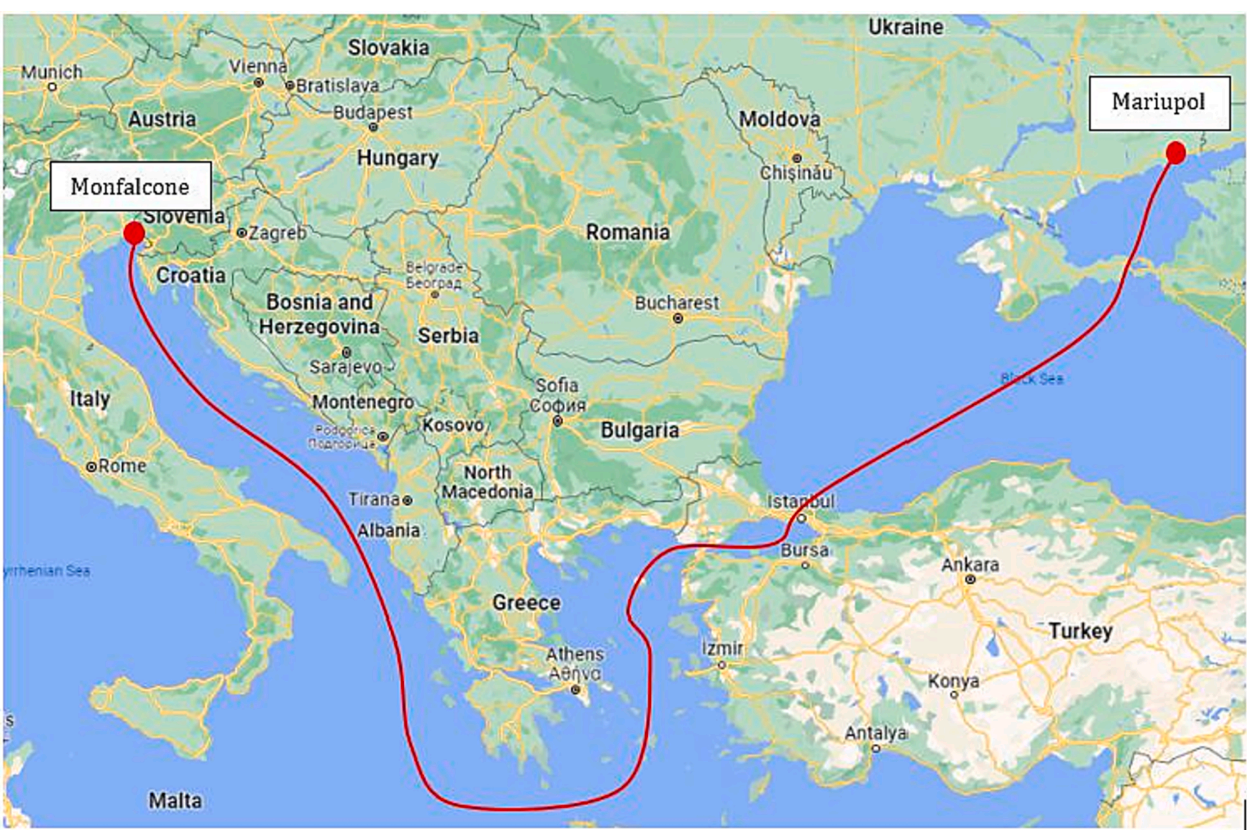

Fig. 3. Route from the port of Mariupol to the port of Monfalcone.

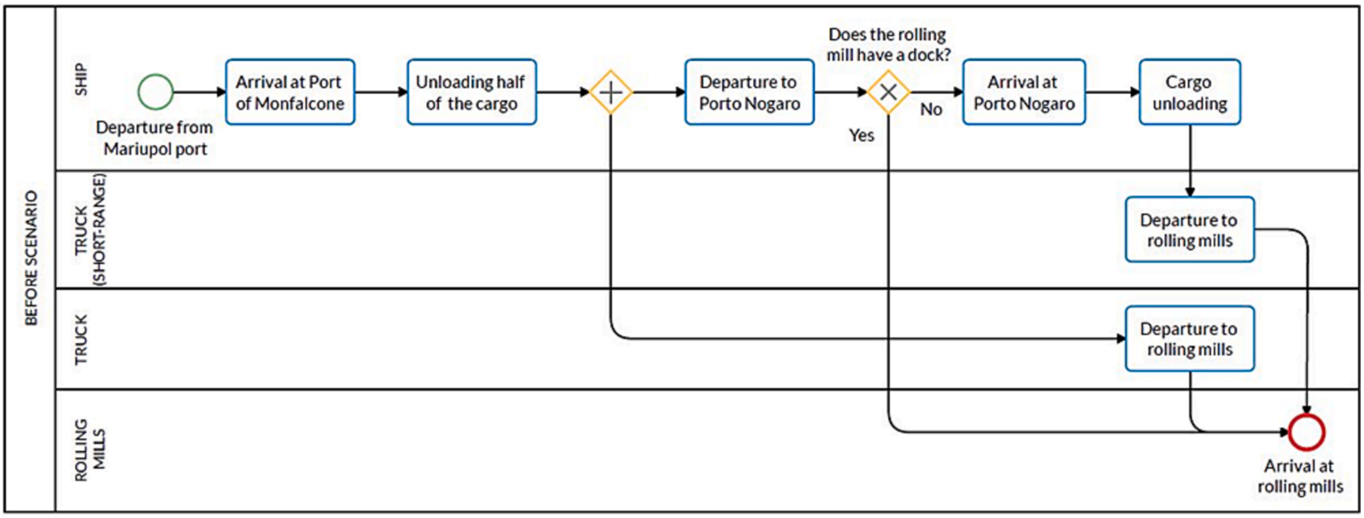

Fig. 4. BPMN model of the pre-war ("before") scenario.

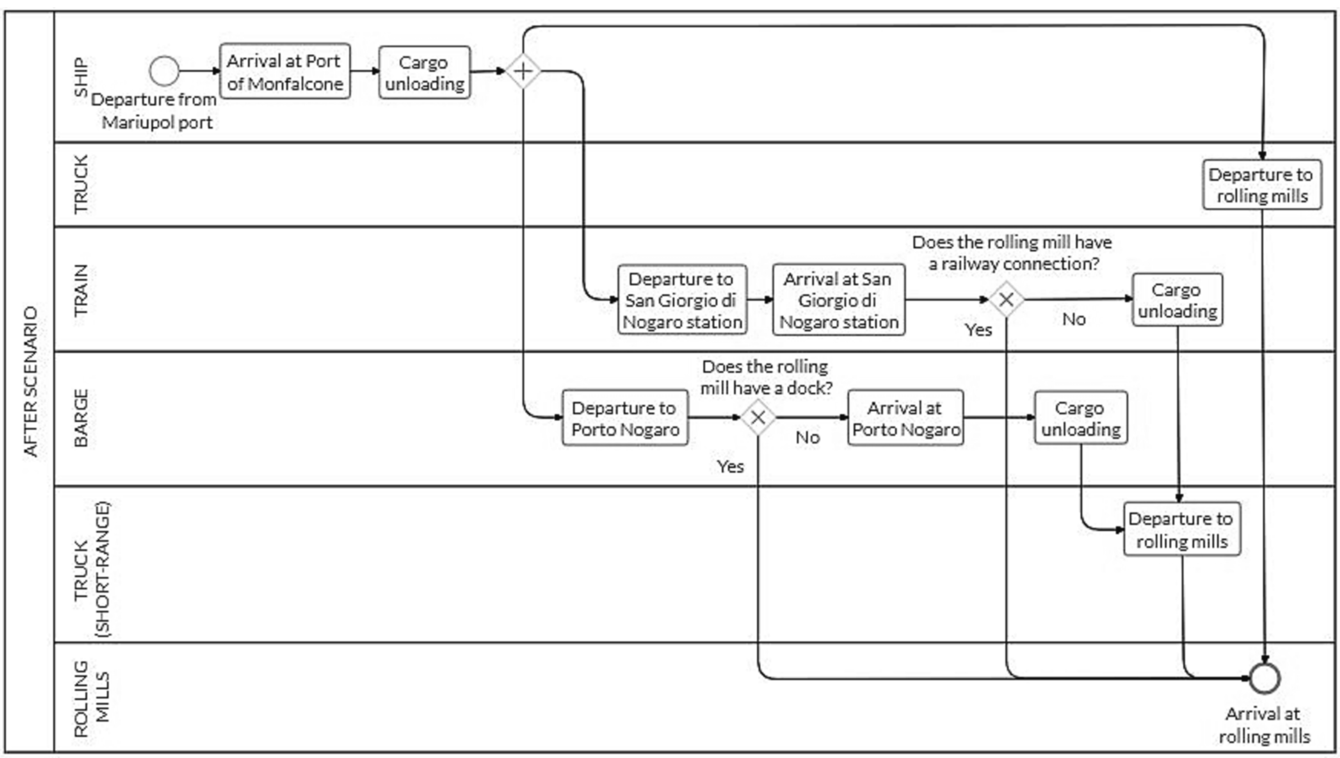

Fig. 5. BPMN model of the alternative scenario.

In regard to the railway mode, Fig. 6 illustrates the railway network connecting the port of Monfalcone with Porto Nogaro and the examined rolling mills served by railway junctions with full red dots.

Fig. 7 shows the BPMN model of railway operations needed for the transfer of steel slabs from the port of Monfalcone to the rolling mills. It can be noticed that the entire process is quite complex, since it involves different actors (i.e., shunting companies, railway companies, Port authorities, and private companies) with relative organisational procedures, which affect operations effectiveness. Besides, most activities take place on specific tracks, whose entity and configuration are not completely adequate to these new movements. Also, the number of required locomotives is higher than before. Nevertheless, such scenario presents some infrastructural and operational drawbacks in correspondence to maritime facilities and inland infrastructures, as discussed in the section 5.

4.2. Analysis of transport costs and times

The BPMN modelling of the examined transport processes has represented the starting point for the estimation of the infrastructural occupancy and the transport costs for each mode. Notably, Tables 1, 2 and 3 report the quantification of the main parameters characterizing different transport modes according to three perspectives, which correspond respectively to:

1) a comparison between the pre- and post-war scenario;
2) a modification in the modal split to reduce transport costs in the post-war scenario;

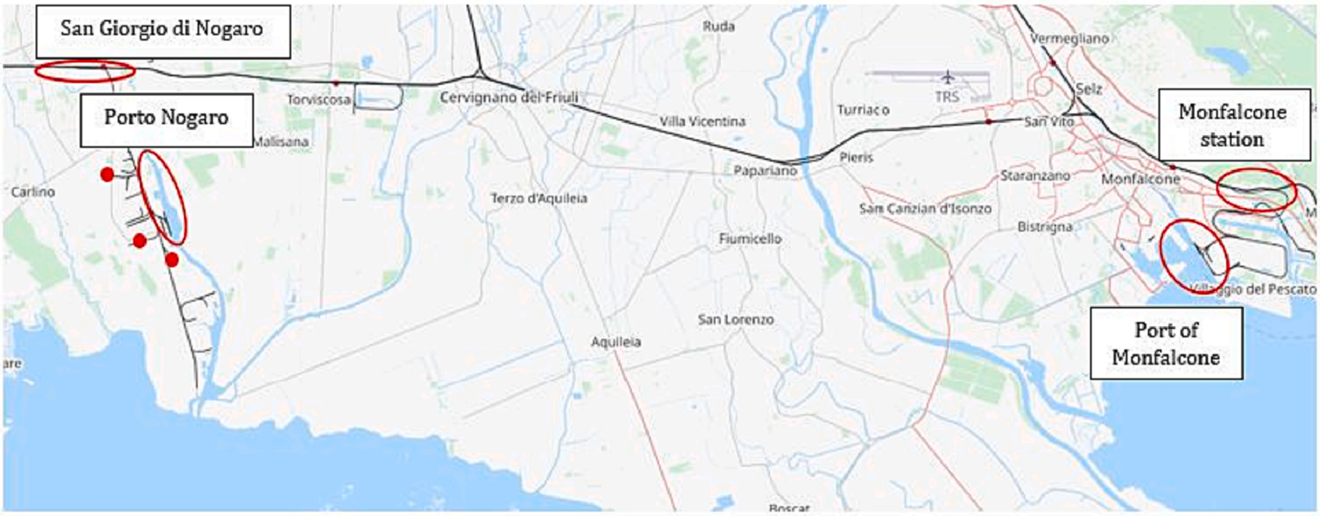

Fig. 6. Railway network from port of Monfalcone to Porto Nogaro and connected plants.

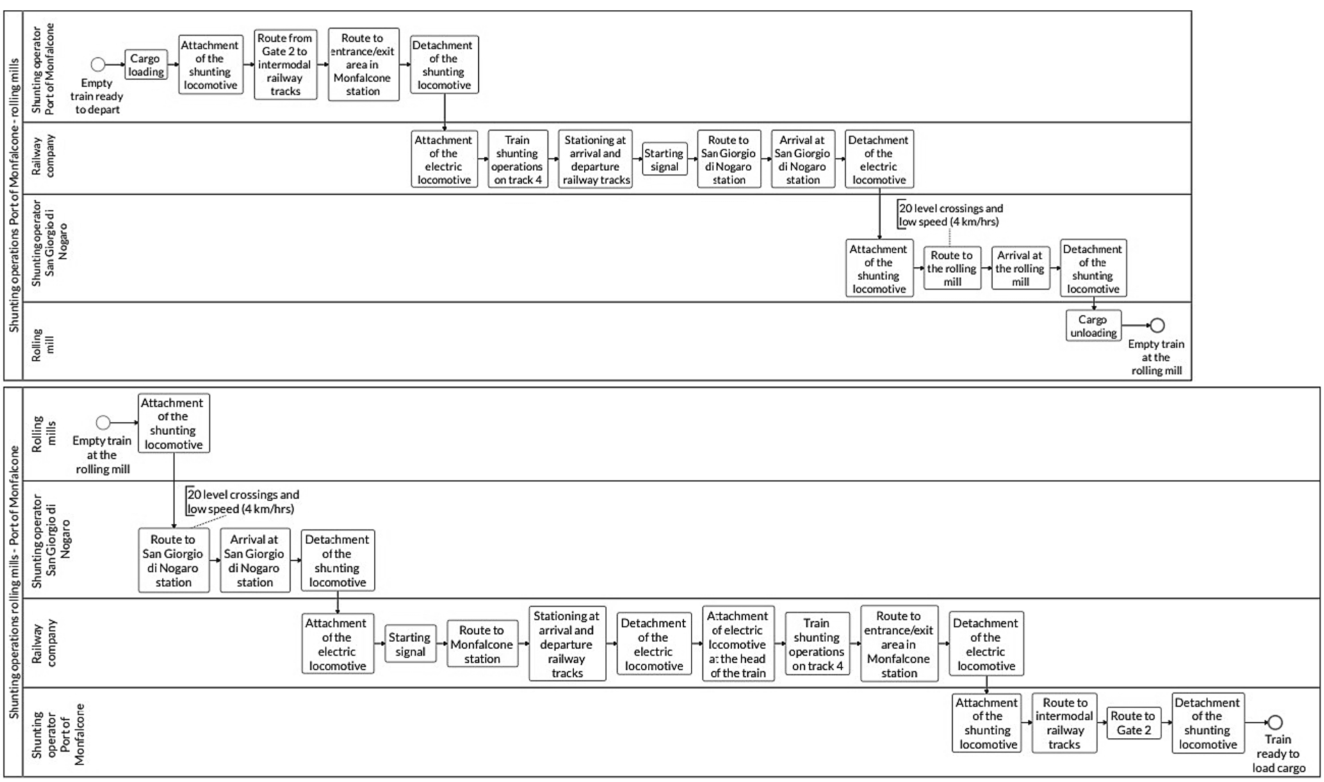

Fig. 7. BPMN model of the railway operations.

3) the application of regional incentives to support environmentally sustainable modes in the post-war scenario.

Row 1 of all tables, named "vessel load", shows the load of each vessel arriving at the port of Monfalcone; before the war outbreak, vessels arrived weekly, while after the war they arrive almost every six weeks. Therefore, the total amount of cargos is the same between the two scenarios, but the difference in the vessel arrival frequency determines a completely different situation from a logistic perspective. According to the modal share (row 2), row 3 shows the amount of load to be carried by each transportation mode from the port of Monfalcone to Porto Nogaro. The corresponding number of trips per unloaded vessel (row 5) is estimated through the proper load per vehicle (row 4). Both the cost per veh*km (row 6) and the roundtrip travel time (row 7) have been estimated considering the distances Monfalcone-Porto Nogaro and all the required activities to be performed in order to use the maximum vehicle capacity in terms of tons/vehicle. Given these values and the loads per transport mode (which depends on modal share), the cost per transport mode (row 9), per unloaded vessel (row 10) and the total costs (row 11) have been calculated. Finally, the total time required to move the vessel load from the port of Monfalcone to Porto Nogaro is shown in rows 13 and 14 in terms of minutes or days respectively. In case of incentives, the proper values are reported in row 8.

Input values included in Tables 1, 2 and 3 have been gathered during

Table 1
Loads, costs and times in the before and after war supply chain asset.

		Before war		SCENARIO 0		
				After war		
Row ID	Means of transport	Vessel	Road	Road	Rail	Barge
1	**Vessel load [ton]**	10,000		60,000		
2	**Modal split [%]**	50	50	25	50	25
3	**Cargo load per mode [ton]**	5000	5000	15,000	30,000	15,000
4	**Tons/"vehicle"**		30	30	2100	5000
5	**No. of trips**		167	500	14	3
6	**Transport cost [Euros/km]**	1008	6	6	529	1175
7	**Roundtrip travel time [min]**	2160	129	129	625	5760
8	**Regional incentive [Euros/ton]**	–	–	–	–	–
9	**Cost per mode of transport [Euros]**	60,500	45,500	136,500	378,000	211,500
10	**Total cost per unloaded vessel [Euros]**	106,000		726,000		
11	**Total cost [Euros]**	**636,000**		**726,000**		
12						
13	**Total time per mode of transport [min]**	2160	21,550	64,520	8750	17,280
14	**Total time per mode of transport [days]**	**1,5**	**5,6**	**16,8**	**7,3**	**12,0**

technical meetings with operators involved in the transfer of slabs through the considered transport modes and on the basis of field measurements. Notably, data concerning transport costs refer not only to expenses for the actual transfer, but also to those necessary for ancillary activities and port services like, for example, loading and unloading operations. Also data concerning transport timings include the duration of side activities, e.g., loading and unloading operations like in the case of costs, delays due to congestion, additional timings required for technical and administrative controls, etc. In particular, time estimations for road traffic come from the analysis of a number of real-life round trips, for which the average value has been considered. For rail movements the expected time is compliant with both the duration of shunting operations and train travel times, including additional waiting times for slot availability along the main network. Timings related to barge transfers have been estimated based on the maximum navigation speed and the necessary time to enter/exit the port, which encompasses the duration of piloting and mooring operations. Starting from these assumptions, calculations have been then performed according to the principles of transport engineering and economics.

At financial level, Table 1 indicates the significant increase of transport costs in the post-war supply chain configuration, which is due to a higher cost to perform freight transfers using trains and barges. The required times to move all the vessel load are lower than the ship interarrival time, thus creating a stable logistic chain.

Table 2 illustrates an alternative modal split which would enable to decrease the difference between transport costs related to the post-war supply chain and the total expenses obtained in the pre-war supply chain configuration for the greater volume of incoming steel slabs after the conflict outbreak. It can be noticed that such condition could be achieved just rising the share of trucks, since road transport is characterized by a lower unit cost with respect to the other considered modes. By contrast, an increase in road traffic flows would entail higher negative external costs, especially in terms of environmental impacts.

Finally, Table 3 indicates the cost reduction which could be accomplished thanks to the implementation of regional incentives for the various transport solutions, while maintaining the current modal split. It can be observed that the cost of the whole supply chain would be comparable to the one necessary to transfer the present amount of cargos adopting the pre-war transport asset. However, taking into account the abovementioned limitations of the current railway network, the provision of subsidies could not be a sufficient stimulus for the survivability of the regional iron supply chain, because of the competition with other significant production chains in the same territory.

Along with the discussion of results reported in the following section, these considerations have contributed to formulate the suggested modifications to the existing investment policies at infrastructural, financial and occupational level.

5. Results and discussion

The analysis of the BPMN models of the examined processes and their quantification according to various scenarios visibly pointed out the main differences in the supply chain structure before and after the beginning of the Russian-Ukraine conflict, revealing the urgence for new

Table 2
Loads, costs and times for a different modal share option.

		Before war		SCENARIO 1		
				After war		
Row ID	Means of transport	Vessel	Road	Road	Rail	Barge
1	**Vessel load [ton]**	10,000		60,000		
2	**Modal split [%]**	50	50	62	30	8
3	**Cargo load per mode [ton]**	5000	5000	37,200	18,000	4800
4	**Tons/"vehicle"**		30	30	2100	5000
5	**No. of trips**		167	1240	9	1
6	**Transport cost [Euros/km]**	1008	6	6	529	1175
7	**Roundtrip travel time [min]**	2160	129	129	625	5760
8	**Regional incentive [Euros/ton]**	–	–	–	–	–
9	**Cost per mode of transport [Euros]**	60,500	45,500	338,520	226,800	67,680
10	**Total cost per unloaded vessel [Euros]**	106,000		633,000		
11	**Total cost [Euros]**	**636,000**		**633,000**		
12						
13	**Total time per mode of transport [min]**	2160	21,550	160,010	5175	5760
14	**Total time per mode of transport [days]**	**1,5**	**5,6**	**41,7**	**4,3**	**4,0**

Table 3
Loads, costs and times in case of incentives.

		Before war		SCENARIO 2		
				After war		
Row ID	Means of transport	Vessel	Road	Road	Rail	Barge
1	**Vessel load [ton]**	10,000		60,000		
2	**Modal split [%]**	50	50	25	50	25
3	**Cargo load per mode [ton]**	5000	5000	15,000	30,000	15,000
4	**Tons/"vehicle"**		30	30	2100	5000
5	**No. of trips**		167	500	14	3
6	**Transport cost [Euros/km]**	1008	6	6	529	1175
7	**Roundtrip travel time [min]**	2160	129	129	625	5760
8	**Regional incentive [Euros/ton]**	–	–	–	1,92	2,15
9	**Cost per mode of transport [Euros]**	60,500	45,500	136,500	320,290	179,209
10	**Total cost per unloaded vessel [Euros]**	106,000		636,000		
11	**Total cost [Euros]**	**636,000**		**636,000**		
12						
13	**Total time per mode of transport [min]**	2160	21,550	64,520	8750	17,280
14	**Total time per mode of transport [days]**	**1,5**	**5,6**	**16,8**	**7,3**	**12,0**

policies related to:

- the development of infrastructural networks;
- the introduction of possible supporting incentive schemes;
- the necessity of professional training.

In fact, from a transport perspective, the above-described changes in the supply chain structure have determined the transition from a logistics system characterised by frequent arrivals of vessels carrying relatively small loads, to a transport solution in which greater amounts of goods at lower headways need to be processed. Consequently, the sizing of the entire supply chain should be revisited, as indicated in the followings for each considered transport mode.

5.1. Maritime transport

In regard to the maritime system, the entry/exit routes from/to ports should be adjusted in terms of both width and water depth, in order to allow the use of larger ships and the simultaneous presence of barges within the same port. Besides, the quay of the port of Monfalcone should be enlarged and better equipped, so as to meet the need of unloading volumes of steel which are six times bigger than the ones managed prior to the Russian invasion.

5.2. Railway transport

With respect to the railway system, following the war outbreak, new bottlenecks have emerged in relation to the three aspects listed below:

1) Shunting connection between the main involved railway stations and the port or the rolling mills: The connection between the quay of the port of Monfalcone and the station of Monfalcone (Fig. 8) is a single and not electrified track, with a steep slope of up to 20 ‰. Therefore, the low speed achievable by trains along this route (around 6 km/h) implies a quite long travel time, which causes a significant capacity reduction, and high costs. The rise in short-range rail trips (from the port of Monfalcone to the industrial plants), which were not considered in the pre-war scenario, leads to a significant decrease in the residual capacity of the port of Monfalcone, limiting its potential of accommodating other shares of railway traffic. The configuration of the railway junction between the San Giorgio di Nogaro station and the rolling mills is also critical, since the presence of a large number of level crossings requires very strict operating requirements which entail a strong increase in the travel time. Therefore, the capacity of this connection is really limited and inadequate to accommodate such a significant increase in railway traffic. In both cases, no interventions for the modernization of connections had been previously planned, leading to a condition for which, at present, the railway mode constitutes a not entirely feasible option for large quantities of steel slabs.

2) Stations: Both main stations on the national railway network, i.e., the Monfalcone and San Giorgio di Nogaro stations, should accommodate higher traffic volumes than before. This increase would create capacity issues due to a different and more challenging use of existing tracks. In particular, the arrival and departure tracks 4, 5, 6 and 7 in the Monfalcone station would be intensively used as buffer tracks for freight services. This buffer area would be necessary to perform an efficient connection between two independent systems, which means considering, on one hand, the needs of the port of Monfalcone and, on the other hand, the availability of slots on the national railway network in one of the most congested sections of north-eastern Italy. Besides, the single track serving the shunting connection in the San Giorgio di Nogaro station appears completely insufficient as volumes increase.

3) Line: As mentioned in the previous bullet point, the Monfalcone station is located in the most critical section of the national railway network serving the port of Trieste. Indeed, it is placed between two junctions where the residual capacity is very low, in the face of a significant increase in traffic volumes registered along the European freight Corridors (i.e., the Mediterranean and Adriatic Baltic Corridors). Therefore, short-range rail traffic, such as the one between the port of Monfalcone and the plants in Porto Nogaro, represents a further traffic component which would be added to the existing ones, competing for residual capacity.

In this context, before the Russia-Ukraine war, the strategic vision for the development of the railway network in the examined area was essentially aimed at accommodating the very significant expected increase in port traffic in relation to the two aforementioned European Corridors. The Monfalcone station should have constituted a potential collection of buffer tracks to better manage freight services involving the Trieste railway node, especially in the presence of disturbances. The role of the shunting connections would have been certainly marginal. Similarly, the role of the quay of the port of Monfalcone, as well as of the one of Porto Nogaro, would have definitely assumed a secondary importance. In line with that goal, pre-war policies were strongly targeted to an enhancement of the technological aspects supporting long-haul railway services, like, for example, the signalling and traffic regulation systems.

5.3. Road transport

With reference to the road system, the transfer of steel slabs by means of specific trucks took place already before the outbreak of the Russia-Ukraine war, creating significant problems while crossing the inhabited centres. Indeed, the Municipality of Monfalcone had emanated

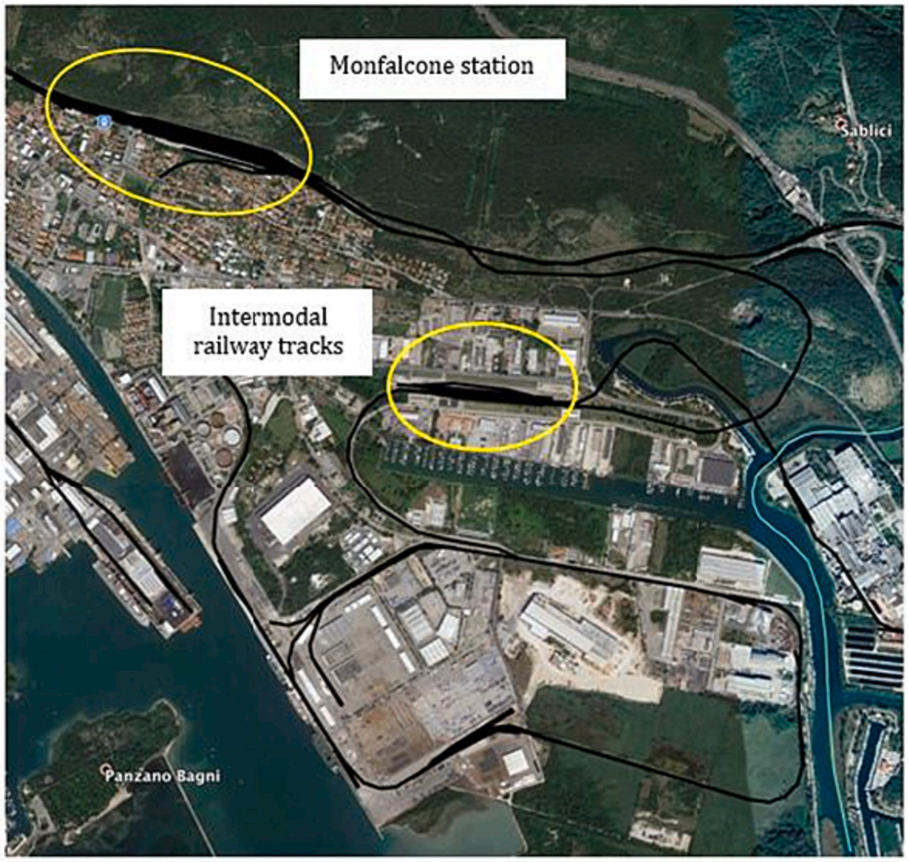

Fig. 8. Railway connection between port station and Monfalcone station.

ordinances aimed both at reducing truck loads and at defining mandatory routes that slightly lengthened the itinerary of vehicles. The recently inaugurated Porpetto ring road was also intended to move heavy traffic outside the inhabited centres. Externalities in terms of social and environmental impacts are expected in case of a further increase in road traffic, which would require trucks to travel along the motorways with an increase in mileage of almost 10 km, as illustrated in Fig. 9.

5.4. Incentives

As described in the introduction to this paper, given the economic and employment impact of the steel industry in the Friuli Venezia Giulia region, the offer of new incentive measures in addition to redesigning the trajectories of infrastructural developments, seems to be an appropriate solution to support the absorption of cost increases generated by the variations in the transport chain. Even the adoption of different logistics strategies considering greater storage at industrial plants could have consequences on the economic and financial statements of the engaged companies, possibly threatening their stability. National incentives named “ferrobonus” and “hydrobonus” have not been explicitly taken into account in the paper, since only incentive schemes at regional level have been considered in calculations. These latter represent possible additional incentives with respect to the national ones and have been estimated in order to equal the total pre-war cost with the post-war one given the considered modal share among the different transport modes.

The discussed changes in the logistic chain point out once again the need to make system-wide strategic decisions regarding network developments, in which the economic incentives are aimed at determining a different modal shift towards environmentally sustainable transport modes.

5.5. Human resources

Last but not least, the analysis of the current situation highlights another important aspect, which is the availability of skilled human resources able to carry out transport operations according to the new loads and vehicles for each selected mode. This issue refers in particular to truck drivers, to drivers, inspectors and trainers for rail transport, and, finally, to seamen for barge transport. All these professional positions require a fairly long training period before becoming fully operational. Based on this perspective, disruptions caused by the Russia-Ukraine conflict made it particularly clear the importance of a synergy between the productive and educational world.

In this regard, the paper is also intended to stress the urgence for the implementation of the suggested policy advancements, considering the quite long formal procedure necessary to actually realize them. The results obtained combining model and quantitative analysis to approach the reported case study definitely shed light on the contrast between the sudden and relevant effects of potential disruptions on supply chains and the more time-consuming regulatory response. Together with the observed infrastructural criticalities, such temporal discrepancy could even generate industrial repercussions, which could lead companies to physically move primary production plants closer to processing facilities in order to shorten the supply chain.

6. Conclusions

The Russia-Ukraine war represents one of the biggest disruptions of the recent past which provoked severe implications on global economy, directly altering the supply chain of products exported by the two conflicting countries. The paper analyses a specific case study related to the transfer of steel slabs from the Ukrainian port of Mariupol to some rolling mills located in the north-eastern Italian region of Aussa-Corno,

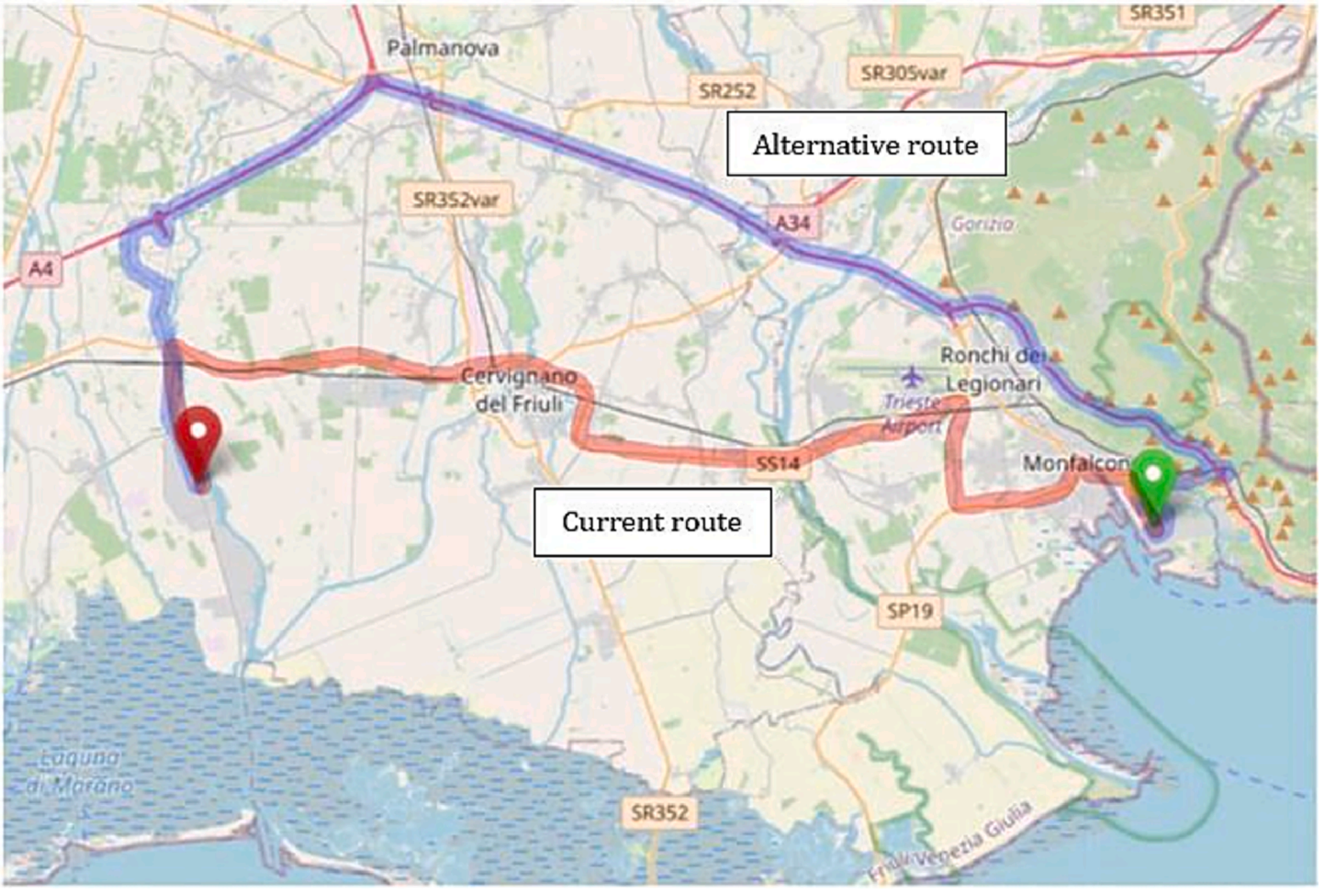

Fig. 9. Comparison between the current and alternative route.

according to a transport perspective. The effects of the war on such freight exchanges have been modelled using the BPMN standard which enabled to their structure before and after the conflict outbreak. Following the stoppage of shipping flows from the port of Mariupol, rolling mills resorted to alternative supply sources which significantly affected the examined transport chain. Such change impacted on the maritime and land side, both at infrastructural and operational level, because of higher volumes of unloaded goods at a lower vessel arrival frequency. The creation of BPMN models of the considered transport processes, along with the quantification of their main parameters and costs, has permitted an in-depth analysis of the occurred modifications, revealing possible bottlenecks. These latter gave insights for the proposal of new policies which would address the critical issues listed below:

- the development of infrastructural networks on the basis of new emerging priorities;
- the introduction of supporting incentive schemes dedicated to production companies;
- the necessity of professional training, to prepare highly demanded skilled people operating in the logistics chain.

In the end, referring to the notion of resilience mentioned in the literature review, the examination of transport processes related to the considered supply chain proved that the reaction of this latter in the aftermath of the Russian-Ukraine conflict actually complied with such concept. In fact, the supply chain analysed in the paper showed high flexibility in sourcing, capacity redundancy given by the substitution of transport modes, adaptability through the re-routing of requirements, and, to a certain extent, recovery in terms of resource mobilization. At the same time, some threats are still present due to, for example, turbulence caused by geopolitical tensions, sensitivity related to the complexity of the supply chain, and resource limits in distribution capacity and human labour.

In light of these features, policy implications illustrated in the discussion of results outline the wide scope of the performed investigations. Bearing in mind the critical role of the examined supply chain for the regional territory, the study exceeded the aim of analysing transport solutions for the survivability of the supply chain, enabling to capture new possibilities of growth for its transport nodes. Proof of this is represented, on one side, by the greater contribution of the Port of Monfalcone in accommodating additional railway traffic thanks to the allocation of further infrastructural investments. Indeed, advancements envisioned for the Port of Monfalcone railway network permits the enlargement of its catchment area and, thus, an increase in its competitiveness in the North Adriatic region. On the other side, the enhanced relevance gained by Porto Nogaro with respect to barge transfers can potentially serve traffic flows involving other regional ports for alternative demand segments, such as container traffic coming from the Port of Trieste.

Future developments of the presented research study consist, on one side, in a deeper understanding and focus on the resilience of the considered case study and, on the other side, in computing the external costs involved in the different transport solutions and performing a comparison with the proposed incentives. Furthermore, additional economic investigations will be carried out to analyse the financial statements of rolling mills, since they have been requested of some storage availability due to the need of processing a greater amount of goods in a shorter time period. Besides, the versatility of the adopted modelling technique enables the transferability of the proposed methodology to other supply chains, with the aim of investigating war implications on further sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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