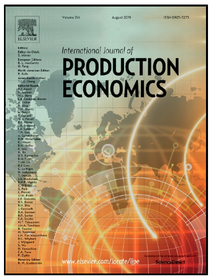
Optimal dry port configuration for container terminals: A non-linear model for sustainable decision making



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OPTIMAL DRY PORT CONFIGURATION FOR CONTAINER TERMINALS:

A NON-LINEAR MODEL FOR SUSTAINABLE DECISION MAKING

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OPTIMAL DRY PORT CONFIGURATION FOR CONTAINER TERMINALS: A NON-LINEAR MODEL FOR SUSTAINABLE DECISION MAKING

Abstract

In recent years the maritime freight transport has rapidly increased, causing congestion in many port areas. In some cases, in order to improve the capacity and the reliability of the temporary storage, a solution, recommended by industry officials, is the expansion of the terminal capacity. When this solution is not available, the 'dry port' area represents an effective alternative. The adoption of a dry port, if on one hand leads to benefits on terminal congestion, on the other hand requires resources and investments due to the transport of the container from port to dry port and vice versa. In the evaluation of the strategy to be adopted different aspects shall be evaluated to estimate time required for the container handling inside and outside the terminal on the basis of the congestion degree. In this paper, to support decision makers in identifying the best strategy to be adopted, a mathematical model allowing to identify the number of containers to be stocked in port and/or in dry port is defined considering the intra-/inter-terminal handling of the containers, in order to minimize the overall running costs and of the carbon footprint. The model, based on a computational algorithm for non-linear programming, is able to provide the number of containers to be stocked in port and/or in dry port, ensuring an effective strategy dependent on 'road' and 'non-road' material handling equipment adopted, on the number and size of containers, as well as on the distance from port to dry port. Results obtained from numerical experiments show that, on the basis of the running cost and the carbon footprint of the container handling activities, it is possible to identify the most economic and eco-friendly container handling configuration. The case study of the Port of Bari (Italy) is investigated. In this case, given the overall number of containers to be stocked and the distance between port and dry port, the solutions found by the model identify a configuration able to ensure a reduction of 7% and 11% of the running cost and of the carbon footprint, respectively, when compared to the configuration in which all containers are stored in the port.

Keywords

Sustainable Logistics, Container terminal, Container Relocation Problem, Dry Port, Container yard

1 – Introduction

The growing attention paid by both governments and practitioners to the concept of sustainability in manufacturing led to consider freight transport as a key factor in the sustainable performance of companies. In the attempt of reducing environmental and social costs of transport, and thus reaching emission reduction goals stated by international agreements, severe standards for new vehicles emissions and for fuels have been adopted, and new taxes on road freight transport have been introduced in some EU Countries based on the pollutant-to-pay principle (Digiesi, Mossa, & Mummolo, 2013). In order to face with new regulations, companies need to re-design their logistic network and operation (Digiesi, Mossa, & Rubino, 2015). In this scenario, the water transport mode represents a valid alternative to other modalities, mainly to the road one, due to its low emissions and costs. Both in USA and EU, policy makers identified and supported the water transport using coastal waterways (Short Sea Shipping (SSS), the water freight transport between ports sharing a common sea coastline or located in the same sea). The effectiveness of water transport in case of inland waterways has been also investigated (Digiesi, Mascolo, Mossa, & Mummolo, 2016). According to European Union (EU) statistics, in 2015 the 29% of the overall freight transport in the SSS class occurred in the Mediterranean Sea, while the North Sea and the Baltic Sea experienced the 26% and the 22% of the overall freight transport in this class, respectively. In other regions, such as the Atlantic Ocean and the Black Sea, the SSS transport is less prevalent (http://ec.europa.eu/eurostat/). In this scenario, Italian ports play an important role in the maritime transport of containers, as stated in the results of the last survey of EU Actualitix (updated to January 2016), in which Italian ports are the tenth in the world rank, and the third in the Europe one, in terms of number of handled containers (see tab. 1).

On the base of the positive trends observed between 2005 and 2012 for both SSS (+2%) and not SSS (+16%) cargo transport in the Mediterranean Sea, it can be stated that the efficiency of EU maritime container terminals will be of crucial importance from both an economic and an environmental perspective in the next years.

Table 1: Worldwide container port traffic in 2016 (TEU: Twenty-foot Equivalent Units)

RANKING	COUNTRY	DATA (TEU x 10^6)
1	China	174
2	United States	44
3	Singapore	33
4	South Korea	23
5	Malaysia	21
6	Japan	20
7	United Arab Emirates	19
8	Germany	19
9	Spain	14
10	Italy	12

Ports are key elements also for other worldwide countries. As an example, 95% of all foreign trade in Brazil (amounting to approximately US$ 100 billion per year in resources) flows through Brazilian ports. This demonstrates the strategic importance of measuring and improving port performance in order to achieve a high level of success in the domestic and international supply chain (Madeira Junior et al., 2012).

Generally, the literature focused on port issues address the interface of ports with shipping lines and shippers, but not the interface of ports with other decision makers (e.g., manufacturers, port manager, final end-users of cargo, etc.) of the maritime supply chains (Talley, 2014). A major contribution on this issue is provided by robotic cargo handling systems, allowing to increase terminal efficiency and reduce manpower costs. In case of high volume handling, robotized gantry cranes, for moving containers, or biped robots, for manipulation tasks such as lifting and carrying heavy weights, are being adopted. Within these applications, biped robots are required to satisfy not only the power requirements (Roberts, Quacinella, & Kim, 2017), but also advanced balancing and locomotion capabilities (Mummolo, Cursi, & Kim, 2016), which are critical for carrying loads (Mummolo, Park, Mangialardi, & Kim, 2016) and that are required to physically interact with the human-made environment (Mummolo, Mangialardi, & Kim, 2014). However, many other factors can affect the efficiency of containers flow in a terminal, and cause port congestion, such vessel schedule reliability, lack or unavailability of docks at some marine terminals, inefficiency of Material Handling Equipment (MHE) as well as berth congestion due to empty container logistics in Storage Yard (SY).

In scientific literature, many contributions are available on the container terminal issues, mainly focused on the improvement of their efficiency, by adopting new technologies (Ballis, Golias, & Abarkoumkin, 1997), work organization models (Paixão & Bernard Marlow, 2003) or information systems (Fanti, Iacobellis, Mangini, Precchiazzi, & Ukovich, 2017). In many cases, the need to increase container terminals capacity is still the main goal. This can be achieved by physically expanding existing terminals (McCalla, 1999), or by (re)building logistic infrastructures, but this requires considerable cost and effort (Pellegram, 2001), and requires reliable investments evaluation (Ambrosino & Sciomachen, 2017). The adoption of a dry port, defined in (Roso, Woxenius, & Lumsden, 2009) as "an inland intermodal terminal directly connected to seaport(s) with high capacity transport mean(s), where customers can leave/pick up their standardized units as if directly to a seaport" is identified as an effective solution to solve congestion of container terminals. Although the positive effects of the adoption of a dry port on the congestion (and hence efficiency) of container terminals have been largely demonstrated, few research has been published on the effects of dry port adoption on the environmental performances of container terminals. In case of the adoption of a dry-port to reduce containers terminal congestion, the transport of the containers, from the seaport to the dry port, requires resources and generates costs. Therefore, in many cases in order to identify the strategy to be adopted for ensuring the optimization of containers flows and the minimization of the staked area, additional evaluation based both on the costs (transport cost, staff cost, cost for services, etc.) and on the environmental impacts due to the handling and transport of the containers are required (Facchini et al., 2016; Böse, 2011).

In the present paper, a model allowing to optimize the inter-/intra-terminal flows jointly minimizing the cost and the environmental impact (evaluated as Carbon Footprint Index) due to the handling of containers is proposed. The model, based on a computational algorithm for non-linear programming, is tested on a full case study concerning a multi-terminal maritime system located in the Port of Bari, Italy.

The rest of the paper is structured as follows: in Section 2 the material handling process in a container terminal is introduced; recent scientific contributions on container terminals issues are discussed in section 3; the model is proposed in section 4; numerical simulation and the Port of Bari case are in Section 5 and 6, respectively; finally, conclusions are in Section 7.

2 – Problem setting

A container terminal ("terminal" in the rest of the paper) in a port is the place where container ships dock, unload inbound containers (empty or filled with cargo) and load outbound containers. Inbound and outbound container operations are very different: inbound containers arrive predictably in large batches at yard, on the contrary the outbound containers depart predictably but arrive in a random order. In case of outbound containers, a rigid ship storage plan is observed, in order to maintain the stability of the ship, and satisfy the loading requirement that depends on destination and size of containers (Chen and Lu, 2012).

A container terminal consists of at least three areas (fig. 1):

1. Operational area between quay wall and container yard (apron area) where the vessels are loaded and unloaded, generally by Ship-to-Shore Gantry Cranes (STS crane or Quay Crane - QC);
2. Container yard for storing inbound (unloaded from vessels) and outbound (to be loaded on vessel) container;
3. Terminal area for landside operations (parking, office buildings, customs facilities, etc.) and for load/unload trucks and/or freight trains for hinterland transport of the containers.

The unloading process of containers can be divided into different sub processes: in a first phase, in the operational area, the inbound containers have to be taken off from the ship by means of a STS crane, the spreader of the STS crane lifts up and moves the containers over the dock, where every container is placed on a truck chassis (trailer) that allows its transportation to the container yard or to the Terminal area, in case of container handling inside or outside the terminal, respectively (fig. 2).

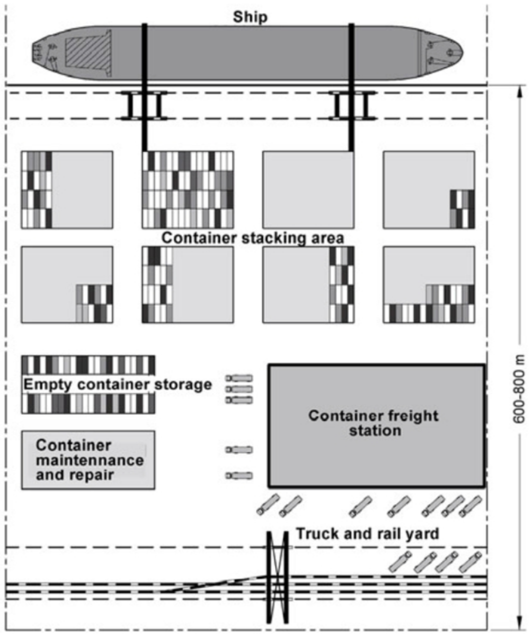

Fig 1. General Layout of a container terminal (Böse, 2011)

In the first case the container is picked by the truck and a material handling equipment (e.g. Straddle Carriers (SC), Reach Stacker (RS), Rubber Tyred Gantry Crane (RTG crane or Yard Crane - YC), etc.) stocks it in the container yard according to different storing modalities (stored on a chassis or stacked on the ground) and different layouts: area, block and linear stack are the most common layouts (Boenzi, Digiesi, Facchini, Mossa, & Mummolo, 2015b). In the second case, the container is transported from the operational area to the Terminal area, where the container is transferred from truck to train or to Articulated Vehicle (AV) and its documentation is checked before leaving the port towards the dry port.

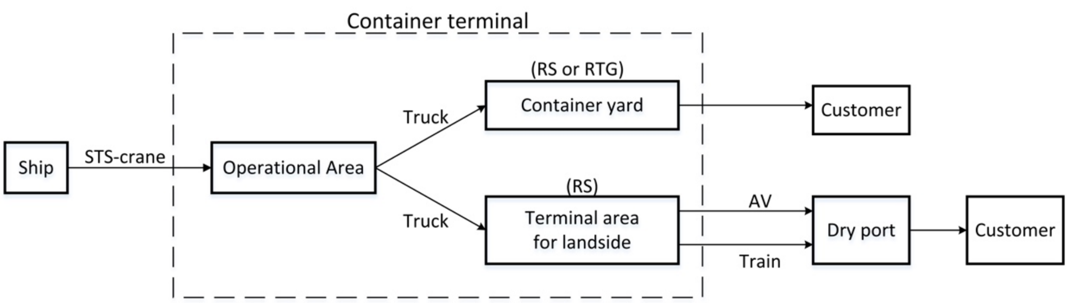

Figure 2. Flow of containers inside and outside container terminal

The flow of outbound containers (loaded from port to ship) has reverse features, therefore requires the same activities starting from customers, which stock the container in port or in dry port, until the next step, consisting of handling of the container in operational area (starting from container yard or terminal area), before the loading of it onto the vessel.

It is clear that the implementation of the dry port in a container terminal radically changes the traditional handling process of the terminal. In most cases the role of the dry port is an effective interface for all the hinterland shippers; it allows to transfer the container storage and sorting functions from congested transshipments point to inland locations, where more space is available. The connection between port and dry port are ensured by fast and reliable services that allows to consider the inland sites as a real extension of the port, thus substantially decreasing the seaport zone congestion (Crainic, Dell'Olmo, Ricciardi, & Sgalambro, 2015).

3 – Literature review

In scientific literature, many models have been proposed in order to increase efficiency and reduce costs of container terminals. Model proposed aim at identifying optimal solutions in both the management and the planning of terminals for a given terminal capacity or in identifying the optimal one, respectively, in order to reduce container transit time (from vessel to truck/rail and vice-versa) and related operational costs. Traditionally, planning and management of operations in container terminals have been studied separately and independently for the three main areas identified in the previous Section (seaside, landside and transport areas). Some (recent) studies focused on the re-configuration of terminal containers in order to reduce congestion due to the temporary storage and transport of containers inside and outside the terminals, identified as the major responsible of the transit time increasing and hence of the reduction of terminal capacity. In these studies, the decentralization of storage areas as well as of operational activities are discussed, and the advantages of this kind of configurations are demonstrated.

More recently, much attention has been paid to port sustainability issue. Studies in this research field often share goals and methodologies of the previously mentioned studies, but they also consider the minimization of the environmental impact both in the planning and in the management of container terminals.

In the following, recent scientific contributions on the above-mentioned topics are discussed.

3.1 Seaside area

In the seaside research field, Authors investigated on both the assignment and the layout of Berths (Berth Assignment Problem – BAP – and Berth Layout Problem - BLP) and the assignment and scheduling of Quay Cranes (Quay Crane Assignment Problem – QCAP – and Quay Crane Scheduling Problem – QCSP) in order to minimize operational time and costs.

A review of studies focused on the seaside operations is in Carlo et al. (2015) and in Bierwirth and Meisel (2015). In the reviews, research published in the periods 2004-2012 and 2010-2015, respectively, are classified on the base of the assumptions adopted and of the potential terminal performance enhancements. Moreover, in Bierwirth and Meisel (2015), studies are classified on the base of the methodology adopted to model and solve the problem under investigation.

In more recent studies appeared in scientific literature, more frequently an integrated problem (BLP/BAP/QCAP/QCSP) is formulated and solved. In Iris et al. (2015) BAP and QCAP are jointly modelled and solved (BACAP) by means of a Mixed Integer Programming (MIP) model in order to obtain an optimal assignment of berths to vessel and QC to berths jointly minimizing the time dependent cost of berths and the QC assignment costs. In Türkogullari et al. (2015), the BAP, QCAP, and QCSP are jointly faced considering cranes set-up times by means of a Mixed Integer Linear Programming (MILP) model allowing to identify the optimal berthing position and berthing times of the vessel as well as their crane schedule during their stay at the quay. The same problem (BAP/QCAP/QCSP) is faced in Agra and Olibeira (2018), where a MIP approach is adopted to minimize the total service time. In Venturini et al. (2017) a multi BAP with vessel speed optimization based on a collaborative approach among ports is proposed in order to reduce energy consumption and emissions of vessels as well as the total time of operation.

One of the main limits in the applicability of the models proposed in this research area is that often they do not consider availability of container allocation space in the landside area as a constraint.

3.2 Transport area

In the transport area research field, the minimization of operational time and costs is mainly based on the selection of MHEs and vehicles (type, size and number to be adopted) as well as their routing and dispatching.

In case of the adoption of automated vehicles (Automated Guided Vehicles – AGVs – or Automated Lifting Vehicles – ALVs), also collision and deadlock problems are investigated.

A review of contributions appeared in scientific literature is in Steenken et al. (2004) and in Carlo et al. (2014a). In the review of Carlo et al. (2014b), among the 55 papers considered, Authors identify only 11 papers (around 20%) in which an integrated problem (mainly transport and yard areas operations) is investigated. In the more recent literature, as in the case of seaside research field, the majority of available studies consider an integrated problem, trying to optimize at once the management of MHE adopted in both transport and yard areas, taking into consideration the existing containers storage layout or defining the optimal one. For this reason, in this paper the recent scientific contributions on transport area are mentioned and discussed in the landside research field.

3.3 Landside area

In the landside research field is the majority of contributions available in recent scientific literature, mainly due to the increasing number of containers to be stored as a direct consequence of the continuous container traffic growth and to the limited space availability in land scarce container terminals. In Zhen et al. (2013) and Carlo et al (2014b) is a review of scientific contributions on these topics published in the period 2004-2013. In the scientific articles published in this period, authors mainly investigated MHE selection and scheduling, storage allocation problem, storage yard layout, container re-shuffling, and truck arrivals management in order to identify potential improvements in terms of operational time and costs (or energy) of container terminals. In Carlo et al. (2014a), in 90 scientific articles published in the period 2004-2012 on the topic above mentioned (except for the truck arrivals management) 8 papers (less than 10%) are identified dealing with an integrated problem (transport and yard areas). On the contrary, in more recent scientific literature on this topic it is quite common to find contributes on an integrated problem. In Chen et al. (2013), Authors investigate the interaction between crane handling and truck transportation in order to minimize the makespan for the loading and the unloading of a set of vessels in a given time horizon. In He et al. (2015), Authors defined a MIP model to find the optimal integrated schedules of QCs, Yard Trucks (YTs), and YCs allowing to minimize both the total departure delays of vessels and the total MHEs energy consumption. In

Sha et al. (2017), Authors adopt an integer programming model in order to evaluate the yard crane schedule minimizing the crane energy consumption. In Wang et al. (2017), a MIP model is formulated to describe the interrelation between vehicles scheduling, yard crane scheduling and container storage location and different searching algorithms are developed and compared for identifying the solutions allowing minimizing vessel makespan. In Gharehgozli et al. (2017) are the results of a simulation study on the performance of twin (non-passing) automated stacking cranes in presence of a temporary containers storage location shared by the two cranes. In order to identify scheduling solutions allowing to jointly minimize the makespan to complete handling requests and the cranes utilization values, multiple heuristics are developed to solve sub-problems considered and simulation is adopted to evaluate the performance of the solution obtained.

The selection of MHE to be adopted is often investigated together with container allocation problem, as in Niu et al. (2016), where a MIP model is defined to evaluate the optimal yard trucks schedules and container storage allocation strategy allowing minimizing the total delay of all jobs required for the handling of the containers. The storage allocation problem in yard area is faced in Lin and Chiang (2017) by means of a decision-rule based heuristic defined in order to evaluate the best containers allocation strategy minimizing the number of gantry crane movements required during their retrieval. In Le and Knust (2017), Authors adopt a MIP-based approach in order to solve the Storage Space Allocation Problem (SSAP) with the aim of minimizing the number of used stacks for a sequence of incoming items taking into account uncertain data for items arriving later. In Dkhil et al. (2017), a multi-objective optimization model is proposed in order to solve the Integrated Problem of Location Assignment and Straddle Carrier scheduling (named IPLASS). With the minimization of the overall operating costs as objective function, the problem is solved by defining a Multi-Objective Table Search Algorithm (named MOTSA).

In the storage yard layout research field, the search for container terminal performance improvements is mainly based on the evaluation of optimal stack layout, from which reshuffling of containers (the process of removing interfering containers to access a desired one) and MHEs process time strictly depend. In Lee and Kim (2013) and analytical model is defined in order to identify the optimal yard layout minimizing the overall costs, sum of the construction and the operating costs of the container yard. In Lehnfeld and Knust (2014) a review and a classification of studies on loading, unloading, and premarshalling problem appeared in scientific literature until 2013 is proposed. Premarshalling of containers is the reshuffling of an initial stack configuration (carried out during MHEs idle time) in order to obtain a final configuration in which the retrieval of containers will not require further relocations. With the common objective function of minimizing reshuffling, the stack layout and loading problems are investigated in Boysen and Emde (2016), in which Authors propose both exact and heuristic solution procedures, in Ahmt et al. (2016), by means of a MIP model, in Gupta et al. (2017), in which a queuing network model is defined, and in Gharehgozli and Zaerpour (2018), in which the minimization of container retrieval time is obtained by means of a mathematical model considering (and comparing) the location of containers of the same or of different types (weight groups and destinations) in the same stockpile (dedicated vs shared stacking policy). In Legato and Mazza (2018), Authors developed a discrete-event simulation model in order to evaluate the optimal configuration of the storage yard in case of SCs are adopted for the handling of containers between quayside and yardside. Block configurations obtained from the model are evaluated on the base of containers capacity, container transfer time as well as with reference to SCs waiting and operation times. Premarshalling of containers is investigated in Ku and Arthanari (2016), in which a stochastic dynamic programming model is proposed in order to identify optimal container relocation strategy considering departure time windows for containers, Ting and Wu (2017), in which Authors propose a beam-search algorithm to solve the relocation problem of containers in yard area, and in Zehendner et al. (2017), where the online container relocation problem is investigated under the assumption of an order of containers retrievals not known in advance, but revealed over time. With the aim of improving container terminals performance, many Authors investigated the effect of different yard and external trucks management policies on the overall time of container retrieval from the storage yard. Some of them proposed models to reduce truck turnaround time (Huynh, Walton, & River, 2005; Kiani, Sayareh, & Nooramin, 2010; Veloqui et al., 2014). Other Authors investigated on truck appointment systems allowing to smooth truck arrivals at terminal gates in peak hours, thus reducing the terminal congestion, by considering mandatory appointment system (Zehendner and Feillet, 2014) or by suggesting a negotiation process between trucks companies and the terminal operator (Phan and Kim, 2015;

Phan and Kim, 2016). More recently, models to optimize truck appointment system with the aim of minimizing waiting times of both external and yard trucks have been proposed (Zhang et al., 2018).

3.4 Dry port

Despite many efforts in new form of technology, in new management strategies, and in the adoption of IT systems, in many container terminals the congestion problem still remains. The lack of a proper manoeuvring area, of space in container stacking area and in the operational area often significantly reduce the terminal productivity (measured as the number of handled containers per working hour), thus increasing the dwell time of vessels at the berths as well as the delay of trucks at gates. In such cases, the only solution is the increase of the seaport capacity by means of a physical expansion and/or a (re)building of logistic infrastructures. However, this requires considerable costs and efforts, and often is not feasible due to the proximity of built-up areas.

In 2009, a new concept of dry port appeared in scientific literature (Roso, Woxenius, & Lumsden, 2009), as a tool for solving the containers congestion problem, rather than a simple area, directly connected to seaport(s), where customers could leave or pick up the containers. In their work, authors classify dry ports into three categories: close (less than 50 km), mid-range (70 to 500 km) and distant (over 500 km) dry ports and discuss potential benefits and negative implications for each of them. Close dry ports are identified as optimal choice when the port is lacking in storage area and its capacity cannot be increased. Nowadays most decisions regarding the adoption of a dry port area, the distance from the seaport (close, midrange, and distant), the MHE selection, and many other aspects are based on experts' opinions. In (Boenzi, Digiesi, Facchini, Mossa, & Mummolo, 2015a), the results of a study aiming at analyze and compare, under a time-based perspective, both the physical flows and the administrative activities at a seaport terminal with and without a dry port are discussed.

In the scientific literature, studies are available on the dry port, focusing on its location problem and its development. A review of contributions appeared in scientific literature in the 2007-2013 period is in (Sağlam et al., 2015). More recent contributions on the directional development of the seaport-dry port are in the work of Wilmsmeier et al. (2011), in which the role of inland carriage companies and public bodies are investigated, and in the work of Bask et al. (2014), with reference to two cases in Northern Europe. The dry port location problem is faced in the work of Awad-Nunez et al. (2014), with reference to the Spanish case, in Ambrosino and Schiomachen (2014), where the location of a mid-range dry port in a multimodal logistic network is proposed, in Crainic et al. (2015), with reference to the tactical planning of a freight distribution network in presence of a dry port, in Nguyen and Notteboom (2016), where a conceptual framework for the inclusion of multiple criteria in the evaluation of dry port location in developing Countries is proposed, and in Komchornrit (2017), in which a hybrid method for solving the dry port location problem and results of an application to a case study in Southern Thailand are proposed.

3.5 Sustainability issues

The growing attention paid by both scholars and practitioners to the environmental effects of freight transport led many researchers to investigate container terminal configuration and operations management strategies allowing jointly achieving economic and environmental goals. In recent scientific literature, one of the first attempt to investigate the environmental impact of container terminal operation is in Golias et al. (2009), where a model for solving the Berth Scheduling Problem (BSP) in case of dynamic vessels arrivals with the aim of reducing vessels fuel consumption and the related emission caused by vessels in idle mode is proposed. A comprehensive review of contributions appeared in scientific literature until 2012 on the port sustainability issue is in Hakam and Solvang (2013), in which authors provide a useful discussion on seaport related initiatives for the improvement of their sustainability. Multimodality, Onshore Power Supply (OPS), seabed contaminated sediments removal and in-site reuse of them, cleaner fuel adoption in both vessel approaching the terminal and MHEs as well as environmental management systems implementation are examples of initiatives adopted in ports, mainly located in Europe and USA. In order to assess the sustainability of operations in container terminal, many researchers developed carbon footprint evaluation models aiming at quantifying the negative effects of emissions caused by Heavy Duty Vehicles (HDV) adopted in terminals for the transport of containers (Konstantzos et al., 2017; Yu et al., 2017). In Saharidis and Konstantzos (2018) a critical review of existing model for the evaluation of trucks emissions in terminal operations is proposed. In Yu et al. (2017), a system dynamic approach is adopted in order to develop a model for the evaluation of the CO_2 emissions due to all processes operated in a terminal for the handling of the containers (vessels manoeuvring, quay and yard cranes operations as well as yard trucks and container trailers transport inside the terminal). In Peng et al. (2018), a simulation model is proposed in order to quantify carbon emissions of a container terminal and to evaluate the effect of the allocation of facilities on the overall emissions. In Dulebenets et al. (2017), a berth scheduling problem is solved minimizing both internal and external costs of operation performed, and results of numerical experiments show how the design of berth schedules might significantly affect the carbon emissions.

As done in the works of Yu et al. (2017) and Peng et al. (2018), many studies identify in vessel operations the main cause of terminal emissions. In scientific literature many contributions are available on vessels emissions reduction strategies. In Dulebenets (2018) a green vessel scheduling problem is formulated in presence of Emission Control Areas (ECAs) in container terminals and cargo transit time requirement constraints, and environmental benefits from the reduction of vessels speed are demonstrated. A further vessels emissions reduction in container terminals can be achieved by means of OPS, in which berthed vessels are power supplied from shore-side electricity rather than onboard auxiliary generators. In Innes and Monios (2018), based on 2017 data of World Ports Climate Initiative (WPCI), Authors show how, in the 200-2015 time period, only 28 ports in the world installed cold ironing (or OPS) systems, and only one of these ports is not a large one (Bergen port), and propose a feasibility study of installing OPS in a medium sized port with reference to the case of a UK port. In (Zhen et al., 2013) different clean energy technologies for the reduction of energy consumption and emissions in container terminals are discussed and the potential savings are quantified with reference to the case study of the container terminals in the Chinese port of Ningbo.

3.6 Open research questions

From the review of contributions appeared in recent years in scientific literature on container terminals issues, it can be concluded that main interests of both practitioners and scholars are in improving their efficiency and sustainability of container terminals. Although the positive effects of the adoption of a dry port on the congestion (and hence efficiency) of container terminals have been largely demonstrated, few studies have been conducted on the effects of dry port adoption on the environmental performances of container terminals. In Awad-Nunez et al. (2014), the Authors investigate the factors influencing the location of dry ports, jointly considering location, accessibility, economic and social, and environmental factors. In Wang et al. (2017) the dry port location problem is formulated considering the optimization of the hinterland dry port-seaport logistic network jointly taking into account the cost concession partnership between dry port and seaport as well as environmental factors.

Moreover, in Author's knowledge very few researches have been published yet (June 2018) on the joint effect of dry port adoption on the efficiency (in terms of operational costs) and on the sustainability (in terms of carbon emission) of container terminals. The adoption of a dry port and the related relocation of containers from seaport to dry port has managerial and environmental implications strictly related. Yard stack layout, container reshuffling, yard cranes scheduling as well as yard trucks operation mainly depend on the number of containers to be stored and handled. If on one hand the identification of a dry port leads to many benefits on terminal congestion, on the other hand the transport of the containers from the seaport to the dry port requires resources and generates extra costs. There are issues that require strategical evaluations (e.g. container distribution network, dry port localization, etc.), tactical assessments (e.g. scheduling of the train or road containers transfer service, sizing of the shuttle fleet, etc.), and operational approaches (e.g. container logistic in port and in dry port, identification of port material handling equipment, etc.).

In this paper, in order to support decision makers in identifying the optimal stock configuration, a mathematical model has been defined to evaluate the number of containers to be stocked in port and/or in dry port minimizing the overall running costs and the carbon footprint. The model considers the intra-/inter-terminal handling of the containers on the basis of the number and of the size of the containers, of the MHEs adopted as well as on the availability, costs and distance of dry port to the seaport.

4 – Methodology

4.1 Assumptions

The model is developed under the following assumptions:

- all the containers to be handled and stored are of the same size and weight (a dedicated policy is considered for the container stacking);
- the MHEs considered (see fig. 2) are:
  - Trucks for the handling of containers in the terminal (one container capacity);
  - RS or RTG for the containers stocking/picking activities in the container yard;
  - RS for the container transfer from truck to train or AV (external trucks);

  all MHEs are considered equipped by diesel engine;
- train or AV (diesel engine powered) are considered for the transport of the containers from the terminal to dry port;
- the time required for the transport of one container from the operational area to the container yard (by truck) is considered equal to time required for containers' transport from the operational area to the container freight station (see fig. 1);
- the containers are stocked in a container yard according to a stacking on the ground configuration adopting a 'block' layout: they are stored in stockpiles of the same height and each stockpile can be accessed only by one side, according to a LIFO strategy (fig. 3);

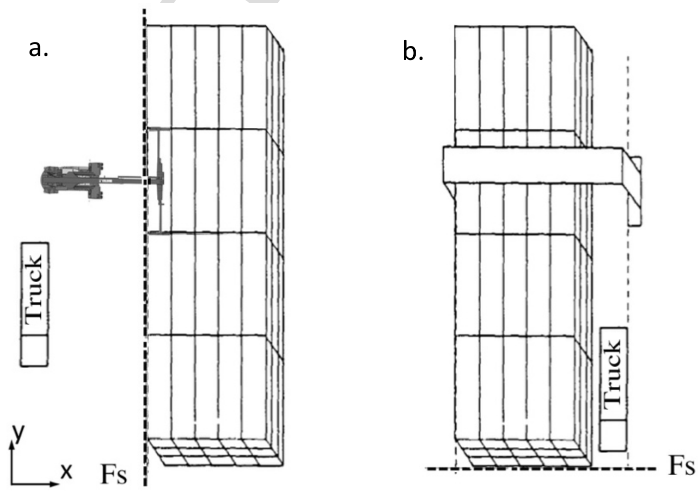

Figure 3. Stockpiles access by Reach stacker – RS (a) and Rubber Tyred Gantry Crane - RTG (b)

- in the container yard, the transshipment of the container from truck to RS or RTG (and vice versa) are performed in the landside area (fig. 3), according to a 'front-end interchange' strategy (Böse, 2011);
- the layout of the block structures (maximum number of rows, bays, and tiers), in the container yard, depends on the MHE adopted (tab. 2);

Table 2. Maximum number of containers according to x, y, and z direction for different MHEs

MHE	Number of row (n_x)	Number of bayes (n_y)	Number of tires (n_z)
RS	∞	∞	5
RTG	7	∞	5

- the containers handling strategy adopted for the storing of the containers in the container yard and for the picking of the containers from the same area, strives to maximize the number of productive movements, thus minimizing reshuffling*;* consistently, there are not priority rules for the containers handling cycle;
- only one RS is adopted for the transshipment of the container/s from truck to AV or train in Terminal area; the maximum number of containers for both transport means (AV or train) is ensured before leaving the container terminal;
- the speed of the MHEs (RS, RTG, truck) does not depend on the weight of the container carried out; for safety reason, an average speed value (for horizontal and lifting movements) equal to 50% of the maximum speed is assumed;
- a constant speed value and a linear distance is assumed for identifying the time required for handling containers inside and outside of the container terminal;
- a 'transit-point' strategy is adopted in the dry port; therefore, most containers are not stored in the dry port, but they arrive in the dry port and are directly picked up from customers; the remaining ones are stored according to a stacking on the ground configuration, adopting a "block" layout in stockpiles of unitary height;
- there are no containers stored in the container yard or in the dry port in the initial conditions;

- an average consumption rate for vehicles is assumed; it does not depend on the travel speed, weight of containers transported, traffic conditions, etc.;
- the activities due to the transportation of the containers from the port or from the dry port to customers are out from the considered system boundaries;
- cost and emission due to other terminal activities not mentioned in the problem setting (e.g. administrative activities, handling facilities, parking, etc.), are not evaluated by the model; the economic and environmental estimates of the model are exclusively related to the container terminal activities performed in the operational area, in the container yard, and in the terminal area (fig. 2) by means of the MHEs listed in the second assumption;
- the value of the rental cost of the dry port decreases with the increase of the distance between the seaport and the dry port.

4.2 Input and Output parameters

The input parameters of the model are summarized below:

N:	overall number of containers to be handled [unit];
d_x, d_y, d_z:	size of the containers handled according to the directions identified in fig. 4 [m];
D:	distance between the seaport and the dry port [km];
t_w:	average waiting time of the containers in the port or in the dry port, before the delivery to the final customer [h];
t_f:	average time required by truck for the transportation of one container from the operational area to the container yard or from the operational area to the container freight station [h/unit];
t_L:	average time required for the transshipment of one container from truck to AV or to the train in container freight station [h/unit];
A_{CY}:	area of the container yard [m^2];
v_h, v_v:	maximum travel (h as subscript) and lifting (v as subscript) speed of the RS adopted in the container yard [m/s];

v_x, v_y, v_z: maximum trolley (x as subscript), gantry (y as subscript) and hoist (z as subscript) speed of the RTG adopted in the container yard [m/s];

v_{AV}: average travel speed of the AV for the transport of the containers from the seaport to the dry port [km/h];

C_{MHE}: hourly operating cost, including variable costs, depreciation and interest charges of the material handling equipment (RS or RTG) adopted for containers' handling in container yard [€/h];

C_{RS}, C_{TRK}: hourly operating cost, including variable costs, depreciation and interest charges of the RS (RS as subscript) and truck (TRK as subscript) adopted for the transportation of containers in terminal and for the transhipment of containers in freight station, respectively (from truck to AV or to the train) [€/h];

C_{AV}: hourly operating cost, including variable costs, depreciation and interest charges of the AV adopted for the transport of containers from terminal to the dry port [€/h];

C_{TRAIN}: full cost of the rail transport for the containers' handling from terminal to the dry port [€/km];

C_{CY}, C_{dp}: hourly average cost per square meter for the rental of the container yard inside the port area (CY as subscript) and of the dry port (dp as subscript), respectively; both values do not include the management costs [€/h m^2];

CL_{AV}, CL_{TRAIN}: load capacity, expressed as the maximum number of containers handled on one trip by AV (AV as subscript) or by train (TRAIN as subscript) [unit];

ρ_{MHE}, ρ_{RS}, ρ_{TRK}, ρ_{AV} : average hourly fuel consumption for material handling equipment (RS or RTG), RS, truck and road AV, respectively [l/h];

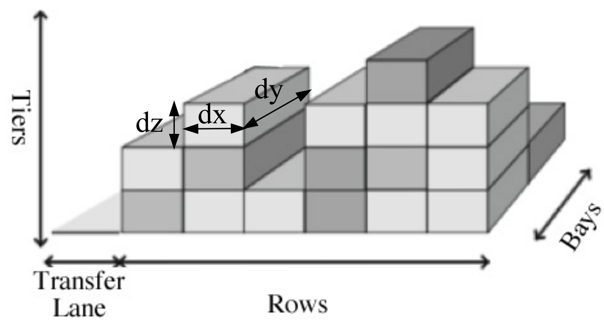

Figure 4. Container and stockpiles size identification

W: overall weight of the containers to be stocked [t];

α: 'AV transport rate', evaluated as the number of containers to be transported by AV, on the overall number of containers to be transported to the dry port, the remaining part of the containers will be handed by train; in case of α = 0, only the train will be adopted for the handling of all containers [#];

β: 'storage capacity rate in container yard', evaluated as the effective space to be dedicated for the storage of the containers on the overall space available in the container yard; in case of β = 1, the full area in the container yard is available for containers' storage ('block' layout without aisles) [#];

μ: 'containers in dry port rate', evaluated as the number of containers to be stored in the dry port on the overall number of containers' transported; the remaining part of the containers incoming to the dry port, will be directly picked up from customers [#].

The output parameters of the model are summarized below:

N_1: number of containers to be stored inside container yard (in port) [unit];

N_2: number of containers to be transported in the dry port [unit]; where input parameter *N*, above mentioned, identifies the sum of N_1 and N_2;

n_x, n_y, n_z: number of containers stored in containers yard, according to rows (x), bays (y), and tiers (z), so as to identify the containers' block configuration, as showed in fig. 4.

4.3 Cost estimation

The model developed searches for the jointly minimization of the overall handling costs (C) and of the carbon footprint (CF) due to activities for the storage, retrieve and transport of containers. Consistently, the purpose of the model is achieved by means of the identification of the containers' number to be stored in the seaport and in the dry port, identified with N_1 and N_2, respectively, according to the value of the following variables:

- overall number of containers to be handled;
- distance from the seaport to the dry port;
- material handling equipment (RS or RTG);
- seaport/dry port's area rental cost, and available area in the container yard;
- transport means (AV or train).

The cost function (*C*) to be minimized is:

$$C = C_{MHE}t_{CY} + NC_{TRK}t_f + t_W \cdot (C_{PORT} + \mu C_{DP}) + C_{TRS} \quad (1)$$

Where t_{CY} identifies the time [h] required, expressed in hours, for the handling of N_1 containers, by RS or RTG, considering storage and retrieval activities from/to the container yard; maximum n_x, n_y and n_z values are identified according to handling equipment adopted (limits of rows, bays and tiered for each MHE are shown in tab. 2) and available container yard area βA_{CY}. The t_{CY} value is estimated, for RS and RTG (by equations 2 and 3, respectively), by evaluating the overall number of movements due to picking/stocking of one (or more) container/s by the stack. Consistently with this purpose, the overall time due to vertical (lift on – lift off) and horizontal (roll on – roll of) movements required by RS or RTG is estimated. The constant introduced in the equations (2) and (3) consider both the different unit measure adopted for speed (expressed in [m/s]) and time t_{CY} (expressed in [h]) and the doubling of movements required by RS. As far as concern the doubling of movements required by RTG, this effect is already considered in m-parameters evaluation (eqs. 4-6) and is not included in the constant of eq. 3.

$$t_{CY} = (5{,}56E-4)\left(v_h^{-1}\sum_{i=1}^{n_x-1}\sum_{j=1}^{n_y-1}(id_x + jd_y) + v_v^{-1}\sum_{k=1}^{n_z-1}kd_z\right) \quad (2)$$

$$t_{CY} = (2{,}78E-4)\left(m_x d_x v_x^{-1} + m_y d_y v_y^{-1} + m_z d_z v_z^{-1}\right) \qquad (3)$$

Where:

$$m_x = n_y \sum_{i=1}^{n_x} 2 i n_z \qquad (4)$$

$$m_y = n_y - 1 \qquad (5)$$

$$m_z = (10 - n_z - 1) + n_x(n_z - 1) + (n_x - 1)(n_z - 1) + 2 n_x \sum_{k=2}^{n_z} (n_z - k) \qquad (6)$$

As far as concern C_{PORT} and C_{DP}, estimated by equations 7 and 8, these values identify the rental costs of the container yard (in-side port) and of the dry port areas, required for the storage of N_1 and μN_2, containers, respectively. C_{PORT} value depends on the number of containers to be stocked in the port and is evaluated on the base of the stock area required (n_x*n_y). The maximum value of n_x and n_y parameters depend on both the MHE adopted (β-value and limits listed in tab. 2) and the A_{CY} available in the port.

$$C_{PORT} = C_{CY} d_x d_y n_x n_y;\ \textit{with}\ n_x n_y \leq \beta A_{CY} \qquad (7)$$

$$C_{DP} = C_{dp} d_x d_y N_2 \qquad (8)$$

$$C_{TRS} = D C_{RS} N_2 t_L \left(\frac{\alpha N_2 C_{AV}}{CL_{AV} v_{AV}} + \frac{(1-\alpha) N_2 C_{TRAIN}}{CL_{TRAIN}} \right) \qquad (9)$$

The equation 9 estimates the costs for containers handling outside the terminal, being C_{TRS} the overall cost due to the transport of N_2 containers from the seaport to the dry port (by AV or train).

4.4 Emissions estimation

The carbon footprint estimation (*CF*) allows evaluating the environmental impact due to the handling of containers. The CF function to be minimized is showed in (eq. 10),

$$CF = CF_{MHE} t_{CY} + N CF_{TRK} t_f + CF_{TRS} \qquad (10)$$

where CF_{TRK} and CF_{MHE} parameters (eq. 11 and eq. 12) depend on speed, consumption and diesel Emission Rate (ER_{diesel}) of the MHE (RS or RTG) and truck adopted.

$$CF_{MHE} = \rho_{MHE} ER_{diesel} \tag{11}$$

$$CF_{TRK} = \rho_{TRK} ER_{diesel} \tag{12}$$

The ER_{diesel} parameter identifies the amount of the tailpipe emissions of CO_2 from the burning of a liter of fossil fuel; in this case the hourly average ER_{diesel} assumed for MHE (diesel is adopted as fuel) is equal to 2,7 [kgCO_2/l] (http://www.dri.edu).

The environmental evaluation of the containers handling outside the terminal is identified by CF_{TRS} estimated by means of the following equation:

$$CF_{TRS} = \frac{CF_{RS} N_2 t_L}{3600} \left(\frac{\alpha N_2 CF_{AV}}{CL_{AV} v_{AV}} + \frac{(1-\alpha) N_2 CF_{TRAIN}}{CL_{TRAIN}} \right) D \tag{13}$$

Where CF_{RS}, CF_{AV}, and CF_{TRAIN} values are evaluated by equations 14, 15, and 16, respectively:

$$CF_{RS} = \rho_{RS} ER_{diesel} \tag{14}$$

$$CF_{AV} = \rho_{AV} ER_{diesel} \tag{15}$$

$$CF_{TRAIN} = W ER_{electric} \tag{16}$$

The carbon footprint due to containers transportation by train, depends on the weight of the containers to be handled (W) and emission factor for rail freight movement ($ER_{electric}$). According to European Chemical Transport Association the average CO_2-emission factor for rail transport, considering the gross power generation mix in EU-27, is 0,022 [kgCO_2/ t km] (https://www.ecta.com/). This value takes into account both the average electrical mix of power source and the average energy efficiency of the locomotive.

4.5 Computational process

The model has been implemented in Matlab® (R2013a); two different arrays (G and R) are generated, the first array identifies the possible permutations of N_1 and N_2 on the basis of the overall number of containers to be handled; the second array identifies the possible permutations of n_x, n_y, and n_z parameters, corresponding to the number of containers to be stored in the container yard, according to rows (x), bays (y), and tiers (z) (fig. 4). In both cases only integer values will be assigned to different variables.

Two nested 'for-cycle' ensure the evaluation of all permutations (fig. 5) of elements in G and R arrays, and for each case the overall cost is estimated (eq. 1) according to the equations above mentioned. Each array is identified with a counter parameter, '*i*' ranging from 1 to Γ, in case of G-array, and '*j*' ranging from 1 to P for R-array.

The variable C_{min} is associated to minimum cost values. In output the N_1, N_2 and blockstructures configurations, corresponding to minimum cost value, (C) are provided. The data input is managed by a query that allows to exclude the adoption of the MHEs or of the transport means not suitable for the case considered.

A database with the technical specifications of most MHEs available on the market, is interfaced with input query, in order to quickly identify the technical characteristics of the MHE adopted on the basis of the model. The algorithm run on Core i5-2,6 Ghz with 8GB 1600 MHz DD3 RAM, performing each simulation in about 10 seconds.

The minimization of environmental impact is based on the same framework computational process, the same number of iterations is considered, and for each of them is estimated the carbon footprint. In output is provided the strategies able to optimize the container allocation and minimize the value of CF function (eq. 10).

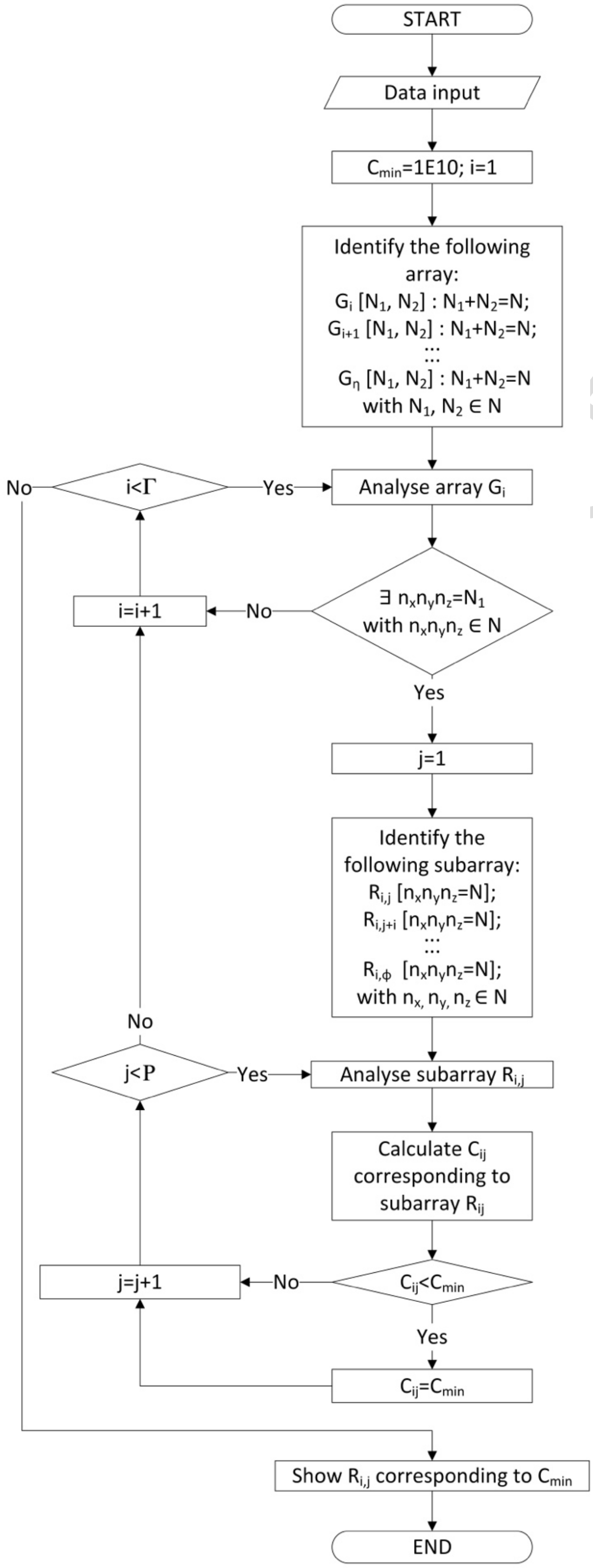

Figure 5. Flow chart of the Computational process

5 – Numerical Simulations

In order to evaluate the efficiency and the reliability of the strategies provided by the model a simulation plan (tab. 3) has been defined. The corresponding input values are listed in table 4.

Table 3. Simulations Plan

ID Simulation	*N* [units]	*D* [km]	MHE	Transport units
#1	875	from 5 to 30 (with increase of 5 for each step)	RS	AV ($\alpha = 1$)
#2	175	from 5 to 30 (with increase of 5 for each step)	RS	AV ($\alpha = 1$)
#3	875	from 5 to 120 (with increase of 5 for each step)	RS	Train ($\alpha = 0$)
#4	875	from 5 to 30 (with increase of 5 for each step)	RTG	AV ($\alpha = 1$)
#5	875	from 5 to 120 (with increase of 5 for each step)	RTG	Train ($\alpha = 0$)

The dataset identified for numerical simulations (listed in tab. 4) are collected according the follows criteria: the values related to 'road' and 'non-road' MHE (e.g. RS, RTG, Train) are referred to most widespread handling equipment, available on the market and generally adopted in terminal containers. As far as concern the characteristics of the containers stock area, the choice of these values is based on a terminal container of medium size (most widespread in European countries) and the 20-foot equivalent units (TEU) are adopted as container to be handled.

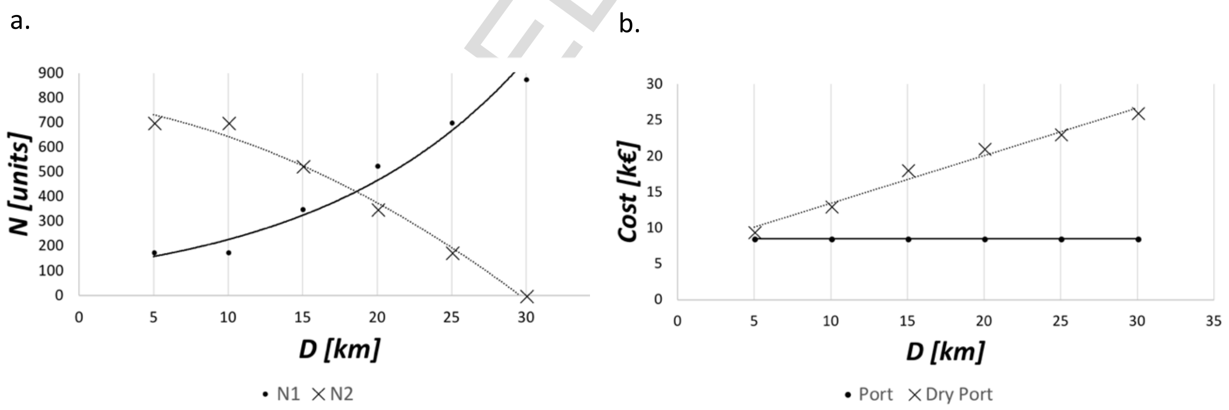

Figure 6. Number of containers to be stocked in port (N_1) and in dry port (N_2) for different port-dry port distances in case of input variables of simulation #1 - N=875 (a). Overall cost evaluation for stock the containers in port and in dry port considering different port-dry port distances for input variables of simulation #2 – N=175 (b).

According to simulation #1, the model provides the number of containers to be stocked in the seaport (N_1) and in the dry port (N_2), changing the distance (D) between them. The configurations suggested by model, under economic and environmental perspectives, are shown in fig. 6a. It is possible to observe that, if the dry port is very close to the seaport, most containers will be transported to the dry port, and only 175 containers will be stocked in the container yard (inside the port). Increasing the distance between the port and dry port, the suggested number of containers to be transport in the dry port gradually decreases. This trend depends on the increase of costs and of emissions, due to more travel time required for the handling of N_2 containers, by means of a road vehicle (AV), from the seaport to the dry port.

Table 4. Input values parameters

Class	Category	Equipment	Parameter	Value
MHE and Transport means*	Technical features	RS	v_h	6,39 [m/s]
			v_v	0,35 [m/s]
			ρ_{RS} (or ρ_{MHE})**	15 [l/h]
		RTG	v_X	1,16 [m/s]
			v_y	1,67 [m/s]
			v_z	0,67 [m/s]
			ρ_{MHE}	20 [l/h]
		Truck/AV	V_{AV}	50 [km/h]
			CL_{AV}	2 [units]
			$\rho_{TRK} = \rho_{AV}$	12 [l/h]
	Cost	Train	CL_{TRAIN}	15 [units]
		RS	C_{RS} (or C_{MHE}) ***	170 [€/h]
		RTG	C_{MHE}	350 [€/h]
		Truck/AV	$C_{TRK} = C_{AV}$	130 [€/h]
		Train	C_{TRAIN}	8,34 [€/km]
Containers	Technical features		d_x	2,4 [m]
			d_y	6,1 [m]
			d_z	2,6 [m]
			W	20 [t]
Stock area (port and dry port)	Technical features		A_{CY}	4300 [m²]
			D	(5 ÷ 130) [km]
			μ	= 0,2
			β	0,67 *(RS as MHE)*
			β	0,90 *(RTG as MHE)*
	Cost		C_{CY}	0, 17 [€/hm²]
			C_{dp}	(0,17 ÷ 0,009) ** [€/hm²]
Idle times			t_w	24 [h]
			t_f	0,05 [h/unit]
			t_L	3,33E-2 [h/unit]

(*) MHE and transport means technical features and cost are from technical specifications available on the market
(**) In case RS is adopted as MHE for container handling in port
(***) The hourly average cost per square meter for the rental of the dry port area is assumed to be 0,17[€/hm²] for $D \leq 5$ [km] and is equal to 0,009 [€/hm²] for $D \geq 25$ [km]; the unit cost for 5 [km]<D<25 [km] is estimated as a linear function 'distance-cost'function where the cost value decreases with increasing D.

Comparing the overall costs corresponding to the strategies suggested by the model (fig. 7a), the dry port ensures a cost saving which varies from 5% (for D=25 km) to 50% (for D=5 km) compared to a configuration without dry port adoption. It is very interesting to note that for a D>27 km (according to variables in simulation #1) the adoption of a dry port does not allow to reduce the costs due to containers handling inside the port. This is not the only case in which the adoption of the dry port is not recommended by the model. In case of the number of containers to be handled is very low (as is the case of simulation #2) the most cost-effective configuration is obtained by storing all containers in the seaport (fig 6b), according to a 'blockstructure' layout characterized by maximum number of rows (n_x) and bays (n_y) (considering the available stocking area in container yard and the MHE adopted) and a minimum number of tiers (n_z).

This result depends by the average time required for the handling of containers in the seaport. Consistently whit the equations 2 and 3, t_{CY} significantly increases with increasing of n_z, therefore the transport of containers outside the port is not recommended for low n_z, on the contrary the handling of containers outside the port can be a good alternative, in terms of containers handling time, in case it allows to avoid the increase of tiers in containers block.

The adoption of the train for the transport of containers outside the port is evaluated in simulation #3, in which the costs and the emissions, if compared to the case of AV adoption, are significantly reduced. According to model output parameters values, considering the same input variables of simulation #1, the dry port implementation allows to ensure a cost saving until a maximum value of D, corresponding to 119 km (five times higher than road vehicles adoption case). Comparing the overall cost, evaluated by the model, adopting the AV (fig. 7a) or the Train (fig. 7b) for the transport of containers outside the port, it is observed that for D=20 km the cost estimated with the AV is around to 35 k€, instead, adopting the train the overall cost due to containers handling is around 4 k€ (approximately 10-fold lower). In both cases the configuration identified is the most cost effective if compared with the cost to be incurred by storing all containers in container yard inside the port, corresponding to an overall handling cost of about 42 k€.

According to environmental assessments of the containers handling outside the port, the same evaluations, already observed for the economic aspects related to the adoption of the AV or of the train, can be considered valid. The train results the best eco-friendly transport mean (fig. 8a and 8b), allowing to ensure a significantly reduction (more than 5 times) of the overall carbon footprint due to containers handling.

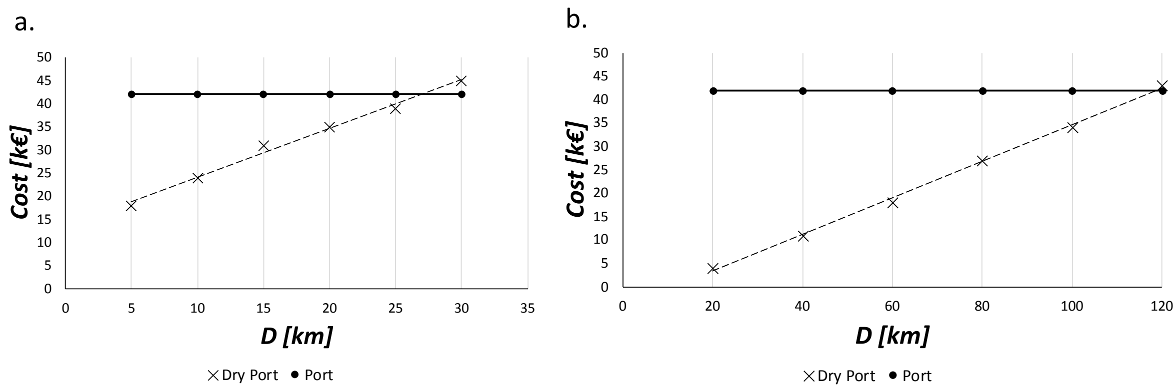

Figure 7. Overall cost evaluation of containers handling, in case of input variables of simulation #2 – N=175 (a) and simulation #3 – N=875 (b)

In all cases the overall costs and the carbon footprint are evaluated by the model considering the full handling of containers both inside that outside the port (fig. 9a).

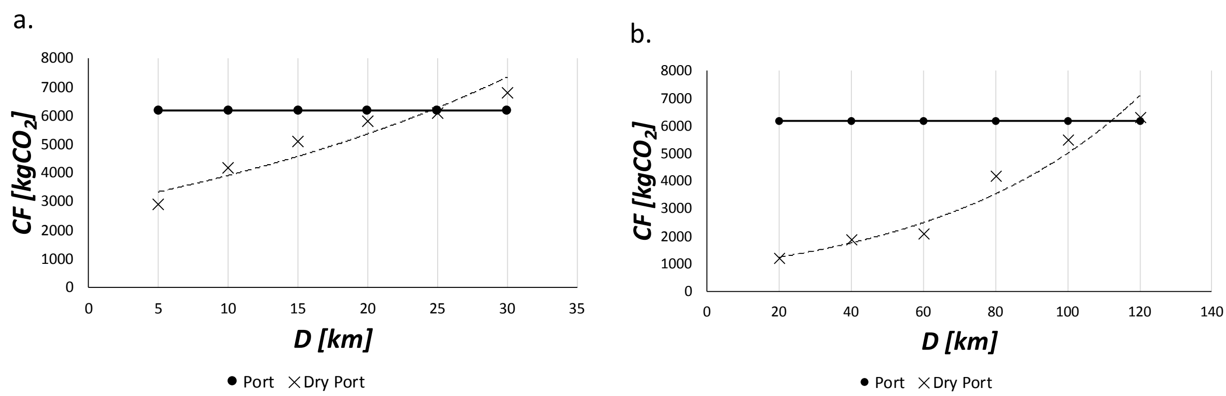

Figure 8. Overall Carbon Footprint evaluation of containers handling, in case of input variables of simulation #1 – N=875 (a) and simulation #3 – N=875 (b)

The adoption of RTG, instead of the RS, for containers handling in the seaport is evaluated in simulations classified whit ID #4 and #5, respectively, with the AV and with the train as transport means for the handling of containers outside the port. If on one hand the average time required for the picking and the storing of containers from/to the block of containers (t_{CY}) is lower in case of RS adoption, on the other hand the hourly operating cost (C_{MHE}) is more than double, if compared to the RS operating cost.

Therefore, the adoption of RTG not significantly changes the strategies suggested by the model in order to minimizing the overall containers handling cost. As far as concern the environmental aspects, the impact for each container handled adopting RTG or RS is quite similar, therefore in this case the lower t_{CY} of the RTG, compared to the average t_{CY} of the RS, affects the overall carbon footprint, making adoption of RTG the more sustainable choice (fig. 9b).

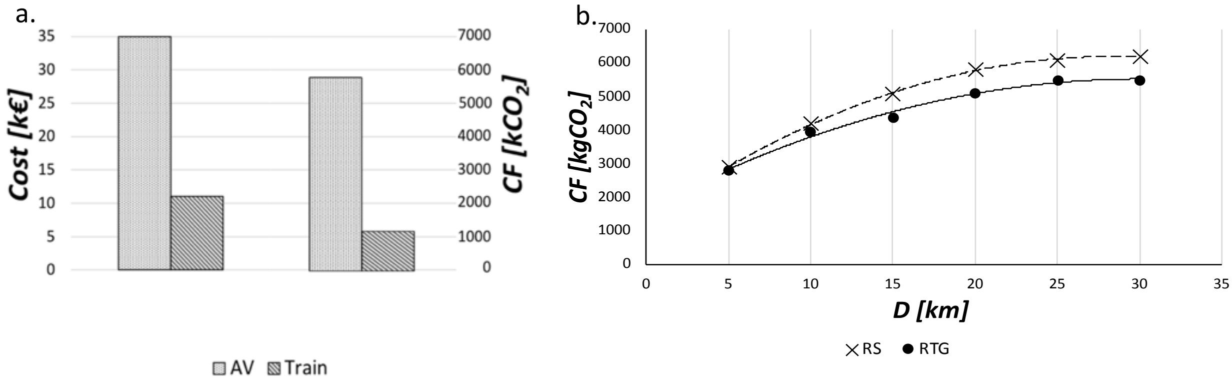

Figure 9. Cost and Carbon Footprint comparison between AV and Train in case of simulation #1 and #3 for D=20 km (a). Carbon Footprint evaluation in case of simulation #1 and #4

The output values of model are summarized in fig 10. It is very interesting note that the number of containers to be stocked in the dry port depends by the MHE and transport means adopted, as well as by the distance from the seaport to the dry port, and by the overall number of containers to be handled.

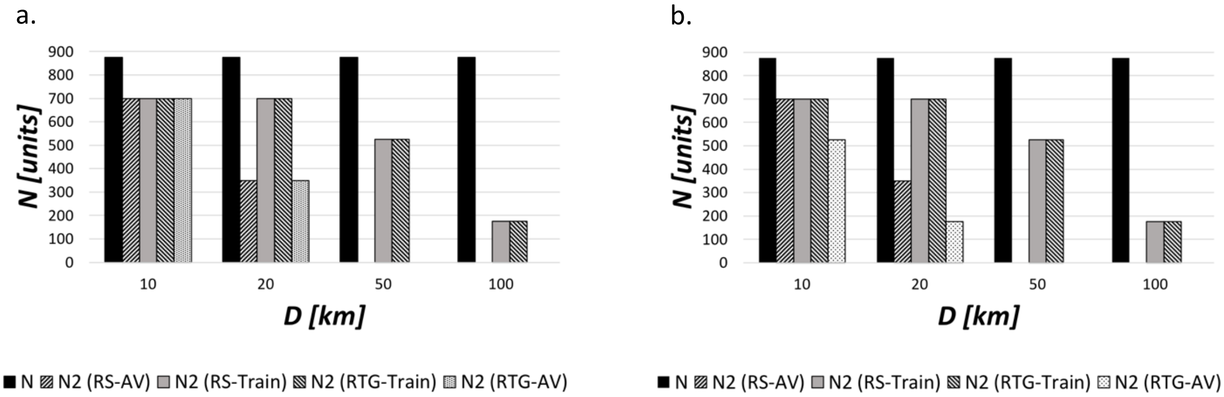

Figure 10. Results of the simulations #1, #3, #4, and #5 for D=10 [km], D=20 [km], D=50 [km], and D=100 [km]

When the train is adopted for the transport of the containers outside the seaport, the model suggests to stock containers in the dry port even in case of high distances. In case of different MHEs adoption, the minimal cost and the minimal carbon footprint are not obtained by the same stock's configuration of the containers.

It is very interesting evaluate the robustness of the model in case of the uncertainty of the N parameter, since in many real cases the number of containers in input to the terminal hub might vary due to many different aspects, that do not dependent by the terminal policies (e.g. capacity of the inbound vessels, customers' demand, etc.). In these cases, it can be observed how the configurations suggested by the model can vary and what are the effects of them on cost saving. As an example, in case the design configuration is optimized for *N*=800 containers (given A_{CY}, *d*, and type of 'road' and 'non-road' MHE adopted) the containers' configuration suggested by the model requires the storage of 600 containers in port (N_1), according to a blockstructure characterized by n_x=20, n_y=10, and n_z=3, and the rest of the containers (N_2=200) in the dry port. Considering a possible deviation from the design configuration due to a reduction of the overall number of containers to be handled (e.g. *N*=600), the best configuration suggested by the model would exclude the adoption of the dry port (N_2=0), therefore in this case the rented area will be empty. Consistently, the overall cost will increase of around 1%, if compared to the cost of the best configuration suggested by the model (fig. 11a – *N*=600). Nevertheless, it is possible to show that these extra costs are negligible if compared with the savings obtained in case of an increase in the number of containers to be handled. In fact, given *N*=1000, with a dry port area sized in the design phase for the storage of 200 containers, only 200 containers will be stocked in it, and the remaining 800 containers will be stored in the seaport. By comparing the overall cost of this configuration with the overall cost of a configuration without dry port adoption (all the 1000 containers stocked in the seaport), a cost saving of 30% is evaluated (fig. 11a – *N*=1000).

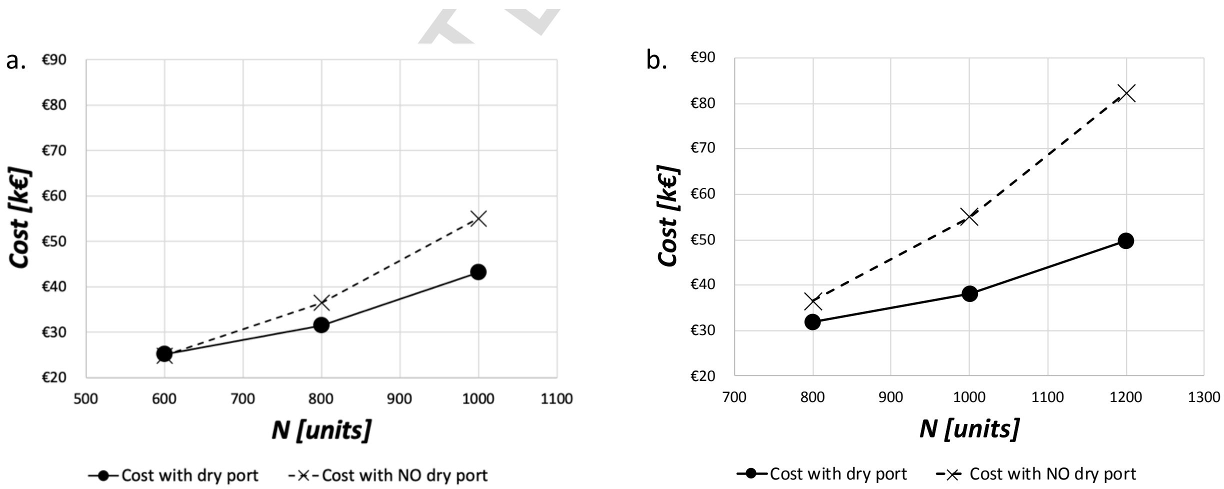

Figure 11. Overall cost due to handling of N=800±200 (a) and N=1000±200containers (b), with RS and α=1, adopting the containers configuration suggest by the model both in case of presence of dry port ('cost with dry port') located at the distance of 10 km from the port (A_{CY}=4300 m^2, adopting RS as MHE), that in case of lack of the dry port ('cost with NO dry port')

The same evaluation has been carried out for a greater number of containers considered in the design phase (fig. 11b).

6 – The case of the Port of Bari

The Port of Bari, showed in figure 12, is a port serving the metropolitan area of Bari; the municipality of Bari (Southern Italy) has activated a smart governance program by a proactive engagement of government and citizens in a series of initiatives promoted by the EU (Carli, Dotoli, Pellegrino, & Ranieri, 2015). The port of Bari is traditionally considered the "Europe's door" to the Balkan Peninsula and to the Middle East and is a multipurpose port able to meet all operational requirements. The port of Bari is one of main node of the Scandinavian-Mediterranean (Scan-Med) Corridor linking the major urban centers in Germany and Italy to Scandinavia (Oslo, København, Stockholm, and Helsinki) and the Mediterranean (Italian seaports, Sicily and Malta). The Scan-Med Corridor covers seven EU Member States and the Norway and currently represents one of the most crucial axis for the European economy, crossing almost the whole continent from North to South.

The total area of the port amounts to 285 hectares, is characterized by an overall ground area of 452000 [m^2] with a coastline of 2500 [m]. The port does not have yet any dry port area, but its implementation is one of the main objectives of the expansions strategic plan. The terminal runs 24-hours operations, 7 days per week.

Figure 12. Satellite photos of Port of Bari

The material handling process and the equipment adopted in the terminal (Mobile Harbour Crane, truck, and RS) fits with the basic assumptions of the model. The data about the number of the containers to be stocked and the available equipment for container handling, inside and outside, of the seaport are summarized in tab. 5. The container yard area (A_{CY}) is 2300 [m^2], the technical features, the costs as well as the characteristic of the containers and of the equipment considered in simulations, are the same of section 4 (tab. 4).

Table 5. Simulation plan of the Port of Bari case

***N* [units]**	***D* [km]**	**MHE**	**Transport units**
608	from 5 to 30 (with increase of 5 for each step)	RS	AV (α = 1)

Consistently with the purpose of the model, two different areas are available that could serve as dry port, the first one 15 [km] far from the Port of Bari and the second one 25 [km] far from the port; both of them are in the industrial area of the Town.

As shown in table 6, the model identified only three possible configurations for the containers that are effective under economic and environmental perspectives, considering the A_{CY} available in port. Each of them is identified by means of a "iso-configuration" curve, shown in figure 13, in which the same number of containers stocked in the seaport (N_1) and in the dry port (N_2) are considered, in accordance with the handling strategies identified by the model (tab. 6), and varying the distance from port to potential dry port (D)

Table 6. Output parameters values in the Port of Bari case

Number of containers stocked [units]	**Handling Strategy**		
	A	**B**	**C**
N_1	608	456	0
N_2	0	152	608

It is possible to observe that for D=15 km, the containers' configuration allowing to minimize the cost is obtained by means of the storage of most containers in the port (N_1=456 units) and a minimal percentage of the overall number of containers in the dry port (N_2=152 units), as showed by the iso-configuration curve identified as 'B' in figure 13a. As far as concern the environmental evaluation, the minimal carbon footprint is ensured adopting the same configuration, for N_1=456 units and N_2=152 units (see line 'B' in figure 13b).

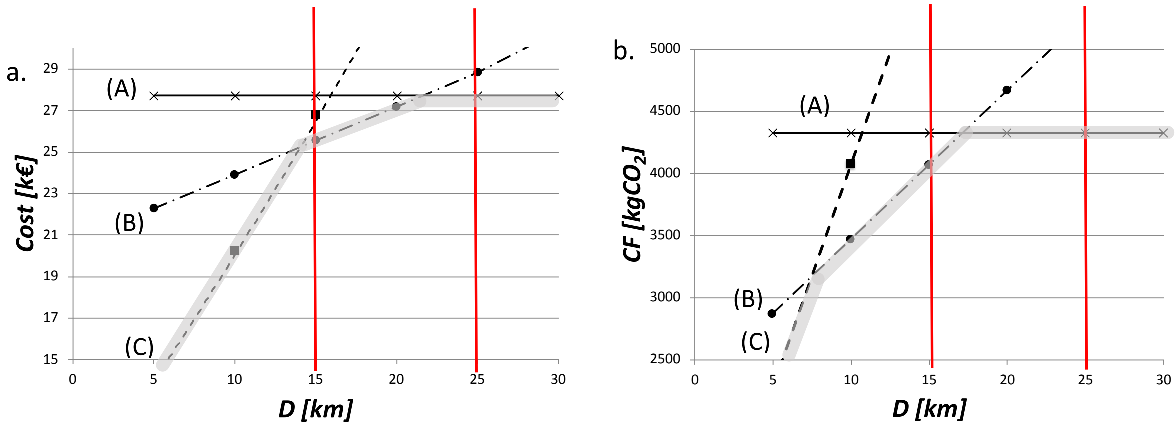

Figure 13. Overall cost (a) and carbon footprint (b) evaluation of containers handling, in case of input variables of simulation A

Comparing the possible configuration of the containers, that includes the adoption of the dry port with the scenario 'as-is' (lack of the dry port) identified by 'A' curve (see fig. 13a and 13b), the configuration proposed by the model allows an average costs reduction of about 7%, and reduction obtained in terms of carbon footprint is about 11%.

In case of D=25 km, the model does not suggest the adoption of the dry port. In fact, analysing the obtained results, the minimal cost and the minimal carbon footprint, respectively, for distance over to 23 [km] and 17 [km] are ensured by stocking all the containers ($N=N_1$) in container yard inside the seaport.

The adoption of the model for different containers configurations, by varying the distance between port and dry-port, allows identifying a threshold curve that represents, for each distance (D), the containers configuration characterized by the minimal cost/carbon footprint (light-gray line in fig. 13).

Adopting the train for the transport of containers from the seaport to the dry port (α=0), the containers configuration with N_1=152 and N_2=456 units is suggested by the model for both values of D. In these cases, considering everything else being equal, the average overall cost estimated by the model decreases of 43% if compared to the strategy adopting AV as transport mean, and 64% is the carbon footprint saving.

7 – Conclusion

The increase of the volumes in the maritime freight transport, especially in the Short Sea Shipping class, caused congestion in many container terminals in EU seaports, mainly in the Mediterranean Sea. The age and the position of many Mediterranean ports do not allow to increase container terminals capacity at reasonable costs. The adoption of a dry port can be seen as an effective solution, but in the decision making process required to evaluate the feasibility of this kind of solution many factors have to be considered: the economic and the environmental feasibility of the solution depends on many variables, such as the Material Handling Equipment adopted and the layout of the Storage Yard in the seaport, the distance between the seaport and the dry port, the transport means adopted to transport containers from the seaport to the dry port and vice versa, as well as the unit cost of the dry port.

In this paper, a model allowing to support decision makers in identifying the optimal strategy to be adopted is proposed and discussed. The model identifies the number of containers to be stocked in the port or/and in dry port, in order to ensure the minimum cost and carbon footprint, due to containers' handling (inside and outside of the terminal container). Results obtained from the application of the model to both numerical experiments and a full-scale case study prove its capability in identifying the optimal containers' configuration to be adopted allowing to minimize the impacts (CF) and the cost due to containers' handling and transport activities.

The model developed represents a useful tool for the strategic decisions, since it allows to evaluate, fast and simpler way, the potential benefit due to adoption of a dry port under economic and environmental perspective, considering multiple assumptions related to the technical features of the 'road' and 'non-road' MHEs adopted, type of containers to be handled, as well as the containers port capacity. It is very interesting note that, in case of uncertainty of the overall number of the containers to be stocked, the benefit deriving from the adoption of the containers' configuration suggested by the model is very high. Indeed, the results of the numerical simulations show that for slight changes in the number of container to be handled (N), the extra cost due to the non utilization of the dry port in case of a decrease of N are negligible if compared with ones in case a dry port is not adopted and there is an increase of N.

In numerical cases examined in this paper, depending on the MHE and transport means adopted, the containers' configuration proposed by the model allows to ensure a reduction of the overall cost from 11% to 57% and a carbon footprint saving from 3% to 86%. As far as concern the Port of Bari case, the model proposes the adoption of dry port in which 152 containers should be stocked; this solution allows to reduce the average handling cost of 7% ensuring a reduction of the carbon footprint of 11%. Both percentages could be significantly increased (43% and 64%, respectively) by replacing the transport mean currently adopted (AV) with the train. Moreover, the model allows to identify, for each transport mean adopted to transfer the containers, the maximum distance (D) from port to dry port, beyond which the dry port adoption does not lead to economic and environmental benefits. In the case of the port of Bari, adopting AV as transport mean, a maximum distance of 20 [km] has been identified by the model. In most of the cases considered, results shown how it is possible to identify a containers' configuration (with or without the adoption of a dry port) allowing obtaining an eco-friendly solution minimizing, at same time, the overall cost for a given number of containers to be handled.

In some cases, however, the proposed model does not suggest a unique configuration, but two different solutions, one allowing minimizing costs and another one ensuring the minimization of the *CF*. In a "green terminal container" perspective, the containers' configuration characterized by the lower impact has to be preferred. Nevertheless, when the two solutions do not correspond, it is not unlikely that the containers' configuration minimizing the overall costs will be preferred. However, this does not reduce the capability of the model proposed. In each case, the relative weight of one solution on the other one has to be evaluated on the base of both international and local regulations on impacts (*CF*) caused by containers' handling and transport activities.

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