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Corresponding Author:	Angela Carboni Politecnico di Torino Torino, ITALY
First Author:	Angela Carboni
Order of Authors:	Angela Carboni
	Federico Orsini
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Dry ports and related environmental benefits: a case study in Italy

Angela Carboni[a1], Federico Orsini[b]

[a] DIATI, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy
[b] DICEA Università degli Studi di Padova, Via Marzolo 9, 35131, Padua, Italy

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[1] Corresponding author. Tel: +390110905641
E-mail address: angela.carboni@polito.it

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The maritime containerised transport continues to grow thus an efficient seaport inland access becomes crucial for the performance of the entire intermodal transport chain. Dry ports are inland intermodal terminals directly connected to seaports via rail, which operate as trans-shipment hubs and provide services such as storage, consolidation, depot and custom clearance. In addition to offering benefits in terms of operational costs and efficiency, dry port concept implementation can produce positive effects also under an environmental point of view, promoting the modal shift from road to rail.

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Highlights

- With dry port implementation, traffic-related emissions can be reduced.
- A general methodology to estimate dry ports environmental benefits is introduced.
- A real-world case study located in Italy is presented and discussed.
- In the analysed case study, a significant reduction in emissions is reported.

Keywords

Dry port, intermodal freight terminal, simulation-based method, environment, emission model

1. Introduction

Nowadays, the phenomenon of increasing ship capacity can lead to a port infrastructure crisis due to the size of the ship and the huge number of containers to be handled (more than 21000 TEU for new generation ships). Often the ports do not have storage areas such as to accommodate and manage these goods flows and the traffic of heavy-duty vehicles around the seaport can cause relevant congestion and environment problems. As underlined by Awad-Núñez et al. (2016), the increase in activity at seaports is producing three undesirable effects: increasing road congestion, lack of open space in port installations and a significant environmental impact on seaports. These adverse effects can be mitigated by moving part of the activity inland, as shown in this paper. In Europe there is an imbalance of cargo market between North European and South European ports, attributable to nautical accessibility, operational efficiency and inland connections (Pachakis, Libardo, and Menegazzo 2017); the last point will be addressed in this paper. As underlined by Acciaro et al. (2017) ports compete both on the sea-side and on the land-side.

In this framework, the role of back-ports (terminals or logistic platforms near ports) and their connections are becoming significant to ensure adequate performances in terms of efficiency, capacity, sustainability. The dry ports are defined as inland freight terminals that are connected directly to one or more seaports with high-capacity transport means, where customers can drop off and pick up their standardised units as if they were at a seaport. In fact, this type of node operates as trans-shipment hubs and provide services such as storage, consolidation, depot and custom clearance. According to Roso (2007), a functional seaport inland access is important for the efficiency of the entire transportation chain if the maritime containerised transport continues to increase. The inland routes are often covered by road transport because ports do not always have good and efficient railway connections. The dry port concept, as underlined before, means that the inland intermodal terminals should be directly connected to seaports via rail, namely high-capacity transport means. In particular, the efficient type of service to connect seaport and dry port can be the shuttle service which implies trains with a scheduled and fixed composition and large quantities of goods with the same path. This kind of rail service guarantees also lower costs and less time for terminal operations. Thus, this solution for connections to the hinterland in addition to providing benefits in terms of operational costs and efficiency, promoting modal shift from road to rail can produce positive effects for environment. Rail transport, in fact, is the less expensive mode in terms of environmental costs in comparison to road transport (Henttu and Hilmola 2011). The proposed alternative can achieve the main objective suggested by White Paper on Transport of 2011: the modal shift of road freight to other modes such as rail or waterborne transport (European Commission 2011).

In Europe in 2016 the 72% of CO_2 transport emissions is due to road transportation in comparison with the 0,5% of rail sector; in particular CO_2 emissions from heavy-duty vehicles represent around thirty per cent of all road transport emissions (European Commission 2018). Considering these statistics, reducing the number of lorries on the road will mean a reduction of emissions and air pollution by the freight transport sector, as well as reduced congestion and accidents on our roads (European Union Agency for Railways 2018).

The inland terminal can function as "extended port gate" to streamline the port and customs practices of the units that could take place directly in the terminal in order to free spaces in the ports since the railway mode can guarantee a controlled transport. Services such as storage, consolidation, depot, maintenance of containers, track and trace, customs clearance, etc. should be available at the dry port, which extends the gates of the seaport inland, with shippers viewing the dry port as an interface to the seaport and shipping lines (Roso 2007). In Italy, the Customs and Monopolies Agency initiated a series of projects called Fast Corridor to move containers with a single transport contract also in the back-port segment. The benefits of this initiative can be port areas decongestion, reduction of container residence times in the port, with consequent cost savings, reduction of travel times, greater security, thanks to the combination of document controls and physical monitoring of the flow of goods and the digitalization of the process[1].

It is also important to consider the digital tachograph obligation, with the associated rest times for drivers, as one of the main limitations of road transport. According to the EU rules on driving hours, a truck driver must not drive more than: 9 hours a day - this can be extended to 10 hours twice a week; 56 hours a week; 90 hours in any 2 consecutive weeks.

To achieve a satisfactory modal shift towards intermodal transport Lupi et al. (2018) suggested an improvement of rail connections efficiency. Among their outcomes, they underlined the possible convenience of intermodal transport also over a short distance as in the case of port and dry port connection due to the elimination of the pre-haulage and related operations. An interesting literature review on research findings of dry port is proposed by Lättilä et al. (2013) to show

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[1] https://www.adm.gov.it/portale/dogane/operatore/ecustoms-aida/progetti-aida/fast-corridor

that dry port is a multi-faceted problem. They have identified the main related topics to classified research papers: stakeholders' analysis, costs of transportation, throughput, container management, case studies and environmental benefits. The last two aspects of dry port concept will be the subject of this paper. A more recent literature review on inland port development is reported in the paper by Witte et al. (2019) which contributes to defining the most important streams in dry port research. Their review shown that the research designs of the analysed papers have been dominated by conceptual studies or case studies, the same category as this work.

Jeevan et al. (2018) investigated the impact of dry port operations on container seaport competitiveness. Roso et al., (2009) extended the theory behind the dry port concept and defined three dry port categories on the basis of their location and function (distant, midrange and close) investigating also their benefits. They underlined that the dry port concept means shifting flows from road to rail generating benefits in terms of environment and quality of life, as will be seen from the following sections of this paper. In addition, the dry port implementation can offer seaports the possibility of securing a market in the hinterland, increasing the throughput without physical port expansion as well as better services to shippers and transport operators. Finally, the seaport cities can benefit from less road congestion and/or less need for infrastructure investments. The concept of dry port further has been addressed by Veenstra et al. (2012) exploring the relationship with the concept of the extended gate and analysing the possible bottlenecks and related solutions. The study by Bask et al. (2014) also contributed to an understanding of the concept of seaport–dry port connection through a description of their development over time, investigating the potential benefits for the actors of the transport system in different types of dry ports implementations (distant, midrange close), including two in-depth case studies from Northern Europe. A process benchmarking strategy among the Malaysian dry ports is proposed by Jeevan et al., (2017) to enhance dry port performance. They obtained that to assist all the key players in the container seaport system efficiently and effectively the dry ports need to improve their transportation infrastructure and operation facilities, container planning strategy, competition, location and externalities. Similar results are shown by Othman et al. (2016). The challenges of Malaysia's hinterland connectivity such as an imbalanced modal share, insufficient rail capacity and limited services, road congestion and space constraints of inland facilities are investigated by Chen et al. (2016) through a qualitative methodology.

Then, Bärthel and Woxenius (2004) used a technological systems approach to evaluate the development of intermodal transport for small flows over short distances. They obtained that the diffusion is hampered by several factors as insufficient network connectivity. Crainic et al. (2015) covered the issue of large flows over short distances, specifically they design a network model to plan a shuttle service between dry port and seaport.

The current paper, as underlined, includes a quantitative evaluation of environmental implications of seaport- dry port connections. Tsao and Linh (2018) also included carbon emission consideration in their Continuous Approximation approach to design a seaport-dry port network. Their results showed that the proposed method could address the seaport-dry port network problems well. Henttu and Hilmola (2011) instead included emission costs in the total transportation costs in their macro gravitational model to support the implementation of dry ports as a strategy for inland distribution. Then they applied the model in the Finnish transportation network composed of several seaports and dry ports. The same case study is proposed by Lättilä et al. (2013) with a discrete-event simulation method that includes the level of CO_2 emissions and costs of freight transport in different configurations. As emerged also in this paper, they show that there are additional emissions in a direct seaport connection due to higher amount of waiting at the seaport compared to a dry port and on the other hand, there is additional handling cost in the dry port as the units need to be shifted from road to rail. Finally, they obtained that the implementation of dry ports can decrease the amount of CO_2 per container by 32% to 45% depending on the price levels of electricity and diesel fuel. Roso (2007) for example, measured a reduction of 25% of CO_2 emissions in addition to benefits in terms of congestion and waiting time in Gotheborg hinterland thanks to Boras dry port. Regmi and Hanaoka (2015) proposed a bottom-up approach to assess carbon emissions from freight transport operations. Their results showed that in the base-case scenario, a 43% mode shift to rail from road and a 30% reduction in CO_2 emissions can be expected compared with the business-as-usual scenario.

As can be observed from this literature review, there is a relatively large literature on operational aspects of dry ports; however, only few works dealt with quantitative evaluation of their environmental implications.

The current paper presents a simulation-based method to quantify environmental benefits for a dry port implementation applied to a real-world case study in Northern Italy. In particular, the study focuses on quantifying environmental benefits, in terms of emission reduction, produced by the intermodal shift in the future scenario. The presented methodology is general and can be easily transferred to other scenarios. The case study discussed in the paper is a good real-world example of how this method can be applied and what kind of output can produce.

The proposed method is not an end in itself and should not be looked at as a standalone application, but rather it is thought to be a part of a more comprehensive cost-benefit analysis, to evaluate the effect of a dry port implementation. In particular, the methodology focuses on the portion of the analysis which takes into consideration transport externalities, such as environmental impacts, congestion and safety.

This paper is organized as follows: Section 2 introduces the method across its main steps grouped into three phases commonly used in the transport analysis traffic demand analysis, traffic supply model and assignment and emission model. Section 3 reports the case study and the application of the steps described above. Section 4 concludes with some remarks and indications for future research.

2. Method

The methodology proposed in this paper aims to evaluate the benefits for the port hinterland, thanks to the introduction of a dry port with the characteristics described in section 1. Thus, to wrap up, the services such as storage, consolidation, depot, maintenance of containers, track and trace, customs clearance should be available at the intermodal terminal with the dry port function to reduce the trucks queue and free up space in the port docks. The connection between dry port and seaport is performed by shuttle train service, which means trains with fix composition, thereby the load remains unchanged until the end of the journey, without the need for decomposition and composition operations, therefore reducing the costs and times of terminal operations. The rail mode, in fact, should guarantee a safe, controlled, fast and reliable connection.

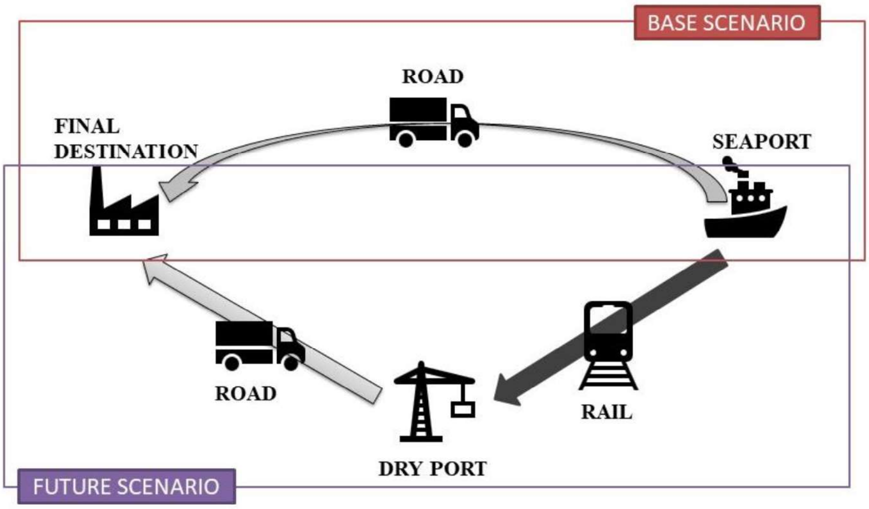


Fig. 1 Schematic representation of possible port-inland connections

The proposed method therefore allows a comparison between: a base scenario, without the dry port, where the connection between the seaport and the final destination (or origin) is covered by road; and a future scenario with the implementation of dry port connected by a frequent rail service and the last mile covered by road (Fig. 1).

In Fig. 2 the schematic diagram of the simulation-based method proposed in this paper to quantify environmental benefits for a dry port implementation is shown. The method is composed of three main phases, described in the following sections, commonly used in the transport world, and, in turn, characterized by two sub-phases which will be applied to a case study reported in Section 3.

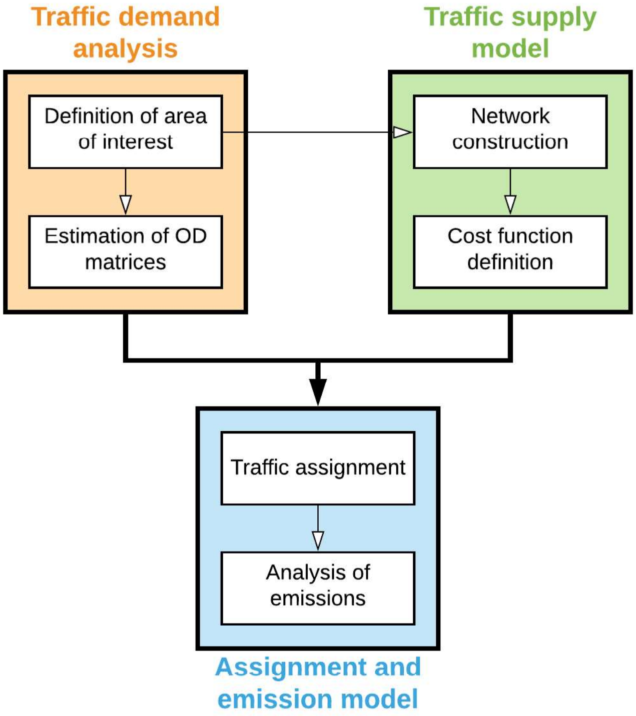


Fig. 2 The outline diagram of the simulation-based method proposed to quantify environmental benefits for a dry port implementation

2.1 *Traffic demand analysis*

In traffic demand analysis the analyst must first define the geographical area in which to concentrate the focus of the study; preliminary transportation demand analysis, previous studies or the knowledge of the scenario may help in defining it. In the specific scenarios in which the present methodology is to be applied, the area of interest must include the region served by the seaport (i.e., its hinterland), which may or may not correspond to geographical/administrative regions, according to the goods flow (origins and destinations) in the inland.

The area must then be divided into several zones, whose extension has to be coherent with that of the area of interest. It is also appropriate to consider a number of zones outside the area of interest, and to reserve additional zones for seaports, dry ports and other relevant attractors in the area, based on the market framework considered in the analysis.

The next step is to estimate trips between the zones previously defined. Several input data may be employed, such as: traffic counts (Bera and Rao 2011), floating car data (Zhang et al. 2010; Carrese et al. 2017), plate scanning (Mínguez et al. 2010).

2.2 *Traffic supply model*

A transportation network should then be built to represent the physical and operational characteristics of the system. The road network should have a level of detail coherent with the extension of the area of interest. Each link of the network is associated to a cost defined by a cost function; for links representing roads the cost can include, for example, travel time and tolls, whereas costs of links representing operations performed within a logistics terminal may be defined by much more complex functions. The links and nodes compose the transport chain between origin and destination; in order to define the cost function for each link, it is useful to investigate the cost of door-to-door transport in its individual components and its variations in the two main scenarios analysed (see equation (1) and (2)). Subsequently, the generalized cost components are included in the link cost function according to the scenario.

The trend in average cost for freight transport can be influenced by several technological, physical and economic aspects as the distance, the weight of goods, the vehicle capacity, the infrastructure congestion, the transport mode, the level of organization, the efficiency, etc. In the proposed methodology, the main factors included in the cost function are the average costs and the time. Obviously, time and cost are related to the different phase of transport in each scenario and can be influenced by the presence of some technologies, the organization and the number of units handled for instance.

According to the scheme in Fig. 1 the generalized travel cost function for base scenario (eq. 1) includes the time and costs due to the activities taking place in the seaport and in the road connection; for the future scenario (eq. 2) the operations are related to the seaport, the rail connection, the dry port and the road connection. It is important to underline that also the allocation of certain activities and therefore relative times and costs change in the two scenarios.

$$C_{Sbase}(d,t) = \beta_1 c_{unl}^{sp} + \beta_2 c_{dc}^{sp} + \beta_3 c_s^{sp} \cdot t_s + \beta_4 c_{ld}^{sp} + \beta_5 c^{rd} \cdot d_{rd} + \beta_6 t_{unl}^{sp} + \beta_7 t_{dc}^{sp} + \beta_8 c_s^{sp} + \beta_9 t_{ld}^{sp} + \beta_{10} t^{rd} \quad (1)$$

$$C_{Sfuture}(d,t) = \beta_1 c_{unl}^{sp} + \beta_2 c_{ld}^{sp} + \beta_3 c^{rl} \cdot d_{rl} + \beta_4 c_{unl}^{dp} + \beta_5 c_{dc}^{dp} + \beta_6 c_s^{dp} \cdot T_s + \beta_7 c_{ld}^{dp} + \beta_8 c^{rd} \cdot d_{rd} + \beta_9 t_{unl}^{sp} + \beta_{10} t_{ld}^{sp} + \beta_{11} t^{rl} + \beta_{12} t_{unl}^{dp} + \beta_{13} t_{dc}^{dp} + \beta_{14} t_s^{dp} + \beta_{15} t_{ld}^{dp} + \beta_{16} t^{rd} \quad (2)$$

where
x^{sp}= seaport
x^{dp}= dry port
x^{rd}= road section
x^{rl}= rail section
c_{unl}= unloading costs [€]
c_{dc}= documents check costs [includes all the procedure related to unit check, customs and weighing of containers for instance] [€]
c_{ld}= loading costs [€]
c_s= storage costs [€/h]
t_s= time of storage [h]
c^{rd}= cost per kilometre by road [€/km] [includes all cost related to rail transport, also the staff costs for example]
c^{rl}= cost per kilometre by rail [€/km] [includes all cost related to rail transport, also the rental of railway wagons for example]
d= distance [km]
t_{unl}= unloading time [h]
t_{dc}= documents check time [includes all the procedure related to unit check, customs and weighing of containers for instance] [h]
t_{ld}= loading time [h]
t_s= time of storage [h]
c^{rd}= cost per kilometre by road [€/km] [includes all cost related to rail transport, also the staff costs for example]
c^{rl}= cost per kilometre by rail [€/km] [includes all cost related to rail transport, also the rental of railway wagons for example]
β= coefficient

2.3 Assignment and emission model

After having defined traffic demand and supply models, it is possible to assign trips to the network. Several traffic assignment models exist (Patriksson 1994; Barcelo 2010) and the choice of which to use must be made coherently with the scale of the problem and the available information.

Having assigned traffic volumes to the network, it is possible to calculate the emissions produced by the vehicles for each link of the network. Several vehicle emission models exist in the literature (Demir, Bektaş, and Laporte 2011); one of the most commonly used method in both research and real-world application is the COPERT method, proposed by the European Environment Agency (Leonidas Ntziachristos et al. 2009) (Leon Ntziachristos and Samaras 2018).

There are three “Tiers” in the COPERT method; the choice of which to use should be made according to the available input information. In this paper (see Section 3.6), Tier 3 method was employed. Having defined:

- *l*, a given road link in the network;
- *t*, a time period (e.g., one day, one week);
- *i,* an air pollutant (e.g., CO_2, NOx);
- *j*, a vehicle class (e.g., passenger car, heavy duty truck);
- *k*, a vehicle-technology (e.g. Euro 5 diesel, Euro 6 petrol);
- L_l, the length of road link *l* [km];

- $V_{l,t,j,k}$, traffic volume of vehicles class j with technology k in link l during time t [veh/unit of time];
- $EF_{i,l,j,k}$, emission factor of pollutant i for vehicles j with technology k [g/km] in link l with given characteristics;
- S_l, average speed of vehicles in l;
- T, air temperature (assumed constant);
- RT_l, the road type of l (e.g., highway, rural, urban);
- HC_l, the rate of "hot" (i.e., engine operating at its stabilized operating temperature) and "cold" vehicles (i.e., engine operating in an initial warming-up phase) in link l;

the emissions of air pollutant i (expressed in grams) in l during t can be computed with the following equation:

$$E_{i,l,t} = t * L_l * \sum_j \sum_k \left[V_{l,t,j,k} * EF_{i,l,j,k}(S_l, T, RT_l, HC_l)\right] \qquad (3)$$

Emission factor EF is a function of many other variables, such as the speed of vehicles, the air temperature, the road type and the engine temperature. More details on the formulae and parameters used are available in (Leon Ntziachristos and Samaras 2018).

3. Case study

The traffic of goods, in particular, the intermodal one, is mostly concentrated in the seaport terminals and the intermodal terminals in their hinterland can be a centre for aggregation and redistribution (i.e. hub and spoke services). According to ReteAutostrade Mediterranee s.p.a., 2017 the North-Adriatic port system has growth perspectives and activate dry port-sea port efficient shuttle services may support this development by offering an increase in capacity and disposal of containerized traffic for ports.

In this framework, the real-world case study selected in Northern Italy is the Venice Port and its hinterland (Veneto region); the seaport and dry port connection analysed is between Venice Port and Interporto of Padua. The chosen freight village and port are "Core Node" of Trans-European Transport Network (TEN-T) for Mediterranean and Baltic-Adriatic Corridors (Regulation (EU) 1316/2013 & 1315/2013). The distance covered by trucks is approx. 32 km, whereas the length of the railway is approx. 34 km, so Padua can be considered as a close dry port according to Table 1. A close dry port offers larger possibilities for buffering containers and even loading them on the rail shuttle in sequence to synchronise with the loading of a ship in the port (Roso, Woxenius, and Lumsden 2009).

Table 1
Dry port classification (elaboration from Crainic et al., 2015)

Configuration	Distance from the seaport	Main function
Close dry port	< 50 km	Satellite Terminal
Midrange dry port	≥ 50 km, ≤ 500 km	Load Center
Distant dry port	> 500 km	Transhipment

In this paper two scenarios are included:

- S0, the baseline scenario wherein the connections between seaport and inland destinations take place by road and the documents and customs clearance procedures occur in seaport area (Fig. 3).
- S1, the future scenario wherein the Interporto of Padua is the dry port for the Port of Venice, this means that the gate procedures take place in Padua and the connection is made by shuttle trains service (Fig. 4).

The *Activity Diagram* of the two scenarios, which graphically represented operational workflows to show the activities of the system for relevant actors (locations) are shown in Fig. 3 and Fig. 4. The allocation of some activities is different when the terminal is the dry port: the document checks take place in the sea port in S0 and in inland terminal in S1. The current analysis includes the yellow workflows without the storage phase (and costs) to better compare the scenarios.

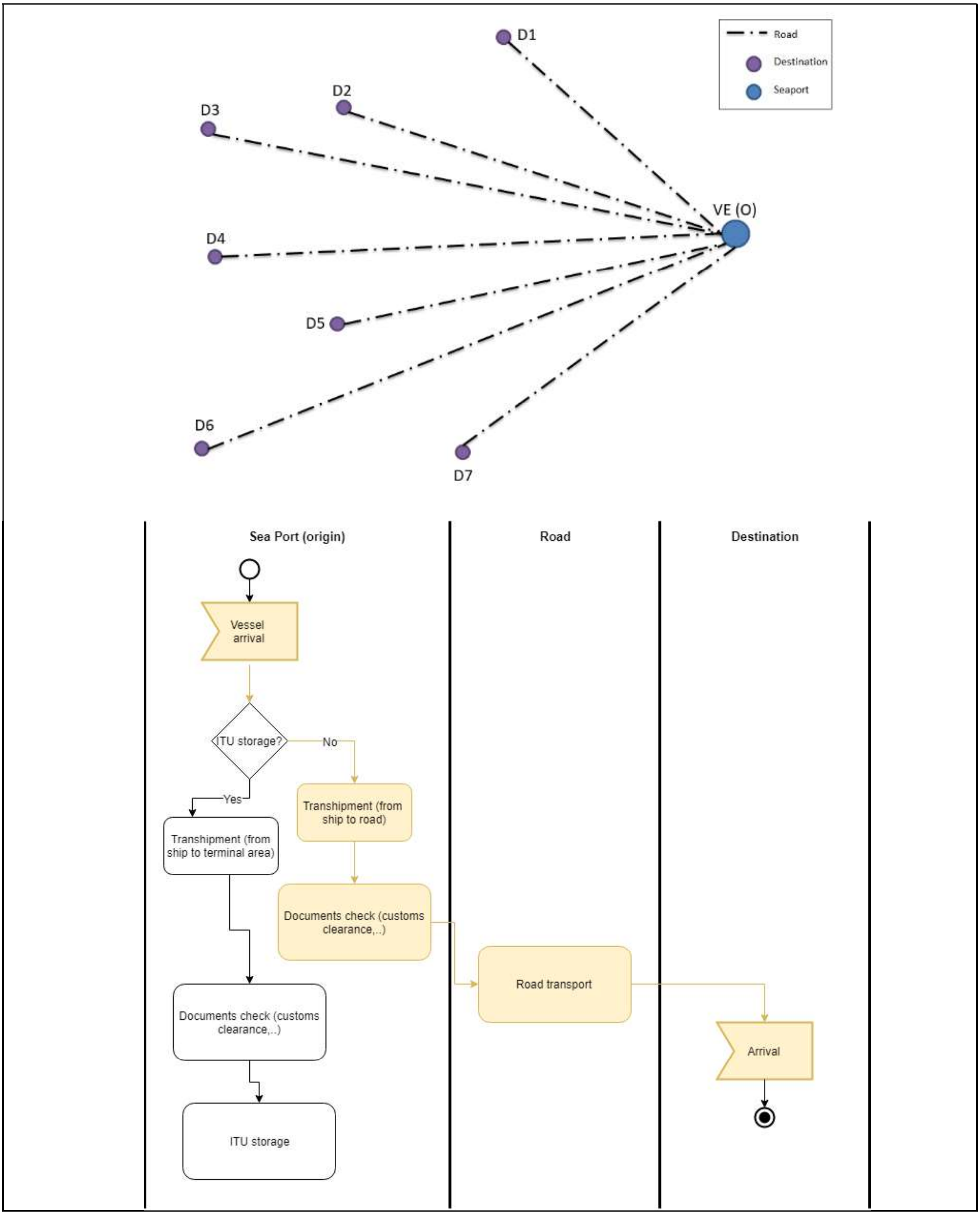


Fig. 3 S0 – Baseline scenario scheme and activity diagram

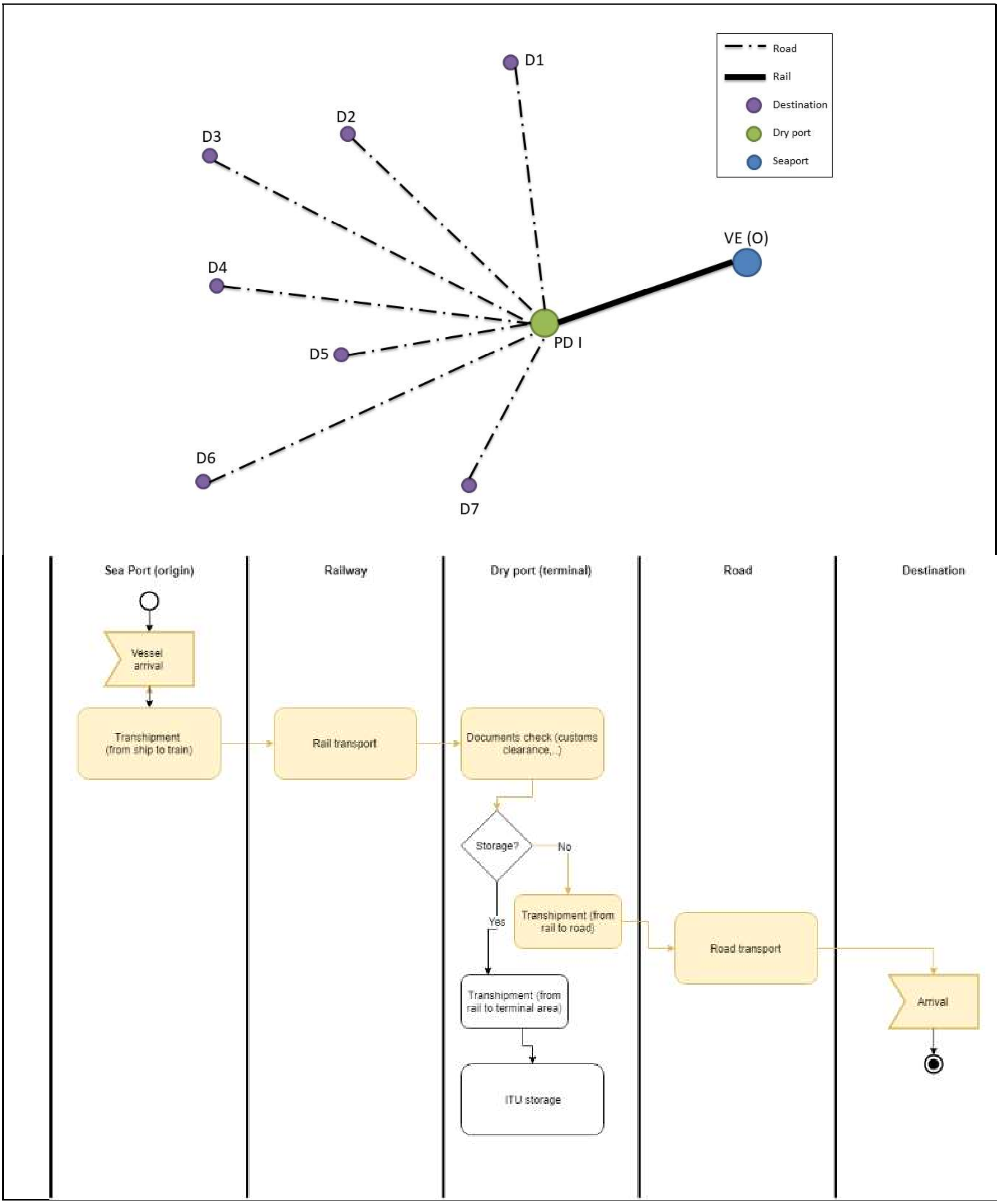


Fig. 4 S1 – Future scenario scheme and activity diagram

3.1 Definition of area of interest

The definition of the seaport and its hinterland is the starting point of the procedure as explained in section 2. The proposed area of interest is around the Venice Port as already underlined. The freight flows of Venice Port are concentrated in Marghera area with 23 cargo terminals, two of which are dedicated to containerized traffic (VECON e TIV). All terminals are connected to the Venice Marghera railway station which has registered 100,745 railway wagons and 5,543 trains in 2018. The 100% of containers handled in Venice Port (632250 TEU in 2018) come from or go exclusively to local, regional or North East productive fabric, within Italian national borders (North Adriatic Sea Port Authority 2019) (Pachakis, Libardo, and Menegazzo 2017). The study developed by Panaro et al. (2018) shown that the 56% of manufacturing companies from Veneto region used the Port of Venice for their traffic and the 96% of the hinterland is covered by road. The amount of Ro-Ro (roll on-roll off) traffic also increased by around 21% in 2018 thanks to the new Fusina terminal only for semi-trailer; this kind of traffic, which continues to grow, could take advantages of good inland connections especially for the consequent space problems.

The seaport accessibility is the following.

- Road side the main highways are: Autostrada A27 Venezia – Belluno and Autostrada A4 Torino – Trieste
- Railway side there are 4 different lines: Linea ferroviaria Bologna - Padova; Linea ferroviaria Milano - Venezia; Linea ferroviaria Venezia - Trieste; Linea ferroviaria Venezia - Udine - Tarvisio.

The Padua Central Station currently does not allow a direct railway connection between Interporto of Padua (the selected as potential dry port) and Venice Port because of infrastructural and capacity reasons. Trains heading east to reach Venice must, therefore, be routed to Castelfranco and this means higher costs and travel time owing to greater distance covered. For instance, to reach the node of Venice from Interport of Padua, passing through the station of Noale, the travel distance is about 70 km, against the 30 km of the direct line. In this paper a new direct railway connection between the selected two nodes (Interporto of Padua and Port of Venice) has been hypothesized in future scenario (S1) to analyse the potential of dry port and seaport connection, without, however, including in this study phase any evaluations about the physical design of the line or its possible capacity.

Based on this information, the main area of interest was defined as the whole Veneto region.

The area of interest was divided into 42 zones, each composed by an aggregation of one or more basic administrative divisions (i.e. *Comune*), which are represented in Fig. 5. A total of 127 external zones were considered (97 Italian provinces and 30 European countries); moreover, 11 additional zones represented the major Italian ports and inland ports, including the Port of Venice.

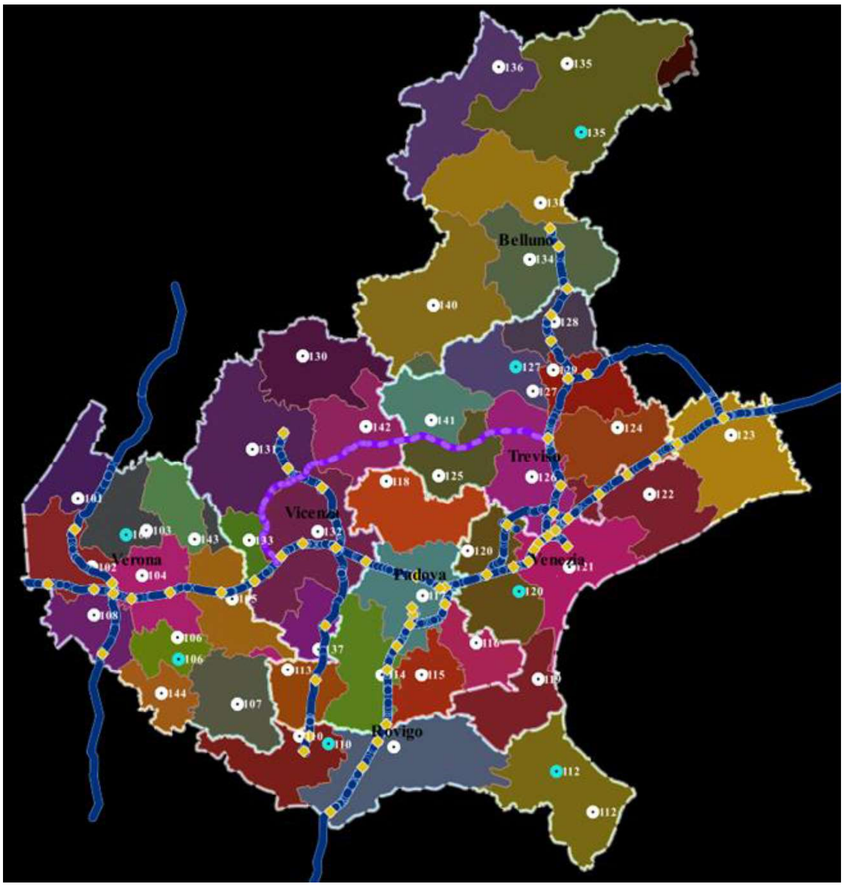


Fig. 5 Area of interest (Veneto) and its zones.

3.2 *Estimation of OD matrices*

A detailed analysis of the current traffic demand in Veneto Region was carried out using floating car data and traffic counts in several road cross-sections.

An initial daily origin-destination (OD) matrix for the zones described above was obtained from floating car GPS data collected for an observation period of 60 working days, between January 8th 2018 and April 12th 2018. Vehicles were divided into four classes: passenger cars, light-duty (less than 3.5 tons - LDV), medium-duty (between 3.5 and 18 tons - MDV) and heavy-duty (more than 18 tons - HDV), resulting into four classified OD matrices.

These matrices were partial since GPS traces were available only for a limited percentage (around 5%) of the circulating vehicles. Therefore, traffic counts from loop detectors were employed to estimate the full OD matrices. Data from a total of 45 road cross sections (13 located in highways, 32 in major suburban and rural roads) were collected during the same floating car observation period. OD matrix estimation was performed with the traditional generalized least square method (Cascetta 1984).

From this traffic demand analysis, it emerged that almost than half (49%) of the heavy-duty trips had origin and destination both located in Veneto, 44% had either origin or destination located outside Veneto and the remaining 7% had both origin and destination outside Veneto (see Table 2). Considering only commercial vehicles (251,160 average daily trips), 49% were LDT, 15% MDT and 36% HDT.

Table 2. Daily trips in Veneto region, according to vehicle class and origin/destination.

Vehicle class	Average daily trips	Regional trips	Exchange trips	Crossing trips
Passenger car	1,918,423	82%	16%	2%
LDT	123,594	63%	32%	5%
MDT	36,794	45%	46%	10%
HDT	90,772	49%	44%	7%

The Port of Venice produced a relevant share of commercial vehicles trips, with 13,424 average daily trips, which represented 5.3% of the whole Veneto total. Trips generated and attracted to the port have peculiar characteristics compared to the rest of the region (see Table 3):

- There is a higher percentage of HDV (more than 45%), therefore a proportionally higher impact in terms of emission;
- The vast majority (91%) of HDV trips has origin/destination inside the region, meaning that it could significantly benefit from a close dry port.

It can be observed that the vast majority of these trips is within Veneto region, therefore confirming that the definition of the area of interest (see Section 3.1) was appropriate.

Table 3. Daily trips of commercial vehicles with either origin or destination in the Port of Venice.

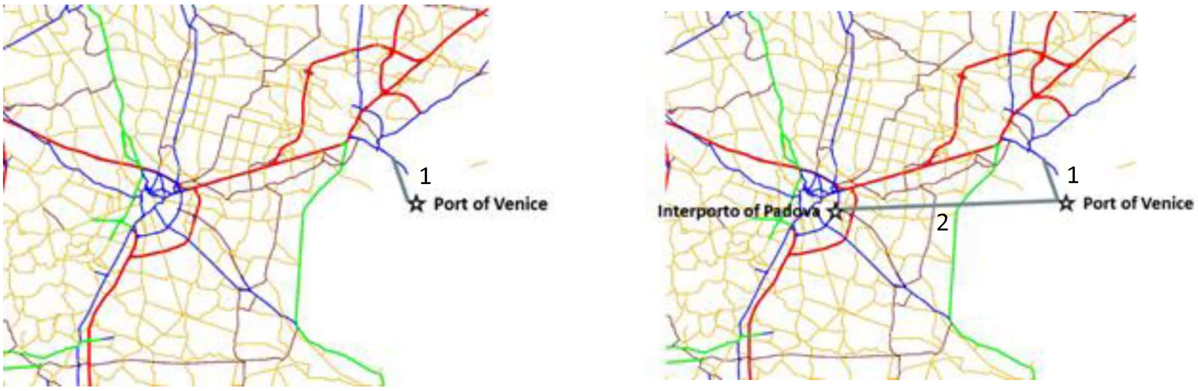
Vehicle class	Average daily trips	Regional trips	Exchange trips
LDT	6,308	92%	8%
MDT	1,072	81%	19%
HDT	6,044	91%	9%

3.3 *Network construction*

An up-to-date road network covering the entire Veneto region was used in the analysis. Each link of the network had the following attributes:

- ID and descriptive name of the link;
- IDs and coordinates of start and end nodes;
- Type of road (8 different categories, plus an additional category for connectors);
- Number of directions (one-way or two-way);
- Number of lanes;
- Capacity (veh/h);
- Free-flow speed for each vehicle class (km/h);
- Length (m)

For each link travel time was assumed equal to the ratio between length and free-flow speed. The network contained also some dummy links. In scenario S0 a dummy link was introduced to connect the road network to the Port of Venice centroid (dummy link 1, see Fig. 6a); in scenario S1 an additional dummy link was added between Interporto of Padua and the Port of Venice (dummy link 2, see Fig. 6b). The two dummy links represented the operations performed in the two ports in each scenario and were associated to a travel time defined as in Section 3.4.



(a) (b)

Fig. 6 Dummy links in scenarios S0 (a) and S1 (b)

3.4 *Cost function definition*

All the physical links in the road network were associated to a cost equal to the travel time. The dummy links' costs were set starting from the definition of generalized cost function in the two scenarios (see Section 2.2), using data from both literature and practical experience of the stakeholders involved in the processes.

The general equations (see eq. (1) and (2)) have been adapted to the case study because of data availability, considering times as the main variables and the distribution of the activities in the different scenarios according to activities diagrams in Fig. 3 and Fig. 4.

The single components of the equations are included in link cost function, and the costs related to the node's activities have been reported on nearest links. The costs related to storage are not included in this analysis according to the activity diagrams reported in Fig. 3 for S0 and Fig. 4 for S1 due to its high variability both in terms of time and costs.

Specifically, the cost function assigned to each dummy link in each scenario are reported in equation (4) and (5) (for the meaning of the symbols please refer to Section 2.2). The numerical values assigned to the components of these equations were chosen according to literature and information from the stakeholders. As a results, in Scenario S0 the travel time of dummy link 1 was 4 hours; in scenario S1 it was 3.5 hours for both dummy links. To compare the two transport modes, the values are related to one transport unit, as commonly used in intermodal transport analysis.

$$C_{dummylink1}(t) = t_{unl}^{sp} + t_{dc}^{sp} + t_{ld}^{sp} \qquad (4)$$

$$C_{dummylink2}(t) = t_{unl}^{sp} + t_{ld}^{sp} + t^{rl} + t_{unl}^{dp} + t_{dc}^{dp} + t_{ld}^{dp} \qquad (5)$$

3.5 *Traffic assignment*

The HDV daily matrix obtained in Section 3.2 was assigned to the network in both scenarios, considering the cost functions defined in Section 3.4. We focused exclusively on HDV for the following reasons: (i) they are the most impactful vehicles, in terms of emissions; (ii) only goods transported in HDV (i.e. containers) are eligible to a modal shift toward railway.

The full HDV daily matrix was initially assigned in S0 (see Fig. 7a), underlining an intense HDV traffic along the West-East corridor, which is highway A4, one of the most congested and accident-prone road in Italy (Automobile Club Italia 2017).

Considering only the trips with either origin or destination in the Port of Venice (Fig. 7b), it is possible to observe that virtually all the HDV traffic coming from the West, South-West and Central part of Veneto already converges in Padua, and that it accounts for more than 25% of the total HDV traffic in the A4 segment between Padua and Venice.

In scenario S1, considering only trips with origin/destination in the Port of Venice, the HDV traffic in the A4 segment between Padua and Venice disappears, as the railway alternative becomes more attractive (Fig. 7c). This alone would be a particularly interesting result, in terms of both road safety and operational efficiency of the infrastructure; moreover, this modal shift would also produce environmental benefits, as it is further discussed in Section 3.6.

(a) (b) (c)

Fig. 7 Traffic assignment of HDV considering: (a) the whole daily OD matrix in scenario S0; (b) only daily trips from/to the Port of Venice in scenario S0; (c) only daily trips from/to the Port of Venice in scenario S1.

3.6 Analysis of emissions

As anticipated in Section 2.3, the analysis of emissions was performed with the COPERT Tier 3 method. Some assumption had to be made on the technologies of these vehicles, since a detailed information was not available: for each vehicle class, the technology share was assumed equal to the overall share in Veneto region in 2018 (Automobile Club Italia 2019).

Link-by-link emission calculation was performed with COPERT Street Level software, which is one of the few publicly available microscopic emissions models ((Forehead and Huynh 2018); (Samaras, Ntziachristos, and Samaras 2016)). Link information (length, travel speed) were already available in the network (see Section 3.3); HDV volumes were obtained with the traffic assignment model (see Section 3.5). The following pollutants were considered:

- CO – carbon monoxide
- CO_2 – carbon dioxide
- NO_x – nitrogen oxide
- PM – particulate matter
- VOC – volatile organic compound

Table 4 summarizes the results of the emissions model (daily values). According to this model, the implementation of the dry port could produce a reduction of around 17% in pollutant emissions produced by HDV traffic to/from the Port of Venice, and almost 1% of the total HDV emissions in Veneto region.

It is not straightforward to visualize and grasp the importance of this emissions reduction. One way to do it is to quantify it economically, by considering for example the cost of CO_2 in EU Emissions Trading System (EU-ETS) (Lättilä, Henttu, and Hilmola 2013), or by using scientific analyses (i.e., Avoidance and Damage costs, (Cavallaro 2018)). The

EU-ETS cost is of course readily available, however, since it is largely related to single jurisdictions, it tends to fluctuate and therefore it is unsuitable for long-term forecasts; scientific methods, on the other hand, are preferable for making forecasts (Nocera and Cavallaro 2014). During year 2019 the EU-ETS cost has mostly fluctuated around 25€ per ton of CO_2. Our model predicts a daily reduction of 31.40 tons of CO_2, which is equivalent of 7,944 annual tons (considering 253 working days in Italy in 2019) and around 200,000 € per year. CO_2 cost should increase steadily in the coming years, according to scientific analyses, possibly exceeding 100€/ton in less than 10 years from now (Lättilä, Henttu, and Hilmola 2013; Nocera and Cavallaro 2014), and therefore the theoretical economic gain from the implementation of a dry port would increase as well.

Another way to picture the importance of CO_2 reduction is to estimate how many trees should be planted in order to absorb the same amount of CO_2 reduced in the new scenario. According to (Toochi 2018), it is estimated that a forest composed by 25-years old maple/beech/birch trees can sequester about 1.97 tons of CO_2 per hectare yearly, meaning that around 40 km^2 would be needed in order to absorb the 7,944 annual tons of CO_2 which are not emitted in scenario S1. For comparison, that area is equivalent to about twice the extension of the urban area of the city of Padua.

To further underline the magnitude of the environmental benefit provided by a direct railway link between the Port of Venice and the Interporto of Padua, the above presented examples refer only to CO_2 emissions, whereas the emission model also predicts a similar reduction of CO, NO_x, PM and VOC (see Table 5).

Table 4. Comparison of emissions between scenarios S0 and S1, considering HDV trips of the whole Veneto region and those whose origin/destination is the Port of Venice.

	Veneto total			To/From Port of Venice		
	Baseline (S0)	Future (S1)	Reduction	Baseline (S0)	Future (S1)	Reduction
CO [tons]	5.939213	5.8835	-0.94%	0.31879	0.263077	-17.48%
CO2 [tons]	3328.646	3297.246	-0.94%	179.0652	147.6657	-17.54%
NOx [tons]	27.04236	26.78907	-0.94%	1.450778	1.197488	-17.46%
PM [kg]	660.7999	654.6055	-0.94%	35.45021	29.25583	-17.47%
VOC [kg]	1169.225	1159.131	-0.86%	60.76533	50.67143	-16.61%

4. Conclusions

The efficiency of intermodal freight transport systems can influence the growth of international trade, because an increase in maritime containerised transport consequently generates an increase in inland freight flows; thus, the seaports' hinterland accessibility can become a very critical aspect for port competitiveness. A frequent rail service towards the hinterland could be a solution to move the high number of containers more quickly increasing the seaport competitiveness which strengthens its land-side connectivity and is able to accommodate vessels with very large capacity in step with the times.

The paper proposed a simulation-based method to quantify environmental benefits of a potential real-world dry port implementation. The method is then applied in a real-world case study in the Northern Italy: the dry port and seaport connection analysed is between Venice Port and Interporto of Padua. The benefits in terms of the environmental impact of new railway connection between seaport and dry-port can be quantified as a reduction of main pollutants around 17%. In terms of CO2, this reduction is about 8,000 tons per year, which corresponds to a value of about 200,000 € per year and is equivalent to the CO2 absorbed annually by a 40 km^2 forest (under the assumptions discussed in Section 3.6).

The task of a dry port should include the combination of the requests and needs from different companies in the area to compose economically sustainable complete train. An efficient, fast and controlled rail service could satisfy also new market shares such as those linked to the world of cruise ships, which, for example, requires large quantities of food to be transported quickly. The new direct railway connection is hypothesized in future scenario without including, in this study phase, any evaluations about the physical design of the line or its possible capacity. Future research will investigate these last aspects and some improvements in the simulation method, such as operational services available at the dry port to reduce the heavy-vehicles queue and free up space in the port docks. Moreover, future analysis will include other externalities such as congestion and road safety; the proposed method in fact could be a part of a more complex cost-benefit analysis, in particular covering the portion of the study which deals with transport externalities.

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