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AGENT BASED DISCRETE EVENT SIMULATION MODELS FOR MONO/MULTI CRITERIA ASSESSMENT OF MARITIME PORTS SUSTAINABILITY

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.....“Education is a human right with immense power to transform. On its foundation rest the cornerstones of freedom, democracy, and sustainable human development”.....

Kofi Annan.

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Abstract

Most of the world economy is based on maritime freight transport and plays a key role in international trade, being a determining factor in the economic growth of countries. The steady and continuous increase in the demand for maritime freight transport in recent years (even in times of pandemic) brought consequences such as delays in operations due to congestion inside the terminal, congestion in the connection with the land transport network, unsuitable storage of containers, or due to human factors since these terminals operate 24/7 and it is necessary to manage work shifts to avoid unfortunate events.

On the other hand, the functional efficiency of a container terminal is no longer the primary goal of a terminal, since different sustainability goals are becoming of great interest and concern port operators, port authorities, decision makers, politicians, citizens.

The considerable increase in container volumes has increased the concerns on:

(i) the global environmental impacts from port emissions.
(ii) the environmental impacts on those urban areas which host several maritime ports because port operations can lead to environmental impacts on air, water, and land.
(iii) the social concerns for the health and safety of ports workers, due to accidents still depends on a wide range of human errors as be psychological fatigue despite the automation level reached nowadays,
(iv) the impacts of in/out traffic flows on the city congestion,
(v) the impacts on the liveability of the areas surrounding a port.

In this context, it is easily understandable why wide attention has been given by researchers to container terminals efficiency, and why terminal efficiency cannot be solely interpreted in terms of logistic efficiency, coherently with the United Nations in 2015 defined the Sustainable Development Goals (SDGs).

The first part of this thesis work is focused on the modelling and simulation of a container terminal through the combination of the two main known simulation techniques, on the one hand the discrete event simulation that allows solving large problems through discretisation and the agent-based modelling that allows to incorporate different behavioural logics, which allows to simulate complex and

different technological contexts. In this way, a hybrid simulation is obtained, in which both modelling approaches usually guarantee an efficient solution in time, adaptable solutions to changes in the problems and computational stability.

This research project simulates container terminal operations, highlighting the potential of this tool to model highly complex logistics systems, such as container terminals, without neglecting sustainability. AnyLogic is adopted as a simulation support tool. Specifically, a container terminal model is developed to assess the operations times, consumptions and emissions generated by handling means, where a descriptive approach was used to assess the consequences of different actions in order to achieve environmental and energy efficiency. To test the flexibility of the tool in simulating any container terminal, a modelling framework is applied to a specific case study, the Salerno Container Terminal (SCT), then the validation is performed with real data provided by the terminal operator and available in the open literature, and a Well-to-Wheels analysis comparing different scenarios (with an increasing level of port electrification solutions).

The results of the Well-to-Wheels analysis show that if at the local level the solutions with the highest level of electrification allow a reduction in emissions, at the global level the energy sources used for electricity production are of vital importance to identify whether this scenario is still the one with the lowest environmental impact.

On the other hand, the internal efficiency of activities in a container terminal has a significant impact both on its competitiveness and its catchment area, as well as impacting (positively or negatively) on the city, and on the residents and economic activities that are located near the port. In other words, various stakeholders, different visions, and different objectives must be coordinated towards a single planning framework to achieve the best compromise.

Considering this complicated context, the second part of this thesis work focuses on emphasising the visions, positions, and corresponding objectives of the different stakeholders in relation to the issues presented above, using a multi-criteria analysis approach, which defines the preferences between alternatives according to their impact on the objectives that the decision-maker has identified how relevant. The specific approach used is the AHP (Analytic Hierarchy Process).

Firstly, a hierarchical structure was constructed with the macro-objectives, relating to functional efficiency and environmental, economic, and social impacts, both inside and outside the ports. At the lower level, sub-criteria or indicators were specified.

Through the construction of a survey, focusing on the pairwise comparison between the different macro-objectives, the weight of each macro-objective was defined for the different categories of stakeholders who participated in the survey. Interviews were held with people with different functions in the port sector, both technical and decision-making, both in the public and private sectors, as well as with citizens directly affected by port activities.

The assessments carried out on an aggregate basis on the total sample, showed a strong focus on functional efficiency macro-objective and on the economic/social benefits induced on the territory. Less importance was attributed to the macro-objectives of energy efficiency and reduction of environmental impact, which were considered relevant mainly by citizens.

In the last phase of this thesis work, a simplified application of the full multi-criteria AHP procedure was developed on real intervention scenarios, reproduced through the simulation model created in the first part of this research project. These scenarios were implemented in the Salerno port model, for these, it was possible to calculate some of the indicators identified in the hierarchy constructed, which allowed a ranking of the alternatives to be established. However, this application does not intend to concentrate on the evaluation of the suitability of the alternatives, but rather to give an idea of the potential of applying the full procedure.

1 Introduction

1.1 Background and motivations

The maritime sector is an important item of the overall transport system, both in terms of the quantity of freight handled and its economic and employment dimension and has proved to be the particularly favoured mode of transport in international freight trade in recent years. Despite its low commercial speeds, it is the most economical system compared to land or air transport (Postorino, 2007). Therefore, suitable for transferring large quantities of freight at low unit cost, preferably of low commercial value or perishable products, where other transport systems are preferable.

Furthermore, the use of containers has led to the formation of specialised infrastructures (container terminals) specifically for their handling. Maritime transport terminals allow the performance of a whole series of activities which, in conditions of increasing globalisation, contribute to the possibility of relaunching economic growth, stimulating innovation and competitiveness (L. F. Girard et al., 2020), being in fact fundamental links in logistics chains, engines of development and progress of countries.

In this context, Italy is very competitive with a constant growth of about 2-3% per year of millions of tons of freights transported by sea in imports and exports in the period 2014-2019 (pre-pandemic period) ("Istat.it," 2020). Besides, Italy is one of the leaders in Europe for Short Sea Shipping, ranking third with 283 million tonnes of goods handled (Panaro, 2021).

Therefore, in such a competitive context, added to the scarce availability of space (specially in small ports), and the constantly growing demand, container terminals have had to push and are still pushing hard to improve performance through better management and organisation. Cleary, as demand grows, it is appropriate to proportionate the enhancement of the transport offer as the point of interaction between maritime and land transport modes.

In view of these considerations, it is crucial to research and develop tools that can support terminal operators, both in management and in the improvement of performance and service quality, hence, part of this thesis work pursued this objective.

However, the negative effects that port activities induce both internally and externally to the hub should not be overlooked, since at the same time as the great development that the maritime sector has shown, they are also sources of pollution that cause damage to the environment with consequences for the port itself and the urban contexts with which it interacts.

On the other hand, when planning logistics activities in a maritime transport terminal, the objectives to be pursued are diverse and numerous, sometimes consistent with each other and sometimes conflicting. Which, can cause impacts in a variety of areas, including environmental, economic, social, administrative, etc. and, therefore, can have effects in various ways and intensities in the pursuit of the various, even conflicting, objectives of the decision-makers. The maximisation of all the relevant objectives is not possible in the real world, therefore, for the achievement of the objective that satisfies the actors that may be interested in the activities in the port area (stakeholders) is carried out by the family of Multi-Criteria Analyses, which make it possible to have at one's disposal a rational method with respect to choice problems that present different objectives and criteria. These methods pursue the search for the best compromise solution between the different objectives. In order to guarantee the maximum functional efficiency of the container terminals without neglecting other macro-objectives such as environmental, economic and social efficiency, which are fundamental for guaranteeing sustainable development, part of the objectives of the present thesis is to define the weights, and therefore the importance associated with these macro-objectives by various stakeholder

1.2 Research problem

As explained above, in carrying out operations in a maritime transport terminal, a number of issues arise that are of interest to different stakeholders in the public and private sector, highlighting the most emergent of these:

Functional issues: The high and growing demand and the increasingly massive development of intermodal transport with the use of containers have led to the formation of facilities specialised in the handling of the latter (Russo, 2007). In addition, the privatisation of terminals has given a further boost to competition between these facilities, thus, the focus is on optimising operations to reduce waiting time for ships, where the main indicators for the pursuit of this objective are: time between entry and exit of trucks, waiting time of trucks at the gate, manoeuvring time of ships, time required for the stationing of ships, time required for the exit of containers, productivity of loading and unloading of the ship, performance of handling equipment (as a percentage of the work shift).

Environmental issues: The objective of environmental efficiency is of fundamental importance for maritime transport, as the latter contributes significantly to air pollution and climate change due to its dependence on fossil fuels and the fact that in the past it has been one of the least regulated sectors with regard to air pollution, in fact, maritime transport is responsible for 3% of CO2 emissions at European level with a share of 138 million tonnes (“European Commission, official website,” 2018).

Issues of a social nature: Which concerns the safe conduct of operations. This issue might at first look be placed in the background compared to the efficiency of the supply chain and the effects related to it, but that should in no way be overlooked, is that related to the reduction of impacts on port workers. These have been better specified through the introduction of indicators: risk of accidents inside the terminal, mental and physical workload, pollutant-induced illnesses taking into account the workload of the workers, noise pollution where it primarily affects the workers in the port but also outside it.

Therefore, it should be noted that it is necessary to combine the steady growth of a commercial port with the protection of the environment, in line with the logic of sustainable development, i.e. the development of port infrastructures and the expansion of logistic spaces are expected to be based on several objectives that partly define their sustainability, in particular:

- on the environment (sea and air pollution);
- on the economy of the territory (induced activities);
- on the efficiency and liveability of the city with which they interact (travel time, pollution, accidents);
- on the well-being of workers (workload, safe working environment).

1.3 Research goals

The aim of this thesis is the development of a decision support system (DSS) by specification of an integrated model for simulation and multi-criteria assessment of logistics activities, personnel management, and environmental impacts of a maritime transport terminal.

The objectives are multiple and of methodological and operational interest

Objectives from an operational point of view:

- Implementation of a decision support system that is modular, scalable and transferable to different port contexts. The proposed DSS would enable:
    - the real-time management of logistics flows;
    - the easy dynamic re-planning of services;
    - management of personnel shifts and workload;
    - simulation and optimisation of environmental impacts;
    - personnel shift and work-load management.
- Identifying and quantifying the weight for different stakeholders of various macro-objectives of functional, environmental, social and economic character related to ports;
- Favouring the acceptance of certain political choices, since in the planning of interventions in the port area the visions are different and conflicting. This is part of public engagement and therefore aimed at involving experts and non-experts, as well as identifying the hierarchy of the different actions of intervention;
- Construction, simulation, and evaluation of real scenarios by implementing different infrastructural technological solutions.

Objectives from a methodological point of view:

- Desk analysis of existing approaches in the literature for the simulation and optimisation of terminal activities, personnel management, energy consumption and environmental impacts,
- Desk analysis of existing approaches in the literature for the estimation of pollutant emissions and energy consumption in ports.
- Desk analysis of infrastructural technological solutions for the efficiency and sustainability of a maritime terminal.
- Identification of the most effective and efficient methods and algorithms for the multi-criteria assessment of the activities of a container terminal.
- Identification of models for estimating the environmental impacts of seaside, innerside and landside activities of a maritime terminal.

The proposed objectives was pursued through the specification, validation and implementation of the DSS on a real case (e.g. Port of Salerno) using a hybrid multi-agent discrete event approach. In particular, the proposed model is a microscopic model with explicit simulation of each loading and handling unit and intergerning a system of bottom-up models able to estimate and optimise the pollutant emissions generated by all the components of a container terminal.

In addition, this instrument addressed 6 of the 17 sustainable development goals signed by UN members by 2030 ("Sustainable Development Goals," 2020), in particular:

- Goal 3: Good health and well-being;
- Goal 7: Affordable and clean energy;
- Goal 8: Decent work and economic growth;
- Goal 11: Sustainable Cities and Communities;
- Goal 13: Climate action;
- Goal 14: Life below water.

The Figure 1 shows the methodological framework developed to achieve these previously stated objectives.

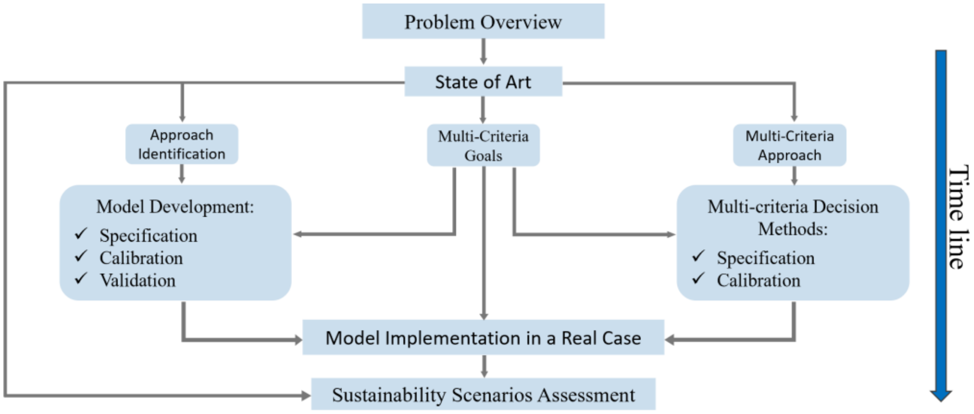

Figure 1.1: Methodological path

The methodological path of research (Figure 1.1) began with the overview of the problem in a qualitative form, which served to identify the research axes to facilitate the achievement of the proposed objectives. Then, a consistent state of art was constructed by disaggregating the research into each of the operations that take place during the logistics of the freight in the terminal, which served to highlight the different needs that emerge in container terminals nowadays. In addition, existing approaches in the literature for the simulation and optimisation of terminal activities were identified, as well as existing approaches for the estimation of pollutant emissions and energy consumption in ports. In addition, effective and efficient methods and algorithms were identified for the multi-criteria assessment of container terminal activities, as well as technological/infrastructure solutions for their efficiency and sustainability.

In the next phase, the simulation model was built through the specification, calibration, and validation of the model, as well as the specification and calibration of a multi-criteria approach for estimating the impacts on the sustainability of a port through the interpretation of the visions of the different stakeholders, both public and private. The port of Salerno was then used as a case study to assess the flexibility and robustness of the model developed through the implementation and assessment of scenarios that would make terminal activities more sustainable.

1.4 Research contribution

Three elements of originality and contribution to research can be identified in the research project, each of which will be explained below:

Specification, calibration, and validation of a simulation model through a hybrid multi-agent discrete event approach of logistical activities in a terminal container.

An analysis of the state of art shows that, at present, the efficiency of a terminal is always addressed separately from the individual elements that make up a maritime transport terminal, aiming at functional efficiency, and sometimes neglecting environmental, energy and technological aspects. As far as the simulation approach is concerned, there are numerous and varied DSS existing in the literature, the major contributions being based on optimisation methods or on simulation methods based on discrete event models. All approaches, beyond some theoretical or analytical tractability limitations, do not allow to explicitly represent the different "behavioural" logics of the different actors involved in terminal activities. Moreover, as far as environmental efficiency is concerned, the main contributions are based on "what if" approaches with implementation/verification of sustainable policies, without any optimisation of activities according to this objective. This confirms the novelty of this part of the research project, i.e. the development of an integrated simulation model, through a hybrid approach combining, on the one hand, discrete event simulation, where the system is represented in its evolution over time, with variables that instantaneously change their value in well-defined instants of time. These instants are those in which events occur (i.e. loading/unloading containers). And on the other hand, in conjunction with an agent-based modelling, defining an agent as an entity endowed with partial autonomy, intelligence and mobility that assesses its state and decides on the basis of a set of rules that define its behaviour within the simulation environment, and the multi-agent system is a set of these agents located in a certain environment and interacting with each other through an appropriate organisation, which with their attributes some state variables of the system can vary even outside the event. Furthermore, this tool integer a system of bottom-up models capable of estimating the polluting emissions generated by all the components of a port.

Specification and calibration of a multi-criteria approach for estimating the sustainability impacts of a port

The present thesis work performs a Multiple Criteria Decision Making (MCDM) analysis to evaluate the functional, environmental, and social impact assessment of port operations. The stakeholders involved in the survey for the identification of the relative weights of macro-objectives include entities with decision-making responsibilities, such as port authorities, ministries, regions and municipalities, entities involved in logistics chains such as carriers and terminal operators, experts in maritime economy, environment and logistics such as professors, researchers, self-employed professionals and employees, and finally figures without specific competences but directly affected by political choices such as citizens.

A sample of 79 people have been interviewed making this work of particular interest in the field because of the number of interviewees (generally a sample lower than 20 is adopted) and its holistic approach (functional, environmental, social impacts etc., not with a specific focus on only one of them). The Contributions of originality of this part of research project are: (1) for the first time in the open literature a MCDM, using Analytic Hierarchy Process (AHP) method, has been applied to a real case scenario with the aim of evaluate the functional, environmental, social and economic impact of a port. In the literature only some of those aspects have been considered (e.g. environmental and economic) or specific analysis on each aspect have been performed on simulation and optimization approaches. Also, (2) an adequate sample of experts conducted the survey allowing this study to be one of the most reliable and complete in the open literature so far (i.e. sample of 79 instead of 10).

Implementation of an integrated framework for the evaluation of intervention scenarios on a real case

The simulation model, developed within the framework of the thesis work and applied to a case study, was used for the complete application of the multi-criteria analysis method. It was used as a tool to apply scenarios other than the current one, in order to be able to compare them by the multi-criteria analysis. In particular, it shows how the indicators, i.e. the sub-criteria referring to the macro-objectives to which a weighting was assigned in the previous analysis, vary in the different scenarios. This consent an orderly ranking of the best sustainable alternatives for intervention at a container terminal to be determined, based on the weights associated with the macro-objectives, the indicators and the different alternatives with respect to the same indicators, thus completing an integrated framework that manages to address a number of requirements that were treated separately until now without an integrated assessment of the different macro-objectives. Confirming the potential and flexibility of the tool developed on the application of the full procedure.

1.5 Thesis Outline

The thesis is articulated as follows:
In the first chapter, an introduction to the research work is given, highlighting the research background, the objectives of the thesis and the contributions made in the following research work.
The second chapter provides an overview of the activities carried out in the maritime ports, focusing on the container terminals, describing the actors involved and their roles, as well as the different operational areas and the logistic cycles (import, export and transhipment) that take place in the development of the activities.
The third chapter presents an extensive and detailed state of the art on models and approaches for the simulation of a maritime transport terminal; approaches to optimise logistic activities in a container terminal and approaches and methods for the estimation of pollutants, energy consumption in a maritime transport terminal.
The fourth chapter, the methodological framework of simulation models is reported, focusing in detail on the discrete event approach and the agent-based approach. After that, a methodological framework on multi-criteria analysis is reported, providing a state of the art on the different methods and models most widely applied in this field able to carry out this type of analysis, describing each one of these with particular attention to the Analytic Hierarchical Process, technique adopted in this thesis.
In the fifth chapter, the simulation model is described, through the specification and validation of these, proposing a real case study (Port of Salerno) to evaluate the flexibility of the developed tool.
The sixth chapter is dedicated to the single-criteria analysis, by implementing different simulation scenarios, to assess both the robustness of the model in representing a real case and to evaluate different functional, environmental and energy consumption indicators of the terminal in study. In addition, the human factors associated with the workload are considered.

The seventh chapter refers to the multi-criteria analysis, where the description of the questionnaire, the description of the main actors involved in the survey and the descriptive analysis of the results of the survey are carried out. During the descriptive analysis of the results, particular attention was paid to the distribution of the evaluations expressed regarding the absolute judgements and the relative judgements, then the weights obtained through the application of the AHP are presented. The last part of the chapter deals with the comparison between real scenarios affecting the sustainability of port activities, especially in the case study of the port of Salerno.
The thesis concludes with a final chapter summarising the conclusions and future research prospects.

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2. Port Activities

2.1 Introduction

A port can be seen as an interchange point between land transport system and a maritime transport system. This facility is quite expensive in terms of initial investment as management costs and cannot therefore be considered isolated from the context in which it is located. It should be contextualised in a broad intermodal transport system that includes interactions with other port systems and interactions with land transport systems, i.e. rail and road links that are essential to guarantees the efficiency of these facilities and the specific function of the port in terms of transport continuity and links to the hinterland. (Cantarella, 2007).

On the other hand, the demand from society for a better quality of life is known, adding to this requires a more sustainable design in intermodal transport systems, which does not leave out port facilities. Terminal operators also pursues these goals but trying to reduce costs through efficient operations. Great results are already being shown in the automotive industry such as electric vehicles, however, progress towards sustainability on the ship has not yet been demonstrated in the shipping industry, in contrast to the design of electric vehicles for lifting containers. Therefore, is imperative that in the absence of sustainable reduction of impacts on the ship side, the functional/operational side of operations must be looked at as well as the environmental/energy side. (Böse, 2011).

A port can be managed by the government authorities, or by private parts (concessionaires), who through their strategic planning policies must guarantee the entry and exit of ships at the times agreed with the shipping companies for the loading/unloading of freights, considering well differentiated yards according to the type of freight, for the storage of these, an internal road network to guarantee the horizontal transport of containers, land and/or rail connections to guarantee the entry and exit of freights in the port, and finally it must provide safe navigation services, such as pilots, tugs, ship supply services, etc.

Regarding the operational functionality of a port, it is necessary to distinguish two flows that take place within it: on the one hand, the physical flow (transport units, cargo units and cargo handling units), and on the other hand, the information flow linked to the transfer of information among the different actors in the port.

The port structure can be subdivided into blocks, which each of these has different functions (Figure 2.1): An entrance by sea can be identified, which can take place through a channel, where port services are generally required to escort incoming ships; one or more quays which ships will dock; equipment for loading/unloading freights, where quay and yard cranes are the main means of vertical handling; a yard designated for moves the containers; a warehouse for storing freights; and finally an exit by land/rail, connecting with land transport systems.

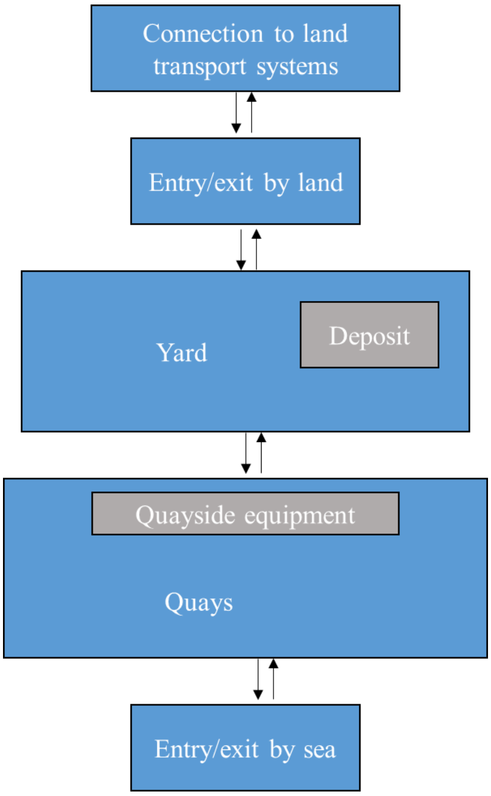

Figure2.1: Functional port representation (Source:(Cantarella, 2007)*)*

In the present chapter, an attempt will be made to give a general overview of the ports, their characteristics, activities and management, however, a more complete and detailed analysis will be made of the container terminals as well as the activities that take place within them, dividing these into the different operational areas: Seaside, Innerside, and Landside, going into the operations carried out in each area, the main criticalities, and the means involved to evolve each one. Finally, an assessment will be made of the problems and challenges facing terminal operators in order to ensure that activities are carried out in the most effective and sustainable way, both from a functional and environmental point of view.

2.2 Ports: Overview

2.2.1 Definitions

A maritime port can be defined from different points of view, it is generally defined as a natural or artificial structure located on the seashore, allowing the mooring of vessels, boats and ships and their protection from adverse water conditions, as well as allowing and facilitating the loading and unloading of freights and the embarkation and disembarkation of persons.(Wikipedia, 2021)

Considering the etymology of the word, it can be defined from the same root as the word "door"; "passage, entrance". An area of water, mostly marine, adjacent to the coast, more or less wide and protected, usually equipped with fixed and mobile installations (dams, piers, quays, docks, basins, docks, warehouses, means of embarkation and disembarkation of freights, shipyards, etc.), where ships can access in all weather and stop safely, either to find shelter during storms and have the repairs they may need, or to carry out the operations inherent in the conduct of maritime traffic (“Vocabolario - Treccani,” 2021).

From a naturalistic point of view, the port constitutes an artificially or naturally sheltered stretch of water and is therefore suitable for the landing or departure of ships.

From a legal point of view, the principle that the port is state-owned and belongs to the State was first enshrined in the current Civil Code, which, in Article 822, includes it among the assets of the necessary state property, and then in the Code of Navigation, which, in Article 28, includes it more specifically among the assets of the maritime state property (“18/1 - Compendio di Diritto della Navigazione - Simone,” 2014).

But what is a port? It is difficult to give a complete definition, as most people have no idea how it works, or which are the innumerable trades carried out within them. In some cities, the port is sometimes experienced by citizens as a resource, in others it is ignored, and in others it is seen as a nuisance, a source of road congestion, pollution, lack of access to the sea, etc. The port is a complex, multi-faceted environment. The port is a complex, articulated environment where the most diverse professions are exercised, which until recently have lived in watertight compartments, enclosed in their own areas, defending their own roles, sometimes in competition, with difficulties in relations, with no interest in the activities of others unless they are functional to their own business (Lupi and Italia, 2011).

Figure 2.2: Port of Naples, in the hearth of the city(Source:(Lupi and Italia, 2011)*)*

2.2.2 Port functions

A port can have different functions/activities, the best known of which are listed below:

- Commercial: They can be considered from two points of view, on the one hand from the point of view of freights, where the port serves for the transport, loading/unloading, transhipment, storage, and trade of freights in a port, considering the port functional for the freights passing through that will take the road by land usually in containers, in this thesis this functional characteristic will be deepened. On the other hand, the commercial function related to passengers has to be considered, serving as transport, boarding/disembarking, transhipment (sometimes), stopping/restoring people. Beyond this, there are several service activities within the port related to freights, e.g., hold cleaning (when the loading time is different to the unloading time there is a time for cleaning the holds of ships) and service activities related to people such as laundries, and supply of tablecloths, refreshment services etc.
- Industrial: This function is given to the port when there are industries near the port in the hinterland that use them to process the freights, for example,

the ports of Trieste and Venice, as well as being tourist ports, are also industrial ports; another example is the port of Civitavecchia, when in the 1970s it was used for the steel industry, where loads of ore arrived from Terni and loads of steel profiles left for various destinations. Therefore, once the freights have been processed, they must be embarked/disembarked and transported to their port of destination. Unlike the commercial function, here the freights are not processed freights in transit, instead the freights (raw materials) arrive, are processed and then shipped as the final product.

- Tourist: In order to define a port within a tourist function (even if sometimes the port itself has a tourist attraction), it needs to be close to places of worship (religious) and places of cultural interest. An example is the port of Livorno, from which specific shuttles depart for tourists to the city of Florence.
- Military: This function is in continuous transformation because it depends on the geopolitical situation of the world, and it is done only with the purpose of defending the territory, for example in the first world war the importance was of the ports of the Adriatic such as the port of Brindisi, Bari, the same port of Venice, there was a need to export freights of military interest to the Adriatic, in the Second World War the important ports were the port of Taranto and La Spezia, and even today the military concentration is centred on the Gulf of Taranto by locating the port of Taranto as a port with a military function.
- Resource exploitation: This function takes place when a port is used for the exploitation of resources, which includes fishing, oil and archaeological resources. Almost all ports probably started with the exploitation of resources and then over the years changed its scope.

All of these functions can coexist in the same port, but not all of them, some ports may omit some functions because they exploit the moment, for example Civitavecchia is a port that was born as a tourist port, then over the years, the port has developed as an exploitation of resources, it had an enormous development in the 18th century with the Papal State as a trade, in the 80s and up to the 90s the commercial function was predominant, then thanks to religious events such as the 2000 Jubilee and the 2016 Jubilee, and thanks to its proximity to Rome, the port was transformed into a tourist port, although it still retains a commercial role.

From studies of logistics and cargo handling, there is a good example of ports that exploit the tourist and commercial function, and it is called perfect dualism, this takes place between the port of Rotterdam and Amsterdam. Until the 1950s, the main port was the port of Amsterdam, which was protected by a gulf (where the city of

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Amsterdam is located). The development of the port as a tourist destination led to an increase in the population, so it was decided to preserve the tourist, cultural and historical part of the port, but it was necessary to move the commercial part of the port, which was constantly growing, since the port of Amsterdam handled the entire northern part of Europe. It is called a perfect combination because it manages the tourist, cultural and historical part from the port of Amsterdam and manages and exploits the commercial part from the port of Rotterdam. As far as Italy is concerned, the port that has taken on many functions in recent years is Civitavecchia, considering that from the cruise and ferry point of view, it is in first place in Italy, given its proximity to the city of Rome (Andriani, Guido, 2019).

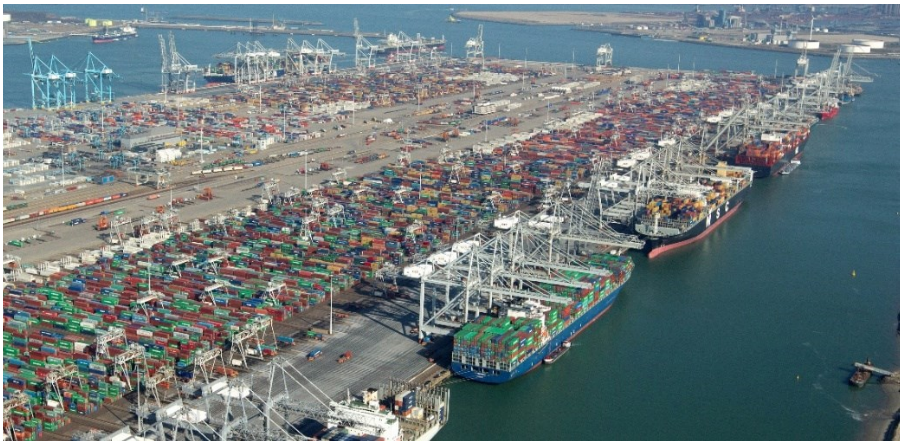

Figure 2.3: Port of Rotterdam, a purely commercial port (Source: ("Transito Study Association | Rotterdam," 2021)

2.2.3 Port terminals and related activities

Within the commercial characteristics of a port there are different equipment and infrastructures that are used to carry out these commercial activities. Inevitably, when talking about infrastructure and equipment, one arrives at the various specificities of the different terminals intended for different types of ships and freights.

Several terminal types can be identified, each one with its own specificities and particular equipment for handling freights:

Container terminal: Structure in which maritime containers are managed and handled in order to change their mode of transport. When talking about a terminal it is necessary that there is a change of at least two means of transport. Generally, a container terminal is associated with the handling of containers between container ships and between ships and land vehicles such as trains or trucks.

The operations, management and planning of these facilities will be studied throughout this thesis, and in particular the following section of this chapter the logistics of the freights inside a container terminal will be studied in depth as well as the equipment to carry out the activities.

RO-RO Terminal: These infrastructures are used to receive Roll-on/Roll-off (Ro-Ro) ships. Ro-Ro is by definition a ferry designed for the transport of wheeled vehicles, and cargoes, arranged on platforms or in containers, which are loaded and unloaded by wheeled vehicles independently and without the aid of external mechanical means.

Multipurpose terminal: These facilities are specialised in offering the best transport solutions for all freights that do not travel in containers: general cargo (pulp and timber, fruit and other foodstuffs, etc.), rolling stock (lorries, new cars, operating machinery, rail vehicles, etc.) or special loads (project cargo, exceptional loads by weight and size, etc.). (“Multipurpose - Autorità di Sistema Portuale del Mar Ligure Occidentale,” 2021)

Oil or bulk terminals: These terminals are used for loading/unloading of liquid freights such as crude oil for refineries, as well as having facilities and warehouses suitable for all types of petroleum and chemical products, vegetable oils and food products or solid bulk such as minerals, coal, briquettes, etc.

Passenger Terminal: Often referred to as a terminal, it is a facility in the port area used for transferring passengers from the land transport system to the sea and vice versa. Within these facilities passengers can purchase tickets, transfer their luggage, and pass their security checks. depending on whether the journey is for travel or tourism, the type of vessel used varies. The ships used for travel are primarily ferries and secondarily Ro-Pax ships, while cruise ships are the most used for tourist travel.

2.3 Container terminals

The history of the container dates from 1956, when Malcolm McLean, an American truck businessman, created the container to speed up the time and reduce the cost of loading and unloading freights from ships in US ports, which marked the beginning of a new concept in logistics and transportation worldwide (T21, 2016). Containers were designed to speed up the time of cargo handling in a more efficient form. In addition to the advantages for the loading/unloading process of ships, the standardisation of containers has provided many benefits for customers, as the container provides protection against weather and theft, also simplify the scheduling and control of these, resulting in a profitable physical flow of cargo (Voß et al., 2004).

There are several possible combinations of length and height for containers, however the international standardisation organisation (ISO), has standardised the combinations of width and height for containers, and these are shown in (Table 2.1), where the letters indicate the ISO standardised abbreviation for the relevant external dimensions.

Table 2.1: Measures of containers according to ISO standars (measurements in feet)

Width	Length (class)	Height	
		8'	8'6''
8'	10'	D	
8'	20'	C	CC
8'	30'	B	BB
8'	40'	A	AA

The definition on an international scale of the reference unit of all containers is that of container C, which is also called TEU (Twenty Equivalent Unity) (Figure 2.4); according to this, for example, a container of type A is 2 TEU (Cantarella, 2007).

Figure 2.4 :20' container (Source: ("A.B. Richards," 2021)*)*

The increasing number of container shipments has led to greater demands on seaport operators, container logistics and management. Currently around 802 million TEUs (2019- pre-pandemic), travel by sea and land to transport freights to their destinations ("World Bank Open Data," 2020), (Figure 2.5), covering approximately 90% of world trade, and there are more than 50 thousand container ships engaged in international trade carrying all types of cargo ("International Maritime Orgnization," 2021).

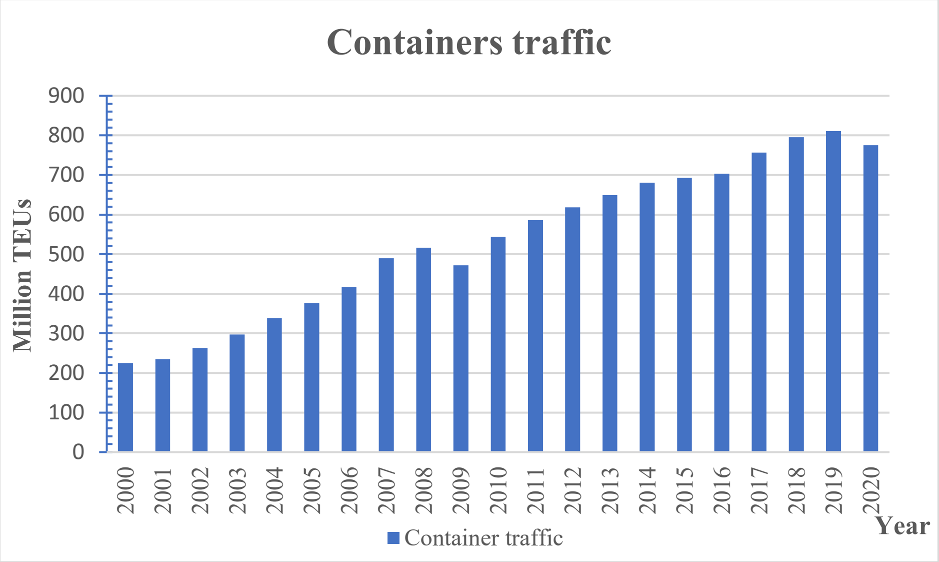

Figure 2.5: Worldwide Container traffic (Source: ("World Bank Open Data," 2020)

From an environmental point of view, this growth in maritime movements and related emissions has brought concerns to government authorities. Studies reveal that shipping activities are a major source of air pollution, as ships' main engines often use heavy fuel. Nowadays, more than 95% of the world's shipping fleet is powered by diesel engines (Saraçoğlu et al., 2013). Also, the energy demand for seaports increased by an average of 1.6% per year between 2000 and 2015 (United Nations Conference on Trade and Development, 2020). Reducing emissions is a direct consequence of energy efficiency, electrification of equipment, use of alternative fuels and renewable energy sources. These aspects, together with operational efficiency, form a large part of the concept of a next-generation port (Iris and Lam, 2019).

This growing demand and the increasing development of intermodal transport using containers has led to the formation of structures which are specialised in container handling. In addition, the privatisation of terminals has given a further boost to competition between these facilities.

A container terminal can be described as a material flow system, with two external interfaces, these are, the quay (seaside), where the arrival of ships and the loading/unloading of containers is handled, and on the other side (landside) it communicates with the road network, where containers are loaded and unloaded on/by trucks and/or trains. On the innerside of the terminal the containers are stored one on top of the other, the container storage area is usually separated into several stacks (or blocks) which are differentiated into rows, bays, and levels, thus facilitating the decoupling of quayside and landside operations. These storage areas are differentiated according to the containers stored, paying special attention to REEFER containers that need an electrical connection, or containers containing dangerous freights; they are also differentiated according to the type of cycle to which the freights belong, there are 3: import cycle, export cycle, and transhipment cycle; and a further classification is made within storage blocks according to the type of container (20/40) and its state (full/empty).

Several handling equipment coexists daily in container terminal operations. For each work area, there are means assigned to evolve the operations. In the area that interfaces with the seaside, there are special cranes for loading/unloading containers onto the ship. Regarding the internal area of the terminal there are a series of means that serve both for the horizontal handling of containers, thus generating a connection between the operational areas and ensuring a continuation of the material flow, and for the vertical handling, i.e. the storage of containers in the corresponding yard, and also to carry out the loading/unloading operations of trucks, and tug masters, inside this internal area are the yard cranes (RTG) which will be used for the loading/unloading operations of trucks, the reach stackers (RS) used for the operations of tug masters (TM) and the trucks of the transport companies that come in to carry out some loading/unloading operations of containers.

In addition to these general functions, some terminals also differ in their operational units. For example, if there are no railway stations within the terminal, containers have to be transported by trucks or other land transport between the external station and the terminal.

2.3.1 Actors involved in processes related to freight flows

The two main actors involved in the loading, unloading, storage and delivery of containers are the Terminal and the shipper.

In a generic Terminal the following main professional figures can be identified:

- Planner: this is the technical figure who supervises the stowage operations (loading/unloading) of containers and their location (by class and by level) in a given place in the terminal; he plans the ship's loading and unloading activities, assessing the types and characteristics of the freights, ensuring the stability of the ship; from an operational point of view, the Planner receives the Loading Plan and prepares the loading/unloading diagrams, i.e. the sequences of activities (work queues) in order to plan the ship's unloading and subsequent embarkation;

- Crane operator: he works on mechanical means for the handling of freights and containers; the Crane operator is connected by radio with the Stevedore (one for each quay crane), which interacts with the Planner as it receives from the latter the work queues from which it can understand which containers to unload and in which sequence;
- Checker: he performs the first check on the incoming container, verifying that it is the one envisaged by the unloading sequences and that there is no damage or tampering with the seals;
- Dispatcher: this figure is placed between the Planner and the Yard Operators; he receives the work queues from the Planner and gives instructions to the Yard Operators, who transport the containers on board mobile vehicles (tug-master);
- Forklift operator: forklift operators (may be of various types) who are used to transfer the container from the yard to the tug-master;
- Yard Operator: identified with the driver of the tug-master, who in the Import phase transports the container from the forecourt to a temporary storage enclosure following the routes indicated by the Dispatcher. In the Export phase, he will obviously follow a reverse route;
- Gatekeeper: the operator in charge of controlling the vehicle entering or leaving the Terminal and verifying seals and transport documents. Fig. 2.6 shows the set of actors involved in the processes related to the generic Container Terminal.

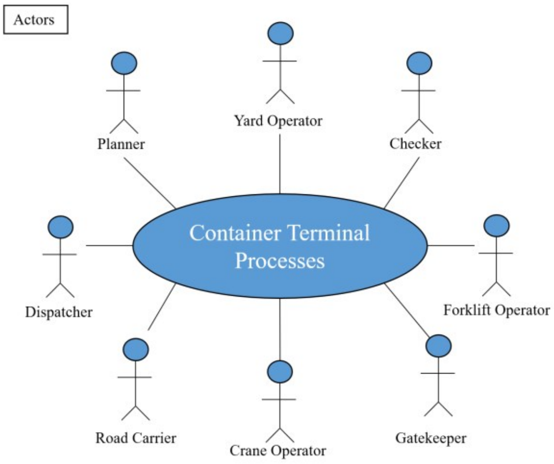

Figure 2.6. Actors involved in the processes of a Container Terminal.

2.3.2 Actors involved in 'last mile' processes

Actors involved in logistics processes related to urban freight transport are the following:

- Importer: the buyer of the freights, the person who intends to import a certain type of freights, and who is supposed to arrange the transport;
- Exporter: the person who intends to export the freights;
- Maritime Agent: the shipowner's auxiliary who represents the ship at the port location, carrying out all commercial and administrative operations;
- Ship's Forwarder: he carries out in the interest of the ship (acting on behalf of the carrier or shipping agent) the administrative and customs formalities concerning the cargo and provisions on board, both on arrival and departure of the ship;
- Customs Forwarder: the operator responsible for shipping the freights; for the sake of simplicity, it is assumed that this is also a customs officer, i.e., a registered professional figure, with a regular professional qualification, to whom the official representation of the customer at customs is delegated;
- Port Terminal: the Terminal Operator who carries out technical and loading/unloading operations on the Ship;
- Intermodal Terminal: infrastructures generally only suitable for the exchange between load carriers and therefore normally without specific areas for warehousing.
- Interport: the organisation that manages all security within a logistic Freight Village;
- Road carrier: the transport operator, hired by the Freight Forwarder or possibly directly by the person importing the freights;
- Railway Operator: the company that provides the supply of railway transport services of freights, compulsorily guaranteeing their traction;
- Customs Agency: represents at the same time the local office of the Customs Agency, and its central management;
- Multimodal Hub Manager: the enterprise that manages an area where sorting and consolidation/deconsolidation of freights takes place.

2.3.3 Terminal activities

Inside a container terminal, the containers are handled and moved in order to change their mode of transport, often a container terminal is associated with the handling of containers between container ships and between ships and land vehicles, whether trains or trucks. To carry out an organised description of the logistical flow, it is convenient to distinguish three major cargo handling cycles covering all operations inside the terminal. These are, the **import cycle** (containers coming from the sea to the hinterland), **export cycle** (containers going from land to the sea) and the **transhipment cycle** (containers moving from sea to sea using the terminal as a ship exchange point). In this section a description of the import and export cycle will be carried out through the representation in BPMN language, which is a standard for the formal representation of information flows, it provides a graphical representation to specify the individual processes through Business Process Diagram (BPD), describing the various actors involved that are triggered in the processes related to the loading and unloading of freights in a Container Terminal.

2.3.3.1 Import cycle

The import cycle involves containers coming from the sea, which must be unloaded, and continue their journey by land transport modes.

The choreography diagram relating to the import cycle is shown in Figure 2.7. Each macro-activity is represented by a block, which shows in the central space the name of the activity, in the upper slot the name of the main actor of the activity (the initiators), and at the bottom the names of the secondary actors. Each of the macro-activities, also identified by an alpha-numeric code (which has the acronym CIT, Cycle Import Terminal), is represented in a dedicated diagram, of the orchestration type, which illustrates in detail the interactions between the various organisations involved in that specific process component.

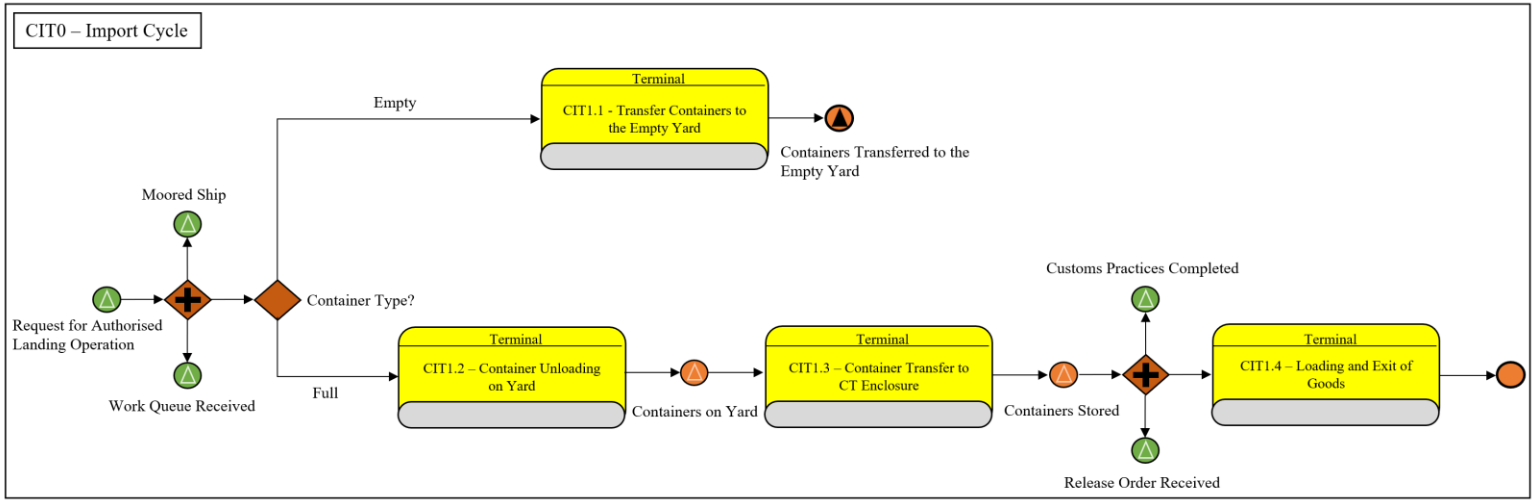

Figure 2.7: Import cycle

The import cycle begins when the following pre-requisites are checked:

- "Moored Ship" signal;
- "Request for Authorised Landing Operations";
- the crane operator and the dispatcher received the work queue. This condition is represented by the event "Work Queue Received".

The operations that fully define the import process differ according to the type of container to be unloaded, which can be either full or empty. In the first case, the container is placed on the ground by the quay crane and then loaded onto the tug-master with a reach stacker. If instead it is an empty container, then unloading can be carried out directly on board the tug-master.

The first macro-activity of the import process is represented by the task "CIT1.1 - Transfer Containers to the Empty Yard". It refers to the set of activities related to the unloading of the empty container, which is placed directly on board the tug-master and then transported to the area of the yard designated for storage of empties.

The task "CIT1.2 – Container Unloading on Yard" is carried out for the case of a full container and refers to the interactions between the various figures of the terminal that are involved in the operations of unloading the container on the dock. The output event of the task is the intermediate event "Container on Yard". The latter event is the pre-requisite for the task "CIT1.3 - Container Transfer to CT Enclosure", in which the reach stacker is involved in order to position the full container, taken from the yard, on the tug-master. While the yard operator will lead the container to the temporary custody part of the yard. The output event of the task is the intermediate event "Containers in storage". In this last task there are already phenomena of interaction between the tug-master and other handling equipment (trucks) that carry out commercial activities in the same area as the tugs.

The last macro-activity is represented by the task "CIT1.4 - Loading and Exit of Goods ". This task refers to the interactions between the terminal and the haulier arriving at the gate to pick up containers. The term "Loading" refers, in fact, to the loading of containers onto trucks.

In addition to the "Stored Containers" trigger event, the other two pre-requisites are as follows:

- "Customs Practices Completed";
- The shipping agent has delivered to the terminal the release order "Release Order Received".

2.3.3.2 Export cycle

The export cycle concerns containers coming from inland regions, arrived at the terminal by land carriers, which will be loaded onto a ship.
The choreography diagram relating to the export cycle is shown in Figure 2.8. As for the import cycle, each macro-activity is also identified by an alpha-numeric code (characterised by the acronym CET, Export Terminal Cycle)

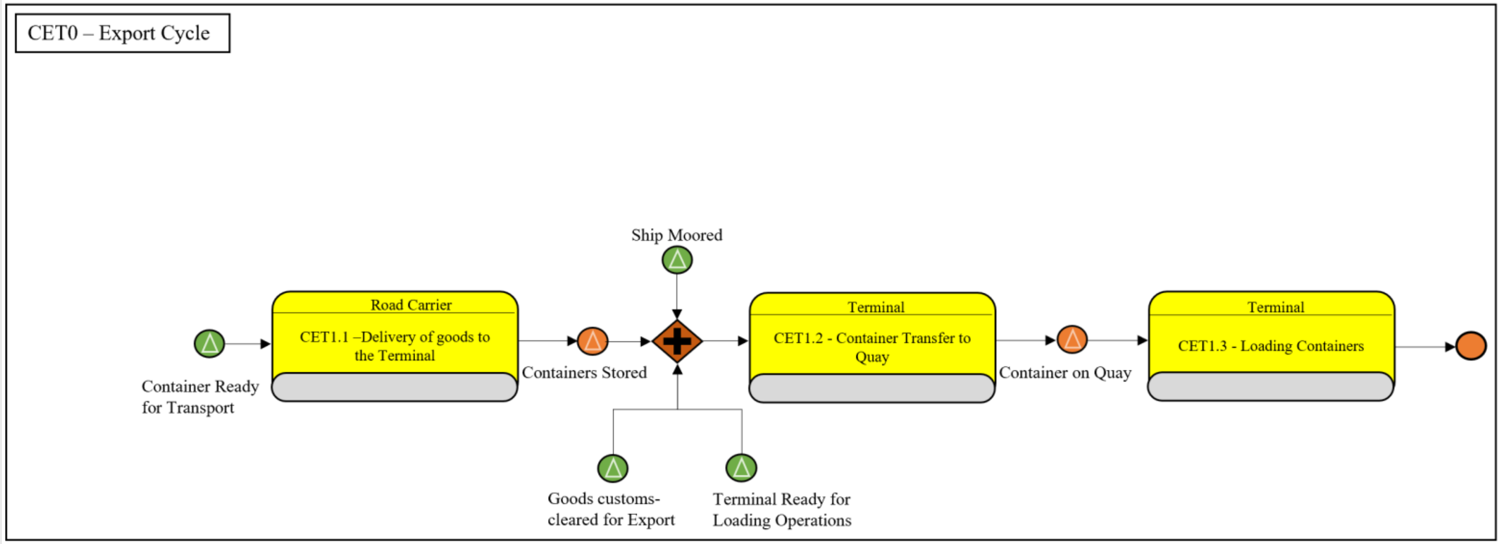

Figure2.8: Export cycle

In contrast to the import cycle, in this case there is no distinction of operations according to the type of container to be loaded. It is necessary to consider a different route, compared to import, that the tug-master takes to move from the loading yard to the crane involved in loading the containers.

The first macro-activity is represented by the task "CET1.1 - Delivery of freights to the Terminal", which refers to the information flow that is triggered between the haulier and the Terminal (in particular, the gatekeeper) to authorise entry of the freights that will subsequently be loaded. The task is activated following receipt of the "Container Ready for Transport" signal. The task output event is indicated by the intermediate event "Containers Stored", which refers to the condition in which the generic container is stacked in the yard place designated for export operations.

On the occurrence of the following events:

- “Moored Ship”;
- “Terminal Ready for Loading Operations";
- “Goods Released for Export”;
- “Stored Containers”, the exit event of the previous task.

the task "CET1.2 - Container Transfer to Quay" may take place. It represents the sequence of operations that allow the containers to be taken from the export area, loaded on the tug-master, and taken to the loading dock, where the crane will take care of the final phase of loading. This activity ends with the generation of the "Container on Quay" signal. In this task, the speed at which the tug-master moves may be influenced by the presence of other vehicles (trucks) moving within the terminal area carrying out other loading/unloading operations (that may involve other docks, and therefore other ships).

The last macro-activity is indicated by the task "CET1.3 - Loading Containers", takes place when the containers have been positioned at the crane involved in the loading operations and following a check by the checker (which verifies that the container is the one to be loaded), the Crane operator takes the container from the tug and places it on the ship, in the slot in the work queue received from the planner.

2.3.3.3 Transhipment cycle

The transhipment cycle is a logistical cycle that takes place in some container terminals, in particular terminals with large handling capacities, since in small terminals it is not possible to keep containers stored for a long time, due to a lack of space, and many times this space cannot be developed in ports alongside cities.

The transhipment operation occurs when a container is moved from one ship (A) to another (B) while it is in transit to its destination. Transhipped containers count twice in the port's throughput because the quay cranes handle them to unload them from

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arriving ship (A) and then load them back onto departing ship (B) which will take them to another port of destination (Figure2.9)("What is a Transshipment?," 2019). The unloading and loading process in a typical terminal can be divided into several sub-processes. Once a ship arrives at the port, the import containers must be removed from the ship. This is done by quay cranes (QCs), which take the containers from the ship's hold or from the deck. Then, the containers are transferred from the QCs to the vehicles that travel between the ship and the stack. This stack consists of several lanes, which containers can be stored for a limited time. The lanes are served by systems such as cranes or horizontal handling equipment. When a vehicle arrives at the stack, a stacker or stack crane picks up the container from the vehicle and stores it in the stack, after a certain period, the containers are retrieved from the stack by cranes and transported by vehicles to other modes of transport such as ships, trucks or trains, however, the transhipment cycle only refers to transport via ocean-going ships which will take these containers to another destination which might not be the final destination (Vis and de Koster, 2003).

Figure 2.9: Transhipment cycle

<u>Reason for transhipment</u>

In general, there are three main reasons in which a transhipment makes sense:

- When there is not (or expensive) land connection between the importer and exporter of the freights;
- When the intended port of destination is not available due to low dredging or if the port cannot accommodate large ships;
- Moving a cargo from one country to another by transhipment to circumvent trade restrictions. As an example, the US administration currently requires China to ship its steel through Vietnam or other Asian countries to avoid tariffs.

However, there are a number of disadvantages to transhipment, although it is usually done to save on shipping costs, it leads to increased transport time, damage or loss of the container and cargo, which are also more likely due to the loading and unloading of the container at the transhipment hub ("What is a Transshipment?," 2019).

2.3.4 Operational areas, main issues and means involved

In general lines, a container terminal can be divided into three main areas (Figure 2.10), **Seaside**, **Innerside** and **Landside**, then the operations will be presented according to each of them, explaining the main criticalities to be considered in their execution, including the equipment involved.

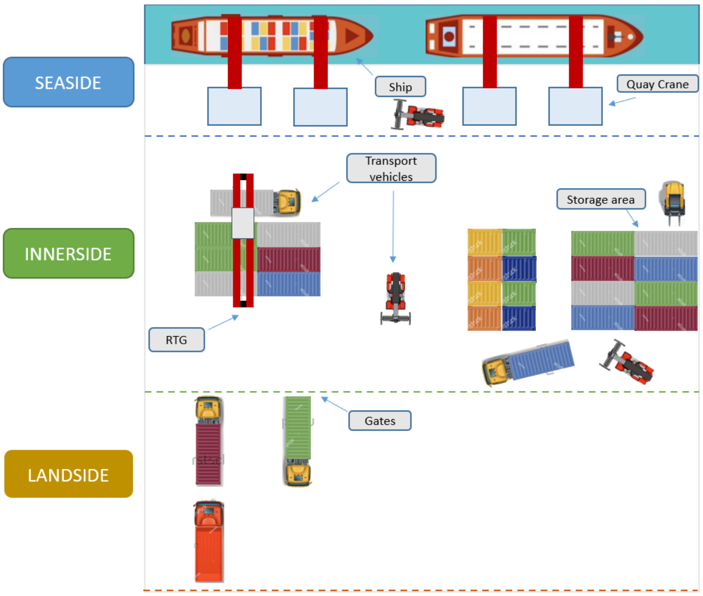

Figure 2.10: Operational areas

2.3.4.1 Seaside

Operations and handling equipment involved

The seaside area is one of the external interfaces of a container terminal. Before the arrival of the ship, the planner prepares a docking schedule, which specifies the docking position, the docking time, the departure time for each arriving ship, called the docking assignment phase, as well as the docking equipment with cranes for loading and unloading containers, called the quay crane assignment. The arrival of the ship is the heart of the terminal's activities, hence precise procedures must be followed in order to be able to work in the shortest possible time.

To start the planning and execution of all container unloading activities, the terminal operator receives a document certifying the presence and position on board of the containers to be unloaded in the port. The first document that specifies the composition of the ship, highlighting the containers to be unloaded in the port where the ship will berth. Once the file is acquired by the terminal's computer system, these containers are automatically coloured to make them easy to view in preparation for unloading.

After arrival at the port, a ship is assigned to a berth equipped with quay cranes to unload and load containers. Once the ship is berthed at the terminal quay, it issues a series of delivery requests for unloading, idle vehicles are dispatched according to the list of unloading requests, which are generally straddle carriers (SC) or automated guided vehicles (AGV), or tug masters (TM).

The unloading of a container is composed of a series of physical activities and a series of documentation activities that operators activate through personal vehicle devices on board the handling equipment. Usually before starting the unloading activities, where the quay cranes unload the containers from the ship and place them on the inland or quay vehicles, it is important to pay attention to the types of containers being unloaded. Regarding the unloading of empty containers, it is possible to unload directly onto TM, but this is not possible for full containers, these must necessarily be placed on the ground, waiting for a terminal lifting device to allow loading onto the vehicle, for example the reach stacker, which is the most efficient means of loading and unloading containers. Then the inland vehicle delivers the containers from the berth to the designated places in the storage yard.

After the container unloading phase, the container loading phase begins. The ship emits a certain number of loading requests, after which the vehicles are dispatched corresponding to the loading request list to deliver the containers to the quay cranes, in which case the cranes can pick up the containers directly from the tug master and release them in a short time.

The main handling equipment used in this sector are quay cranes. Different types are used in container terminals, two types can be distinguished: mobile harbour cranes (Figure 2.11) and quay cranes with single (Figure 2.12b) or double trolleys (Figure 2.12a). The trolleys travel along the boom of a crane and are equipped with spreaders, which are specific devices for collecting containers. Modern spreaders allow two 20' containers to be moved simultaneously (twin-lift mode). Conventionally, single trolley cranes are engaged in container terminals, these are man operated. Double trolley cranes represent a new development, the main trolley moves the container from the ship to a platform while a second trolley picks up the container from the platform and moves it ashore, the main trolley is man-driven while the second trolley is automatic. The mobile harbour cranes can serve small container ships as well as the latest generation of multi-cellular ships, using manual, semi-automatic or fully automatic telescopic spreaders, these cranes are an innovative wheeled travel system, each wheel position can be individually controlled allowing maximum mobility in all directions and turning on the spot.

Figure 2.11: Mobile harbour crane

Figure 2.12a: Quay crane with dual trolley system

Figure 2.12b: Quay crane with single trolley system

Main critical issues

There are several issues to be faced in carrying out port activities in the seaside area. These will be divided into different types according to their impact.

Functional issues

Critical issues on the functional aspect, and how these directly affect terminal operators and shipping companies are discussed in the literature. The main objective in this area is to serve the ship in the shortest possible time. There are two main operations: berth allocation and the assignment and scheduling of quay cranes.

Regarding the berth allocation phase, this consists of assigning incoming ships to berth positions. Operators are faced with two interrelated decisions: where and when ships should berth (Cordeau et al., 2005). Usually, these decisions are made according to priorities, ship lengths and ship handling times. The handling times are assumed and known in advance in order not to overlap ships (Meisel and Bierwirth, 2009). When a ship arrives at the terminal, planners have to consider certain characteristics, such as the size, quantity of containers to be unloaded and loaded, and the positions of these in the storage yard (Arango et al., 2013). This information is known in advance to execute the berth allocation plan. On the other hand, a late arrival of a ship depends on the congestion status of the port, if a port is congested a delay in the service ship could cause a delay for the following ships. Therefore, the arrival of these must be interdependent (Shangyao Yan et al., 2019).

Regarding the assignment and scheduling phase of quay cranes, this is an important management task. The manager has to make two decisions: The first one is to assign tasks to the quay crane and the second one is to find the sequence of task handling such that the turnaround time of ships is minimised(Azza et al., 2014). There are two waiting lists in this area. The first relates to internal vehicles that are used to transfer containers between the quay and the storage yard, such as tug masters, straddle carriers, automated guided vehicles, automated lifting vehicles, reach stackers, etc., while the second relates to cranes. A vehicle must wait near the crane place if it is occupied by other vehicles. A quay crane must wait to operate a vehicle that has not yet arrived at the quay. In general, the waiting time of quay cranes is more critical because any delay in their operations will cause the same delay in all subsequent operations assigned to this quay crane, consequently affecting the ship's operation time (Rashidi and Tsang, 2013). Planning decisions associated with the assignment of quay cranes and internal trolleys are typically made independently. However, consistent estimation of ship service time and truck requirements can be achieved if these planning decisions are made simultaneously (Karam and Eltawil, 2016).

On the other hand, quay cranes are the most expensive single units of handling equipment in port container terminals, and for this reason, one of the keys to addressing congestion in the port is to achieve effective scheduling of quay crane activities while avoiding delays in ships service time (Zhang and Kim, 2009). Therefore, terminals need to reduce the ships turnaround time, which is a significant factor in their service level. However, due to the high acquisition cost of handling equipment, container terminals can hardly purchase extra handling equipment to promote productivity. Therefore, the reasonable scheduling of these handling equipment, such as quay cranes, internal vehicles, lifting equipment, and coordination among them, is critical to the service level of container terminals (He et al., 2015b).

Environmental issues

Emissions produced in the port area generally result from the combustion of ship engines. The increasing number of maritime movements and the associated release of air pollutants have drawn attention to this source of emissions. Shipping activities are one of the main sources of air pollution in particular ships, as more than 95% of the world's ship fleet is powered by diesel engines(Saraçoğlu et al., 2013)

In this context, the maritime sector has attracted attention from the point of view of environmental pollution, overall, the impact of ports on the cities in which they are located. Despite the use of new technologies in the field of ship propulsion, such as new engines and more refined and desulphurised fuels, the environmental footprint of maritime transport is still a problem that has not been solved. Numerous epidemiological studies have now shown that exhaust fumes from internal combustion engines increase the risk of cancer (International Agency for Research on Cancer). The main air pollutants from the exhaust fumes of such engines that can affect human health are particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NOx) and sulphur oxides (SOx).

In this terminal area, the main sources of pollution are:

- Ship engines during approach manoeuvres and while hoteling in ports;
- Horizontal and vertical freights handling equipment, such as quay cranes and inland vehicles.

Energy consumption

The accelerated consumption of energy has become a global concern. There is now a problem of resource depletion, energetical resources. Due to the considerable number of handling equipment, terminals play a significant role in the energy consumption of the global supply chain. Container terminal operators are facing pressure to save energy and reduce emissions. Therefore, the green port concept has caused widespread concern in academia, society, and the port industry. Undoubtedly, ports should improve the service level of container terminals as much as possible, but this cannot be implemented at the expense of the environment.(He et al., 2015b).

Human factors

Despite all the improvements and even the automation of some or all parts of a port, human operators still play a central role in it. Fatigue is thought to be a significant factor in accidents occurring in transport systems. Many studies have been conducted to relate fatigue to performance. Moreover, these studies may link the working environment and conditions not only with deteriorating performance, but also with a potential health risk, both physical and mental.(Fancello et al., 2008).

Human factors can be classified as mechanical and psychophysical, each of which is dealt with in the passive and active parts, respectively. In order to reduce the negative effects of human factors on performance, active safety focuses on how the perception of external factors is implemented, how this information is handled by the mental processes underlying perception and finally on human decision-making processes. Human factors that can be related to decreased performance may include, for example:

- Improper control/supervision;
- Consumption of alcohol;
- Tiredness;
- Errors of judgement;
- Negligence;
- Defects in compliance with regulations, etc.

In the case of cranes in general, all handling manoeuvres are carried out within view of a control station using the glass walls of the cabin, which allow a direct view of both the ship and the quay. In general, quayside crane operators adopt a forced, non-neutral seated posture, involving particularly the trunk and neck in order to always have a better view of the container being handled, despite the wide field of vision offered by the cabin. This, combined with 4- to 6-hour shifts and a high level of vibration, has been considered as a potential cause of musculoskeletal disorders and therefore directly affects operators' performance (Leban et al., 2017). As crane operators are subjected to this type of working environment on a daily basis, it is important to understand how work-related stress affects them and what are the causal factors (Yakub and Sidik, 2014).

2.3.4.2 Innerside

Operations and handling equipment involved

Generally, operations in the inland yards take place 24 hours a day, since it is necessary to work permanently with the aim of locating containers in the most convenient way, in order to facilitate the loading and unloading operations of both ships and trucks.

The inland area is characterised as the storage area divided into several zones, each zone consisting of a block of containers, usually arranged in six lanes of containers stacked in four or five levels of containers (Figure 2.13). The number of lanes and the height depend on the geometric configuration of the yard cranes that are used to stack the containers in a block.

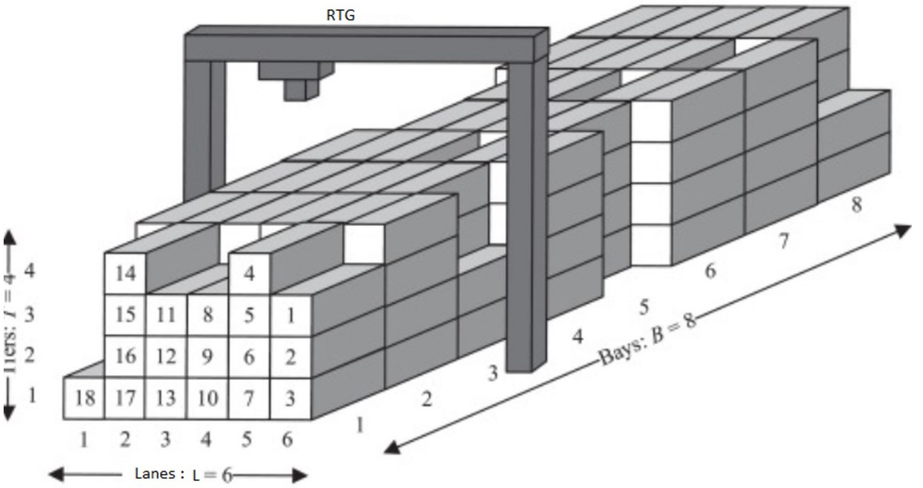

Figure 2.13: An example of a container block (Source:(Gharehgozli et al., 2014)*)*

In this area the containers are stacked and serve as a buffer for them. Outbound containers arrive at the terminal by road or rail, then are handled through the internal equipment and taken to the respective yard storage facilities, where the yard crane unloads the containers from the vehicles and places them on the yard stacks. The incoming containers arrive at the terminal from the ships, during the unloading operation the containers are unloaded from the ship and the inland vehicles take the containers to the designated storage blocks and the yard cranes unload the containers from the vehicles. Then the containers are placed on the yard stacks.

For unloading management, space must be provided inside to ensure that the containers are stored in the best possible way, to make it easy for them to be picked up for delivery to the trucks, and similarly, for loading operations, it is necessary to set up areas where containers are placed that will go on the same cargo ship, destination and type, to eliminate the unloading required during the loading of the ship.

In this area there are two main decisions to be made: the storage of the yard and the movement of the yard crane. Within each block, one lane is reserved for the retrieval and delivery of containers by trucks, while the rest of the lanes are reserved for the container's storage. The retrieval and stacking of containers within each block is carried out by yard cranes. To make their operations efficient, and to overcome the imbalance of workload between the blocks, the cranes must move from one block to another. The allocation and movement of yard cranes between blocks is called yard crane scheduling. The purpose of yard storage is to distribute import and export containers between all blocks from the point of view of an entire yard. The concept of workload is used as a measure of the amount of operation time required for a block. It is important to analyse the relationship between the stack height and the number of re-handlings in order to minimise the expected total number of movements for the external trucks picking up containers in the yard (Jiangang, 2016).

Regarding handling equipment, there is an expensive piece of equipment in the storage area for container handling, referred to as Rubber Tyred Gantry Cranes (Figure 2.14). The efficiency of operations often depends on the productivity of these and their displacement. To balance the workload between blocks, RTGs are sometimes moved between blocks, thus that they can be fully utilised.

Figure 2.14: Rubber Tired Gantry Crane (RTG)

The horizontal handling vehicles that perform the operations within the yard are usually: the straddle carrier (SC) (Figure2.15), the automated guided vehicles (AGVs) (Figure2.16), or the tug masters (TM) (Figure2.17), and the reach stacker to perform the vertical handling operations (stacking of containers) (Figure 2.18).

Figure 2.15: Straddle carrier (Source:(Konecranes, 2021)*)*

Figure 2.16: Automated guided vehicle Source:(Konecranes, 2021)*)*

Figure 2.17: Tug master (Source:(Kalmar, 2021)*)*

Figure2.18: Reach stacker (Source:(Konecranes, 2021)*)*

Main critical issues

Due to the high competition in the container transport sector, the pressures to improve, cargo throughput increase. The quality of service at the container terminal can be measured in terms of ship operations where containers are unloaded from and loaded onto a ship; and reception and delivery operations where containers are transferred to and from external trucks. However, maximum productivity in part could be achieved by efficient scheduling of quay and yard cranes, rational allocation of storage space and effective reduction of terminal traffic (He et al., 2010). Various problems arise from different perspectives in the hinterland to achieve this productivity.

Functional issues

The workload in the yard depends on whether a ship is unloaded or loaded. During the unloading operation, incoming containers are unloaded from the ship and stored in designated blocks in the import yard, conversely, during the loading operation, outgoing containers are retrieved from specific blocks in the export yard and loaded onto the ship. Usually, an operation will take place during the ship's services that will require the yard cranes to be in various blocks. Therefore, an efficient RTG shifting plan is needed to cope with the variable work volume and is imperative to reduce the turnaround time of the ship. The problem to be faced with the inter-block displacement of RTGs is the allocation of these between blocks in a dynamic way, thus the total incomplete work volume in the yard is minimised.
(Sharif et al., 2012).

The optimal scheduling of yard cranes between blocks is crucial for the efficient operation of the storage yard in a container terminal. In typical container terminals, import and export containers are stored separately in different container blocks, but in some ports, for example in East Asia, this separate mode fails to make the most efficient use of yard space. As the scale of global trade expands, the storage capacities of some East Asian container terminals are becoming more and more tight during peak import/export seasons. This can cause huge economic losses and damage to the reputation of container terminals (Yu and Yang, 2019).

On the other hand, traffic congestion is the most significant problem that limits the efficiency of internal processes, and it is a phenomenon that prevents TMs from travelling freely. Typical events observed are of crowded TMs around certain small areas for loading/unloading containers to/from yard storage locations, or TMs being able to travel along a particular passing lane at the same time, which forces them to slow down during travel(Zhen et al., 2016).

Typically, terminal planners are informed of ship arrivals a few days in advance. Then they start planning the container storage/recovery locations in the yard. However, due to the uncertainty of ship arrivals, the sequence of container loading/unloading in the QC work list is planned only a few hours before the actual ship arrival. This work list is then translated into a work list for RTGs, which have to improvise the movement times of these, using the historical average container handling times for QCs and RTGs, and the travel times for TMs, respectively(Li et al., 2009).

Environmental issues

Handling equipment as mobile source of emissions has become the subject of public attention due to the high pollution caused by their diesel engines, and the lack of control over this problem (Zhang et al., 2017). Nowadays, many ports, in order to reduce and control the air pollution caused by cargo handling equipment inside storage yards, have proposed the goal of accelerating the elimination of old high-emission cargo handling equipment by using alternative fuels (Li et al., 2019).

Energy consumption

Performance in container terminals should be improved not only in terms of productivity, but also in terms of sustainability. Container terminals are key nodes in the global transport network and energy saving is a main goal for them. The yard crane, as a type of handling equipment, plays an important role in service efficiency and energy saving of container terminals. However, traditional methods of programming them only aim at improving terminal functionality instead of saving energy. Therefore, it is imperative to search for an appropriate approach for scheduling yard cranes that considers the trade-off between efficiency and energy consumption (He et al., 2015a). Thus, the goal of container terminals at the operational level is to seek the optimal trade-off between energy saving and service efficiency improvement. Since the energy consumption and service efficiency of container terminals are mainly contributed by the handling equipment, the scheduling of the handling equipment is critical. The total energy consumption cost of a container terminal's handling equipment is between 15% and 25% of the total cost of operations (Ja et al., 2012). The yard crane is the most energy-using equipment in a terminal, accounting for approximately 25-35% of the total energy consumption cost.

2.3.4.3 Landside

Operations and handling equipment involved

This area is the second external interface of a container terminal, connecting it to the land transport system. Several studies concerning gate operations can be found in the literature (Maguire et al., 2010). The main operations are the gate-in and gate-out of transport companies. To analyse the entry of trucks into the terminal, it is necessary to understand the activity of preparing for the receipt and processing of work orders requested by a customer. This starts with the booking of a transport. In the booking phase it is necessary to specify the destination to be reached, the size of the container and the type of freights to be transported. This information is needed by the shipping agency, whose task is to find the shipping company that can meet the customer's needs. Once all the information has been acquired, a reservation is generated and sent to the terminal. The operators will know which type of container they need to receive, store, and then prepare for loading.

A booking number is assigned, in which all the movements that the terminal must perform in order to fully satisfy the customer are stored.

At this moment the terminal is ready to receive the driver to complete all the required services.

They may be divided into two main blocks, the first one refers the gate-in activities, which are necessary to provide the interchanges and the positioning itself, and the second the gate-out activities, from which the truck driver receives the necessary documents to pass the port gate and deliver the freights to the right company.

Figure 2.19: Gate operations (Source:(“SCT - Salerno Container Terminal,” 2021)*)*

Main critical issues

The issues in the landside area can be studied from two points of view. The first is the customer's point of view and the second is the terminal's point of view. Landside operations are gate operations, which are interrelated with inland activities. The main objective of landside operations is to serve trucks outside the gates, increasing the utilisation of terminal equipment, facilities and achieving high customer satisfaction, which occurs when they are served with minimum time and cost. Many ports are facing heavy truck congestion in the terminal, which leads to longer waiting times for trucks and lower efficiency of operations, affecting functional, environmental and energy aspects.

Functional issues

This area is continually exposed to a problem of outgoing traffic congestion, making it a common problem at many container terminals around the world.

When shippers need to pick up or deliver incoming or outgoing containers, they ask transport companies to send trucks to the container terminal. If all transport companies send their trucks to the terminal in the same time window, the terminal will be overloaded, and consequently the storage yard in the terminal will be congested, thus trucks on the road may have to wait at the gate for a long time (Phan and Kim, 2015), therefore queuing problems will occur. As a result, long queues of trucks at the terminals lead to delays, congestion and high costs for both the terminal and the customer (Azab and Eltawil, 2016). Due to this, a major challenge is the evaluation and planning of investments aimed at adapting a port to future traffic (Veloqui et al., 2014).

Another significant problem caused by the increased waiting time of trucks at the gate is the delayed delivery of cargo, resulting in loss of value of products and increased docking costs among others.

Therefore, it is essential that the terminal operator determines the optimal appointment rate, considering the factors that influence the truck turnaround time, considered as the sum of the waiting time at the gate and the waiting time in the yard plus a fixed value that. The terminal system contains both the gate and yard computer systems thus there is a constant link between the gate and the yard (Zhang et al., 2013). An excessive turnaround time for trucks is often the result of fluctuating truck arrivals. That is, as trucks arrive at the terminal at their first convenience without any prior announcement of their arrival to the terminal operator, there are times during the day when the number of trucks waiting far exceeds the terminal resources. When demand greatly exceeds supply, truckers remain unproductive. In contrast, when supply far exceeds demand, the terminal is wasting resources (Huynh, 2009).

Ideally, system operations should have some level of built-in resilience to adapt to the frequent deterioration of scheduled services, because these services will often experience various disruptive events. For example, truck arrivals may be delayed due to cargo delays, a traffic congestion on the way to the port, or bad weather such as fog. Some of these events may be interconnected and occur simultaneously, causing an overlapping service disruption. These disruptions will have an impact on the system, thus terminal system operations should be designed to manage them in order to maintain the level of service (Li et al., 2018).

Environmental issues

Truck congestion in port areas has led to serious environmental problems in many countries. One of the main reasons is congestion due to the concentration of truck arrivals on the road during peak hours (Figure 2.20). A negotiation process to mitigate peak hour truck arrivals between several transport companies and a terminal is necessary. The negotiation process should be used for the appointment system for road trucks at terminals (Phan and Kim, 2015).

Figure 2.20: Trucks' congestion

Due to the increase in container and mega-ship traffic, many seaports face the challenges of huge amounts of truck arrivals and congestion problems at terminal gates, which affect port efficiency and generate serious air pollution. Gate capacity (which also depends on the efficiency of terminal operation) is relatively stable when given resources and facilities. Also, the extension of gate opening hours is not possible in many seaports, for example seaports in Asia are already open for 24×7 hours throughout the year. Therefore, it is essential to look for a demand-side solution. Conventionally, terminals do not place any constraints on the arrival time, thus a truck can schedule its arrival as it wishes. With an effective and reliable method, it can be advantageous to control the arrival fluctuation(Chen and Jiang, 2016).

A summary table (Table 2.2) is presented with the main decisions to be made in a container terminal divided by areas and issues to be considered with the use of performance indicators, as well as a summary table with the main actors divided by operational areas with their respective tasks is presented (Table 2.3).

Table 2.2: Summary of the main decisions to made in container terminals

Port area	Actors involved	Operations
Seaside	Berth allocation	Ships service time Ships waiting time out harbour Ships emissions Ships energy consumption
	Quay crane assignment	QCs emissions QCs energy consumption Cranes operator's workload
Innerside	Yard crane scheduling	Yard congestion Internal vehicles waiting time Internal vehicles energy consumption Internal vehicles emissions
	Yard storage	RTG delay RTG emissions RTG energy consumption Cranes operator's workload
Landside	Gate operations	Gate utilization Trucks appointments Trucks congestion Trucks emissions Trucks waiting time Trucks energy consumption

Table 2.3: Summary of the actors involved and operations by port operational area

Port area	Actors involved	Operations
Seaside	Quay crane operators	Works on quay cranes handling containers, moreover it is in communication with the Planner to know which containers to load/unload and in what sequence.
	Planner	Supervises the stowage operations (loading/unloading) of containers and their location in a given place in the terminal; he plans the ship's loading and unloading activities ensuring the stability of the ship
	Checker	Performs the first check of the incoming container, verifying that it is the one foreseen by the unloading sequences and that there is no damage or tampering with the labels
Innerside	Yard crane operators	It works on RTG cranes handling containers from tugs to storage as well as delivery to carriers.
	Dispatcher	This figure is placed between the planner and the internal truck operators; he receives the work queues from the Planner and gives instructions to the internal truck operators.
	Internal trucks operators	Identified with the tug master drivers, who in the Import phase transports the container from the yard to a temporary storage area following the routes indicated by the dispatcher.
Landside	Gatekeeper	The operator in charge of controlling the vehicle entering or leaving the Terminal and verifying seals and transport documents
	Road carriers	The transport operator, contracted by the importer/exporter of the freight

2.4 Challenges of Terminal Planning

In recent years the work of those involved in superstructure planning and container terminal management has been influenced by the demands of a constantly growing market that requires more capacity from these facilities, and by legal pressure in environmental matters, has meant that operators have to adapt their offerings to these regulations.

Due to the (relatively) reliable traffic forecasts associated with an efficient use of resources, the challenges to provide terminal capacity at competitive costs are rather limited. The tasks of facility planning and management in the context of facility expansion and technological conversion of operating terminals or greenfield projects are currently the focus of attention. In addition, planning activities in industrialised countries are usually accompanied by considerations for the automation of one or more operational areas to decouple operational activities as far as possible from labour costs and thus create lasting competitive advantages, gaining not only economic but also safety and sustainability.

Various global trends in international container traffic (such as the growth in ship size on intercontinental container shipping voyages, or the continuous increase in handling capacity in many ports) have led to a significant increase in competition in recent times, particularly between seaport container terminals in regions with high terminal density. A dramatic acceleration of this development was the result of the global financial crisis of 2008.

The world's growing environmental problems and stricter legal provisions concerning environmental protection have led to the fact that even for companies in the container transport and handling industry, the environmental aspects of their operational activities play a very important role.

In order to be successful in the long-term as a terminal operator, existing environmental guidelines and emerging legislative changes have to be systematically included in management decisions and also operational processes have to be aligned to these regulations according to their environmental impacts.

In the background of the outlined changes, the requirements for the superstructure of container terminals are changing and thus also the range of planning tasks. The challenges of superstructure planning in the future will be to create the necessary conditions for the operation of the terminal that enables the successful realisation of conflicting objectives in different sizes. Thus, in a relatively hard competition for terminal operators, it will mainly depend on the implementation of objectives in the areas of:

- Cost efficiency;
- Coping with exceptional peak load situations in all terminal areas;
- Limitation of environmental impact;
- Systematic logistical development of the terminal hinterland.

Hence, to cope with long-term market needs, promising ways can be applied to identify good solutions for multi-criteria problems in system planning that derive from the concepts of integrated and forward planning. Instrumental support can be provided by modelling techniques, which allow a flexible representation of real-world aspects in terms of complexity, stochasticity, and dynamics according to the requirements of the modeller or the application case(see Chapter 4), proving to be the most efficient way to analyse the different criticalities in each terminal operational area, through different performance indicators that can be from the functional, environmental, or energy point of view (Böse, 2011).

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3.Literature Review

This chapter presents a systematic review of the problems and decisions facing container terminals in seaports. The focus of the research has been from 2000 to 2020. This study reviewed a total of 68 articles from 27 high-ranking journals as well as conference articles, all related to transport science and other areas such as social sciences and economics, showing a strong increase in this field of research in the last six years. In addition, this new literature has been classified according to the areas of operation within a typical container terminal. Previously in the chapter 2, the individual operations of each area, the problems related to them and the decisions to solve them were described. Instead in this chapter, for each decision, the main solutions found in the literature will be list and formulated in optimisation approaches or simulations.

3.1 Introduction

Most of the world global economy is founded on freight maritime transport and occupies a key role in the international trade, as much as the world trade as percentage of global Gross Domestic Product (GDP) has increased from 27% in the early 1970’s to 60% in 2019 (Figure 3.1), where the maritime transport has played to fundamental role in the world economy, currently accounting for 85% of the world's total freight transport.

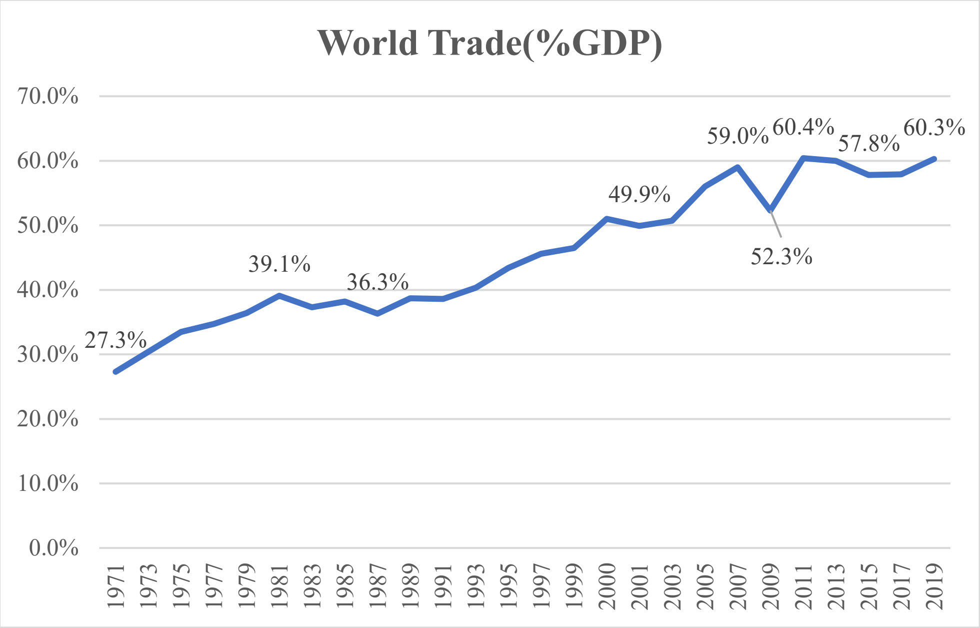

Figure 3.1: World Development Indicators (Source: ("World Bank Open Data," 2020)*)*

In general, the trade is a determinant of countries' economic growth. In (Michail et al., 2021) have studied the relationship between the freight transport by sea and economic growth in a country taking a sample of 135 countries over a period of 10 years, concluding that a 1% increase in transported of TEUs will lead to an approximate 1.7% increase in GDP (Figure 3.2).

Since container revolution began in the 1960, the evolution of container traffic has always increased even during the major world economic and pandemic crises (Figure 3.2).

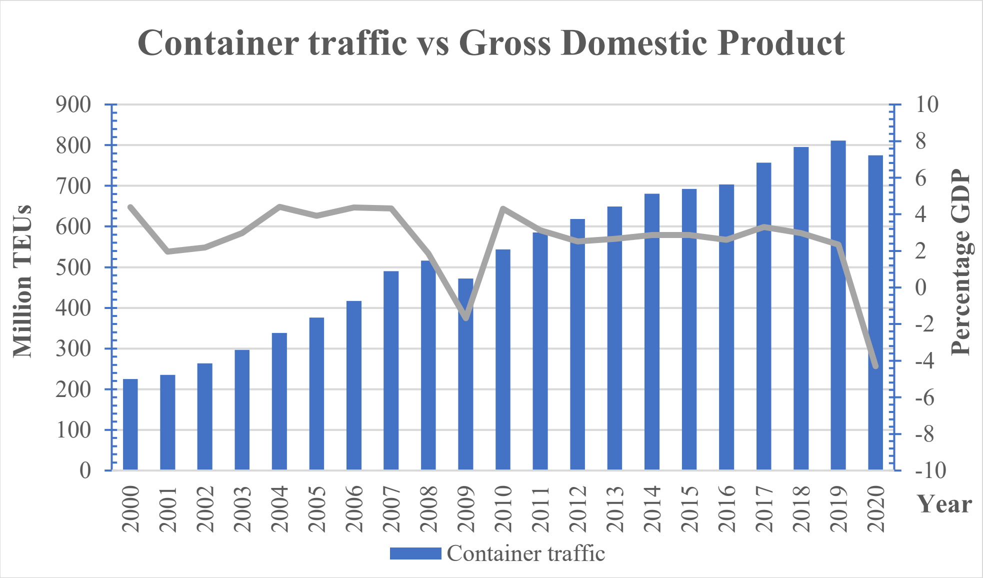

Figure 3.2: Evolution of container ports traffic vs GDP, according to World Bank data.

The continuous development of containerized transportation has led to a global competition among nations, shipping companies and ports. Although the competition is based on several factors, the maritime container terminals represent the fundamental link of the logistic chain, and their efficiency is the cornerstone of the whole logistic chain, moreover the technological innovation. Finally, the functional efficiency of a container terminal is no longer the primary goal of a terminal, since different sustainability goals are becoming of great interest and concern for port operators, port authorities, decision makers, politicians, citizens.

The significant increase in container volumes has increased the concerns on:

- The global environmental impacts from port emissions. Currently, the global annual emissions of the main greenhouse gas carbon dioxide from shipping amounted to around to 3% of global manmade emissions, that in the absence of mitigation policies, port emissions are projected to double or even triple by 2050(“air pollution from ships | airclim,” air);
- The environmental impacts on those urban areas which host several maritime ports because port operations can lead to environmental impacts on air, water, and land. Many communities have experienced serious health problems, such that some researchers have attributed in part, to exposure to emissions from port operations;
- The social concerns for the health and safety of ports workers, due to accidents still depends on a wide range of human errors as be psychological

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fatigue despite the automation level reached nowadays;
- The impacts of in/out traffic flows on the city congestion;
- The impacts on the liveability of the areas surrounding a port.

In this context, it is easily understandable why wide attention has been given by researchers to container terminals efficiency, and why terminal efficiency cannot be solely interpreted in terms of logistic efficiency, coherently with the United Nations in 2015 defined the Sustainable Development Goals (SDGs).

In the last decade numerous contributions have faced logistics issues in container terminals and several literature reviews exist. Indeed, (Voß et al., 2004)conducted a literature review where describe and classify the main logistics processes and operations in container terminals, moreover presents an overview about the optimisation methods in the terminals operations. In (Böse, 2011) is presented a collections of individuals contributions about important technological and organizational system from a planning point of view in container terminals, by going into different topics such as energy and environmental efficiency.(Angeloudis and Bell, 2011) provides a review of the container terminal simulations, then presents some simulations applied to real world cases. Likewise (Dragović et al., 2017) presents a review about the most relevant applications of container terminal simulations in the last fifty-four years.

In recent years, research has been focused on optimization field, for instance (Kastner et al., 2019) presents an update literature review of simulation-based optimisation in container terminals covering all the mains operations and examine the similarities and differences among the provides approaches, the same proposal of review is presented in (Kizilay and Eliiyi, 2021) however limited to the quay crane and yard crane operations and the integrated analysis of these.

All these reviews address the container terminal issues from a functional point of view, someone with optimisation of operations in terms of time and others without faced the optimisation problem. An overview of energy and environmental efficiency is given, although without any optimisation proposals in these aspects. Despite the great interest of the scientific community in these topics there are undoubtedly some limits to the reviews analysed, such as:

- Functional approach to operations without considers other topics such as energy or environmental efficiency;
- Human factors and safety in the operations are rarely mentioned;
- Lack of research on integrated port optimisation issues;
- Lack of research about the energetic optimisation;
- Lack of research about the environmental optimisation;
- The issue of road congestion due to the port operations is not addressed.

The aim in this chapter is to propose a literature review about the main contributions regarding to the container terminal operations from different perspectives: (functional, environment, energetic) and regarding the different operative areas of a container terminal (seaside, innerside and landside).

3.2 Research Method

3.2.1 Research questions

Nowadays, wide research is available on the existing problems in container terminals and the policies or methods adopted to make their operations more efficient. However, these problems have always been treated under a single perspective, that is from a functional point of view, which is mainly of interest to terminal manager and shipping companies, leaving aside other perspectives such as environmental, energetic, security, economic, which are mainly of interest to governments or citizens. This section aims address to response some research questions:
What are the main areas and operations that take place within a container terminal daily? These operations are carried out in the same space-time interval, which creates a series of issues to be solved. Thus, this review aims to answer, what are the main issues to be solved in each one of the activities to achieve functional, energy and environmental efficiency?
On the other hand. What are the most efficient optimisation methods today?
Is it possible to think that, based on the contributions made at present, the research is oriented towards sustainability in the port operations with a view to meeting the objectives of Sustainable Development Goals?

3.2.2 Research process

The search process was a manual search among conference proceedings and journal papers since 2000. The selected journals and conferences are shown in Table 3.1. Journals were selected because they were known to include either empirical studies or literature surveys, and to have been used as sources for other systematic literature reviews related to container terminal analysis.
The search was focused on the optimisation and simulation of container terminal logistic activities, in addition has been considered the environmental and energetic issues. A total of 88 papers per topic published from 2000 to 2020 were reviewed, which 68 papers deal about the logistic activities (Table 3.3), extracted from 27 high-ranking journals and conference papers related to transportation science and other areas how social or economics sciences, these were obtained from the Web of

Science and Scopus databases (Table 3.1). Moreover, has been reviewed 12 papers on environmental assessment of port operations, and finally 8 papers that deal about environmental and energetic optimisation.

As shown in Table 3.1, 27 different journals have published papers on the investigated topics. Among them the "Transportation Research Part E: Logistics and Transportation Review" was the most significant journal in this study, with 8 publications on the topics. European Journal of Operational Research and Transportation Research Part B: Methodological, had the second and third rank with 5 and 4 publications respectively; the frequency of other published journals is shown in Table 3.1.

Table 3.1: Distribution based on the kind of journal

Journal	**Quantity**	**Web of Science**	**Scopus**
-Transportation Research Part E: Logistics and Transportation Review	8	x	x
-European Journal of Operational Research	5	x	x
-Transportation Research Part B: Methodological	4	x	x
-Transportation Research Part D: Transport and Environment	3	x	x
-OR Spectrum	3		x
-Transportation Science	3	x	x
-Sustainability	3	x	x
-Transportation Research Record: Journal of the Transportation Research Board	2	x	
-Annals of Operations Research	2	x	x
-Computers & Industrial Engineering	2	x	x
-Operational Research	2	x	x
-Advanced Engineering Informatics	2	x	x
-Procedia - Social and Behavioural Sciences	2	x	x
-International Journal of Logistics Systems and Management	2		x
-Computer-Aided Civil and Infrastructure Engineering	2	x	

-Expert Systems with Applications	2	x	x
-Discrete Dynamics in Nature and Society	1	x	x
-Computers & Operations Research	1	x	x
-IEEE Access	1	x	x
-International Journal of Production Economics	1	x	x
-International Journal of Research in Manufacturing Technology & Management	1		
-International Journal of Transportation Science and Technology	1		x
- Journal of Maritime Research	1	x	
-Maritime Policy & Management	1	x	x
-Mathematical Problems in Engineering	1	x	x
-Networks and Spatial Economics	1		x
-Procedia Manufacturing	1	x	x
-Journal of Optimization in Industrial Engineering	1		x
-Conference papers	9		

As regard to the distribution of papers by year, the results of this study indicated that are more papers related to seaport optimisation in 2015 than in any other year. Figure 3.4 shows that the interest in this research field has grown up in the last five years. Journal publications scaled up to 6 or more per year after 2014, and evidenced the continuous effort spent on research in the optimisation of operations at container terminals.

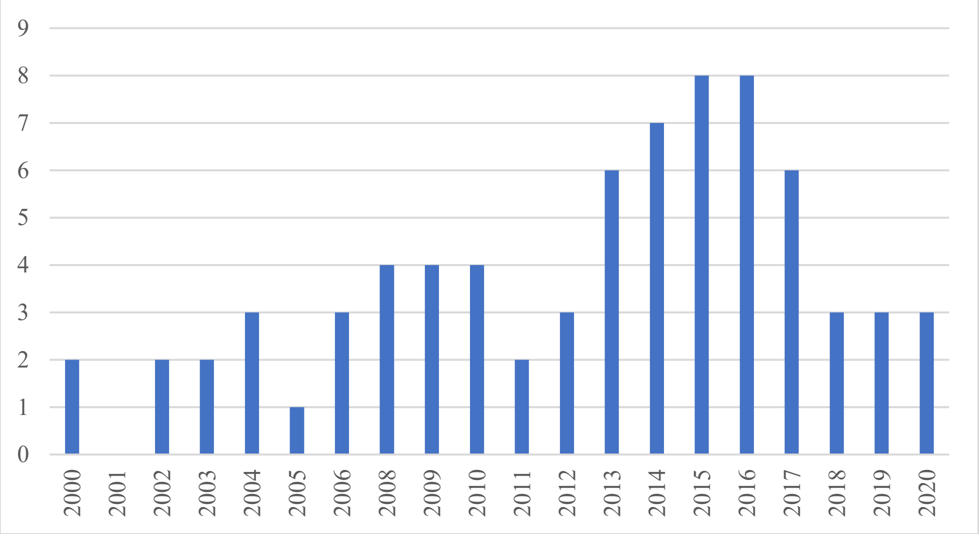

Figure 3.3: Distribution of papers per year

Table 3.2 shows a summary of the studies in some of the container terminals across the world including the port name, the city and country where is placed. The results of this analysis highlighted that that most of the studies have been carried out in China (Figure 3.4). However, findings of this paper indicate that European countries as Italy, Spain, France, and Netherlands have published papers focused on ports in their countries. Moreover, there are 8 ports where studies related to the optimisation of their operations were repeated more than once, reaching 32 ports mentioned in the studied literature. In addition, there are 24 papers that refer to studies in generic ports and 4 studies that, for privacy reasons, do not specify the location of the port.

Table 3.2: Ports in study

Port	City	Country
-Port of Kobe	-Kobe	-Japan
-Port of Goia Tauro	-Reggio Calabria	-Italy
-Port of Kaohsiung	-Kaohsiung	-Taiwan
-Port of Algeciras	-Algeciras	-Spain
-Port of Busan	-Busan	-South Korea
-Port of Ningbo	-Ningbo	-China

-Port of Alexandria	-Alexandria	-Egypt
-Pusan Eastern Container Terminal	-Pusan	-South Korea
-Port of Beirut	-Beirut	-Lebanon
-Port of Cagliari	-Cagliari	-Italy
-Port of Brisbane	-Brisbane	-Australia
-Port of Shangai	-Shangai	-China
-Port of Shahid Rajaee	-Hormozgan	-Iran
-Port of Hong Kong	-Hong Kong	-China
-Port of Singapore	-Singapore	-Singapore
-Port of Houston	-Houston	-USA
-Port of Naples	-Naples	Italy
-Port of New York–New Jersey	-New York	-USA
-Grand Port Maritime de Marseille.	-Marseille	-France
-Port of Chennai	-Chennai	-India
-Port of Tiajin	-Tiajin	-China
-Port of Shenzen	-Shenzhen	-China
-Port of Dover	-Dover	-United Kingdom

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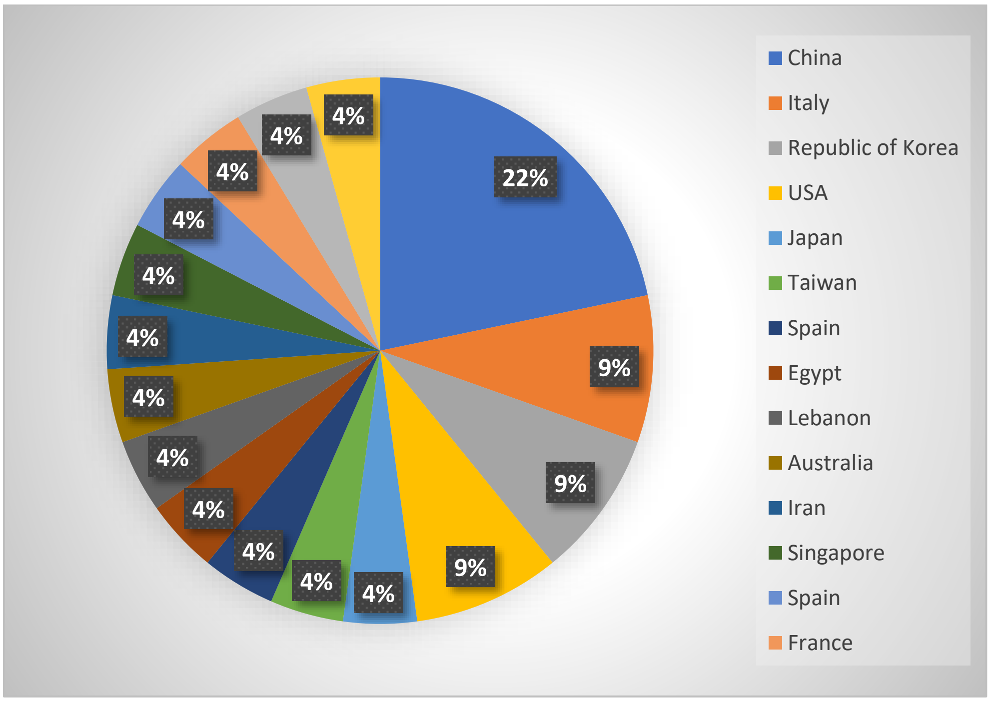

Figure 3.4: Distribution of ports studied by country

The papers were first classified with respect to the operation area and with respect the type of macro-operation.

Table 3.3. Distribution based on operation area and problems

Issues	Operation area	Quantity	Percentage
Quay Cranes Assignment	SEASIDE	19	28%
Berth Allocation		17	25%
Gate Operations	LANDSIDE	13	19%
Yard Cranes Deploying	INNERSIDE	10	15%
Storage		9	13%
Total		68	100%

However, when energy and environmental optimisation issues are added, the following distribution is obtained (Figure 3.5). Which shows the lack of existing research on these topics, as well as the non-existence of studies on how to optimise the workload of terminal operators and how human factors affect the performance of operations.

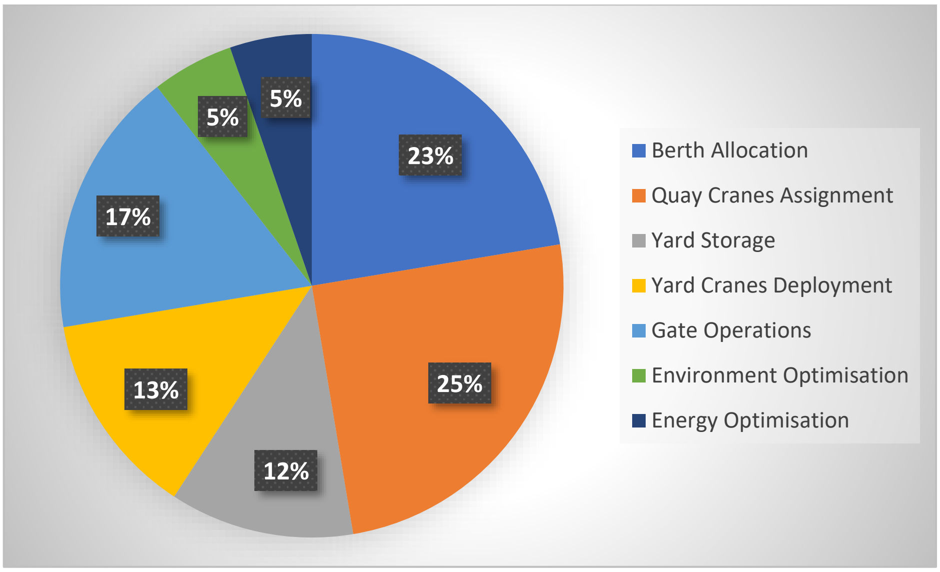

Figure 3.5. Distribution by topics

The rest of chapter is organized as follows: The Section 3.3 presents a literature review about the decisions to be made in the terminal management and their formulation. Then the summary and future challenges are shown in Section 3.4.

3.3 Formulations

In the chapter 2, the section 2.3.4, the main operations in a generic container terminal were described subdivided it in three areas, Seaside, Innerside and Landside, as well as defining the main issues and decisions to made inside each one of them.

This section presents a survey on research done in these decisions to solve the main issues presented previously. The decisions are formulated separately according to the operational area of the terminal (Seaside, Innerside, Landside) and the type of operation or decision to be taken. These formulations can be found in Appendix B.

3.3.1 Seaside

3.3.1.1 Berth allocation

In container terminals, the terminal operators are trying to attract carriers by automating handling equipment, providing, and speeding up various services. However due the high cost of handling equipment, they must to reduce costs by utilizing resources efficiently, including human resources, berths, container yards, quay cranes, and various yard equipment (Dai et al., 2003). Besides, the port operator is measured by shipping enterprises by her ability to utilize the resources in the most efficient way. The berth is the important resource that affects the terminal capacity, due of that there are several surveys in the literature dealing with this problem (Bierwirth and Meisel, 2015), (Bierwirth and Meisel, 2010), as well as the integration with crane allocation (S. Theofanis et al., 2009)

If the terminal operator puts more cranes on a ship to try and spread the traffic, more congestion is created along the quay (“LongRead,” 2015), thus an efficient berth allocation avoided great congestion problems outside and inside of the terminal. Regard to the berth allocation decision, the Table 3.4 summarizes the major research done over that, it shows the researchers, modelling approach, data size (if it is mentioned), and main results achieved.

The berth allocation and crane scheduling are not always integrated into the literature, but since the duration of the berthing depends largely on the number of cranes assigned, they must be integrated simultaneously.

(Yan et al.) proposes a berth-flow network modelling approach to deal the berth allocation decision considering a stochastic ships arrival time and flexible (continuous berth space) berth allocation, formulated as an integer multiple commodity network flow problem, based on the berth-flow networks, using a commercial solver CPLEX. The authors compared this stochastic model with the manual assignment (currently used by the sample port), resulting in more effective compared to the method currently used in practice (Yan et al., 2019). (Zhen, 2015) focused on how to obtain a berth allocation schedule under stochastic operation time of ships. The operation time depends on the number of containers that need to be handled, If the number remains the same during each one of the future periods, the operation time for each ship is the deterministic data. However, the global maritime logistic market contains a lot of uncertainties that in her it from the fluctuation of the demand for freight transportation. The author proposes 2 objectives functions: the first one in order to minimize the total cost for waiting time out the harbour and the second one is the case when the amount of container arrivals is uncertain then the dwell time of the ship will also be uncertain. Instead (Meisel and Bierwirth, 2009) integer the berth allocation problem with the crane assignment. The formulation includes an important aspect such as the decrease of marginal productivity of quay cranes assigned to a ship and the increase in handling time if it is not berthed at their desired position at the quay. Three types of cost are distinguished by the author, namely the cost to speed up a ship on its journey to catch a berthing time earlier than, the cost for exceeding the expected finishing time, and penalty cost for exceeding the latest allowed finishing time. (Cordeau et al., 2005) consider two cases for the berth allocation formulation, the discrete case with a finite place of berthing point and a continuous case where the ships can berth anywhere along the quay. The authors utilize two formulations for the discrete case: the dynamic berth allocation problem and the Multi-Depot Vehicle Routing Problem Time Windows, then solve the discrete and continuous cases through of the metaheuristic (tabu search), supporting the calculation with the commercial software CPLEX.

Table3.4: Major contributes to the Berth allocation decisions

Reference	**Type of approach**	**Modelling (algorithms)**	**Data size**	**Main Results**
(Yan et al., 2019)	**Simulation and optimisation**	Integer multi-commodity network Mixed integer linear programming	#Ships= 59 #Berths=39 Horizon Planning= 1 day	The model represents a significant advance in modelling the dynamic Berth Allocation Problem within a stochastic environment.
(Zhen, 2015)	**Optimisation**	Stochastic programming model formulation (Squeaky Wheel Optimization)	Randomly generated problems	Develops a scalable meta heuristic algorithm that can well solve the proposed models in large scale realistic environments.
(Meisel and Bierwirth, 2009)	**Optimisation**	Mixed integer programming (Squeaky Wheel Optimization	#Ships= 3 #QCs=5 #Berths=2	Provides a rich model for the Berth Allocation and Crane Assignment Problem. Factors influencing the crane productivity have been modelled and optimised, as well as practical aspects like to speed up ships and to care

				for the cost of operating cranes.
(Cordeau et al., 2005)	**Optimisation**	Tabu Search) Integer linear programming (Tabu search)	#Ships= 35 #QCs=5 #Berths=10	An optimisation model able to handle the various features of real-life problems, including time windows, favourite, and acceptable berthing areas, etc. Applied to real case
(Arango et al., 2013)	**Simulation and optimisation**	Mixed integer programming (Genetic algorithm)	#Ships= 160 #QCs=max 3for ship Horizon Planning= 1 month	The allocation planning seeks to minimise distances travelled by the forklifts and the quay crane in the container operations for each ship as optimisation criteria, then a simulations model has developed in a real case
(Dai et al., 2003)	**Simulation and optimisation**	Neighbourhood Search Using Simulated Annealing	#Ships= 42 #Berth= 7 Horizon Planning= 1 week	The authors proposed an efficient heuristic to construct a berthing plan for ships in a dynamic berth allocation planning problem. Simulation results based on a realistic set of vessel arrival data shows that for a moderate load scenario, this approach is able to allocate space.
(Rajendran et al., 2015)	**Simulation and optimisation**	Integer linear programming and discrete event simulation	Randomly generated problems	To over 90% of ships upon arrival, with more than 80% of them being assigned to the preferred berthing location.
(Boile, 2006)	**Optimisation**	Mixed integer linear programming	#Ships= 10 #Berths=2	The proposed study analyses the effect of the number of berths on the total waiting time outside the port analysing different scenarios in order to optimise the ships operational time.
(Iris et al., 2015)	**Optimisation**	Generalized Set Partitioning formulation (GSPP).	#Ships= 40 #Berths= 1 (1000 mt.) #QCs=10 Horizon Planning= 1 week	The author proposed novel formulations for the BACAP considering both time-variant and time-invariant QC assignment policies, shows that the performances of both the time-variant and time-invariant GSPP formulations are strong with respect to both upper and lower bounds improving the benchmark

				solutions of the current state-of-art optimal approaches.
(Imai et al., 2003)	**Optimisation**	Mixed integer linear programming (Genetic algorithm)	Not mentioned	This paper modifies the existing formulation of the berth allocation problem in order to treat calling ships at various service priorities by developing a genetic algorithm based heuristic for the resulting non-linear problem
(Karam et al., 2020)	**Optimisation**	Mixed integer programming (Lagrangian relaxation)	Randomly generated problems	Berth allocation problem it's formulated considering priority consideration allows be more flexible in the decision-making process
(Dulebenets et al., 2017)	**Optimisation**	Mixed integer programming model (hybrid evolutionary algorithm)	#Ships= exponential distribution with an average of 2 hours Handling productivity at the berth: [120,150,180,210] TEU/hour #Berths=6	This work presents a planning model that integrates berth allocation, quay crane assignment, and internal truck assignment problems, considering the energy consumption in the integrated planning.
(Xu et al., 2012)	**Simulation and optimisation**	Robust berth scheduling algorithm that integrates simulated annealing and branch-and-bound algorithm.	#Berths= 1 (1200 mt.) Horizon Planning= 1 week	The authors develop an efficient heuristic method robust formulation of the problem to provide a reliable decision-making basis for scheduling the subsequent operations. Allowing a balance between the customer service level and the robustness of the baseline berth plan.
(Guan and Cheung, 2004)	**Optimisation**	Heuristic formulation combining the tree search procedure and pair-wise exchange	#Berths= 10 Horizon Planning= 1 week	This paper study a berth allocation model that allows multiple ship mooring per berth, considers ship arrival times, minimizing the total weighted waiting time of these, thought of composite heuristic that combines a pair-wise exchange heuristic and

				the tree search procedure. The computational experiments show that the composite heuristic HB is quite effective
(Imai et al., 2001)	**Optimisation**	Heuristic procedure based on the Lagrangian relaxation	#Ships=50 #Berths= 10 Horizon Planning= 1 week	This paper presents optimal solution for planning of the ship-berth-order assignment. However, it can also be useful for decision-making on how many berths to operate.
(Venturini et al., 2017)	**Optimisation**	Multiple Depot Vehicle Routing Problem with Time Windows	#Ships=20 #Ports= 4 #Berths= 15 by port	Develop a novel mathematical formulation that extends the classical Berth Allocation Problem to cover multiple ports in a shipping network. Speed is optimized on all sailing legs between ports, demonstrating the effect of speed optimization in reducing the total time of the operation, as well as the fuel consumption and emissions

(Arango et al., 2013) focused the berth allocation decision considering the distances travelled by the handling means and the quay crane as a optimisation criteria, then the authors develop a simulation model of a Port of Spain in order to applied the berth allocation planning developed using Arena Software. (Rajendran et al., 2015) proposes an integer linear programming in order to schedule the ships at the port with the objective of minimizing the total minimize the waiting time of ships outside the port, in the case of studio the ships enter and leave the docks through a common access channel that can handle only one ship at a time, then a discrete event simulation model is developed where various alternatives are developed to understand its impact at port. (Boile, 2006) consider berth allocation policies with service priority, since are important in situations where involving various ships sizes consequently different handling volumes, the discrete and dynamic berth allocation problem is formulated as a linear mixer integer program problem with the objective to minimize the weighted total service time taking into account the priorities with the shipping liners, Imai et al. applied the same formulation considering a service priority in a berth allocation decision (Imai et al., 2003). (Karam et al., 2020) presents a mixer integer programming model for integrating the berth allocation problem with the quay crane assignment and internal trucks assignment considering energy saving goals, using a Lagrangian relaxation method to solve the model. The model estimates the ships handling time consider in the number of QCs to the ship, numbers of Its to the QC, and the distance among the berthing position of ship and its storage yard.

Assumptions

1. The configurations and locations of the berths are known, a priori (Yan et al., 2019) (Zhen, 2015) (Cordeau et al., 2005) (Arango et al., 2013) (Boile, 2006).
2. Every berth can be allocated to only one vessel at one time(Yan et al., 2019) (Zhen, 2015) (Meisel and Bierwirth, 2009) (Cordeau et al., 2005) (Rajendran et al., 2015).
3. Every vessel must be assigned exactly once to one of the available berths specified in the blocking plan (Yan et al., 2019) (Zhen, 2015) (Boile, 2006) .
4. The physical conditions of a berth, such as berth length, water-depth and quay length, must be suited to the vessel to be serviced by that berth (Yan et al., 2019) (Arango et al., 2013).
5. The types, operational times, and handling times of the ships arriving within the planning horizon are precisely known, a priori (Yan et al., 2019) (Meisel and Bierwirth, 2009) (Cordeau et al., 2005) .
6. The dwell time of ships is considered stochastic rather than deterministic (Zhen, 2015)
7. The arrival time distribution for each vessel follows a discrete probability distribution which is known, a priori (Yan et al., 2019) (Zhen, 2015) (Meisel and Bierwirth, 2009) .
8. number of containers to be loaded and unloaded; location of these containers in the storage area are knew (Arango et al., 2013)
9. The arrival times are obtained from a data in an external file from a real case (Arango et al., 2013)
10. It is assumed that the arrival times of the vessels in the outer harbour of the port are stochastic and independent of each other, because generally there is adequate space in the outer harbour to accommodate incoming vessels. Theoretically, if there is no congestion inside a port, the arrival of a vessel is independent of the others (Yan et al., 2019)
11. In practice, a safety gap is required between two vessels that dock at adjacent (nearby) berths (Yan et al., 2019) .
12. A short-term planning horizon or period (Yan et al., 2019). However, the planning period can be extended to several days or a week (Zhen, 2015).
13. Ship waiting area has infinite capacity (Rajendran et al., 2015) (Boile, 2006).

3.3.1.2 Quay crane assignment

Quay crane operations plays the most important role among various handling equipment in terminals, which perform unloading operations and loading operations onto the ships, some advanced QCs have been developed to increase the number of lifts per unit time (twin-lift or tandem lift) or the number of containers per lift (double trolley) attempting to increase the number of containers per lift in terminals and consequently the performance of these (Phan-Thi et al., 2013). There are several studies in the literature regarding the allocation of quay cranes(Stahlbock and Voß, 2008). In the Table 3.5 the main contributions found in literature about this decision-making phase in container terminals is presented.

(Azza et al., 2014) Focused on the assignment task of the quay cranes considering the spatial constraint for the solve the problem avoiding the cross between these, using the metaheuristic method to solve the problem. Similarly, (Legato et al., 2012a) incorporates at her study the unidirectional schedules, which the cranes move along the same direction, the study find the schedules in order to minimize the handling time, developing a novel approach in order to determines the starting times of the operations in the schedules.(Zhang and Kim, 2009).

With the aim of minimize the turnaround time of the ships (Zhang et al.) focused in the reduction of the number of operation in each cycle of a quay crane, the authors attempts to minimize the operations applying the dual cycle in the quay cranes tasks (Legato et al., 2012b). Instead (He et al., 2015b), considers that the quay cranes assignment and scheduling problem cannot deal it without have into account the internal trucks and yard cranes scheduling. The authors not only considers the minimize the total delay of the ships, also considers the energy saving as a goal of their study, utilizing two metaheuristics methods (GA and PSO) to solve the optimisation problem. (Karam and Eltawil, 2016) presents a mathematical model used to solve the quay crane assignment and internal trucks assignment problem simultaneously, but without any estimations of emissions or energy consumption.

Table 3.5: Major contributes to the Quay cranes decisions

Reference	**Type of approach**	**Modelling (algorithms)**	**Data size**	**Main Results**
(Azza et al., 2014)	**Optimisation**	Integer programming (Ant colony optimisation (ACO), Genetic Algorithm (GA))	Not mentioned	This paper presented a new approach for solving Quay Crane Assignment Problem based on ACO paradigm. Authors founds that the ACO algorithm is very performing compared with GA heuristic for large instances.

(He et al., 2015b)	**Simulation and optimisation**	Mixed integer programming and integrated simulation-based optimisation (Genetic algorithm-Particle Swarm optimisation)	Randomly generated problems	Minimized the total departure delay of all Ships and the total transportation energy consumption of all tasks considering a integrated QC, TM, YC scheduling.
(Zhang and Kim, 2009)	**Optimisation**	Mixed integer linear programming (neighbourhood local search)	#Ships= 10 #Ship bays= 68	Using a dual cycling QC scheduling in some numerical experimental data from real cases, the ships service time is minimised
(Legato et al., 2012b)	**Optimisation**	Timed Petri Net	Not mentioned	The new method of QC scheduling, provides high quality solutions within short runtimes
(Karam and Eltawil, 2016)	**Optimisation**	Mixed integer programming (Lagrangian relaxation-subgradient optimisation)	#Ships= 2 #QCs= 5 #TM=5	The proposed model providing a unified model for the QC assignment and scheduling problem, and the TM assignments
(Park and Kim, 2003)	**Optimisation**	Integer programming (Subgradient optimisation)	Randomly generated problems	This study presents a method for scheduling the Berth and Quay cranes, proposing a more efficient method than one proposed in the past for the same case study
(Nehme et al., 2019)	**Optimisation**	Mixed integer programming	Randomly generated problems	The integration between the scheduling of quay and yard sides for multiple berthing ships with transhipment containers is investigated, where the unloading of containers from several ships berthing at the same time is considered.
(Fadda et al., 2015)	---------------	------------------	Crane operators of the real port -Horizon time= 1 working day	Provides the build of performance curves for each quay crane operator, in order to analyse how mental fatigue affects them.
(Talavera et al., 2016)	**Optimisation**	Mixed Integer Programming model (General Algebraic Modelling System)	#QCs= 3 #Ships= 1	The main results show that the quay crane emissions play a significant role of the total emissions during the hoteling phase, affecting quay crane workload distribution and berth

				allocation, hence they should be considered when trying to minimize emissions at the terminal operations.
(Liu, 2018)	**Optimisation**	Convex mathematical programming model	Randomly generated problems	In this paper only is analysed and optimised the import process. The main result is that the optimal number of QCs increases with the expected arrival rate of AGVs and the mean fuel consumption per AGV per hour, but it decreases with the mean queue service rate of QCs and the electricity consumption per QC per hour.
(Theodorou and Diabat, 2015)	**Optimisation**	Lagrangian relaxation algorithm	#Ships=9 #QCs= 6	The main result of this paper is that the Lagrangian relaxation heuristic constitutes a successful approach for the quay crane assignment problem, especially when employed for small and medium-sized problem instances. For larger problem instances its performance is compromised in terms of bounds and computational time due to the extreme increase variables.
(Zeng et al., 2015)	**Simulation and optimisation**	Mixed-integer programming (bi-level genetic algorithm)	The processing time of quay cranes for single and dual cycling are generated from uniform distribution	A heuristic method, called bi-level GA, is designed. Numerical experiments indicate that dual cycling can reduce the operation time of quay cranes compared to the method of scheduling loading and unloading separately. Comparing with a simple scheduling method, the model developed in this article can decrease the reshuffling of outbound containers and the operation time of quay cranes.
(Al-Dhaheri et al., 2016)	**Optimisation**	Mixed-integer programming (Genetic algorithm)	#Berths=10 #QCs=3	The authors proposes a novel model for the quay crane scheduling problem considering several practical features of the problem such as pre-emption, non-crossing, safety margin, QC traveling time, QC initial position and ship stability, providing an optimal unidirectional schedule for all considered small-sized problems, in relatively reasonable time.

(Park and Kim, 2003) considers the integration between the berth scheduling and quay crane scheduling, developing this in two phases: The first one determines the berthing position, service time of ships and quay crane assignment, the second one detailed schedule for each quay crane based on the first phase results. Instead horizon (Nehme et al., 2019) focused in the integration between the quay and the yard sides, developing an integer linear programming model to minimize the total number of cranes used in both quay side and yard side for a samples of ships in a discretized time.

On the other hand, there are few studies in the literature that focus on the workload of cranes operators, such as (Fancello et al., 2008)presents an analysis of the performance curves obtained for a gantry crane operators in a container terminal on the bases on the Yerkes-Dodson theory for the construction of these, demonstrating a drop in operator performance throughout the working day due to mental fatigue; in the same way (Fadda et al., 2015) studies the trade-off between productivity and biological behaviour, for this specific job task. The proposed methodology, based on a simulation environment, aimed to objectively evaluate the quantity and quality of work performance and to detect early signs of fatigue.

Assumptions

1. Each vessel has a maximum and a minimum number of cranes to be assigned. Sometimes, contract terms between terminal operating companies and shipping companies specify the minimum number of cranes to be assigned to a ship. The maximum number of cranes that can be simultaneously assigned to a vessel is limited by the length of the vessel. (Park and Kim, 2003)
2. The duration of Berthing of a ship is inversely proportional to the number of cranes assigned to the ship. The linearity of Berthing time with the number of cranes may not be true. However, the linearity was assumed for the simplicity of the analysis. (Park and Kim, 2003)
3. For each vessel, a penalty cost is incurred by Berthing earlier or later than the previously committed time. A departure of a ship later than the previously committed departure time also incurs a penalty cost. ships and the terminal operating company continuously communicate with each other for adjusting the Berthing schedule. In the process, a ship may be requested to arrive at the terminal earlier than her previously committed time. It will require speeding up her voyage to catch up the schedule, which results in an extra fuel consumption. Also, delayed Berthing or departure of a ship beyond the committed time may lead to a trouble in meeting the schedule at the next port. (Park and Kim, 2003)

4. Every vessel has a most favourable location of Berthing. The most favourable location is the location nearest to the marshalling yard where outbound containers for the corresponding ship are stacked. The preference of a Berthing location over another may also be due to the depth of water or the strength and direction of waves. (Park and Kim, 2003)

3.3.2 Innerside

3.3.2.1 Yard storage

At the moment, there are no suitable tools available to assist the management in obtaining the optimal efficiency of container terminals. Hence is necessary to develop a technique that allows managers to better control the terminals by ensuring that container transfers allow maximum throughput, considering operational constraints and service reliability.

Container terminals can be viewed as a temporary storage area, which the containers can be kept there from the time of unloading until delivering to the customers. After, the unloaded container from the ships, the internal trucks or tug masters, carry the containers to the container yard. Since the unloaded container could be full, refrigerator (REEFER), tranship or empty, it should be moved to the related blocks determined in the yard. As soon as the trucks arrive to the yard, other equipment called Rubber Tyred Gantry Cranes start unloading trucks and arrange the containers in predefined blocks (Ghanbari and Azimi, 2016). Inbound and outbound containers are temporarily stored in the storage yard. A combination of container demand increase and storage yard capacity scarcity create complex operational challenges for storage yard managers (Carlo et al., 2014).

(Wong and Kozan, 2006)focused in an integrate way, the sequencing and scheduling of machine operations at the yard container, developing a model able to minimize the total travelling time of internal vehicles, hence increasing the throughput of the port and in consequence reducing the fuel consumption and analyses different strategies in order to obtain the optimal container storage in the yard and the handling scheduling. (Zhang et al., 2003) solves the storage allocation problem in two phases, the first one, the total number of containers to be placed in each storage block in each period of the planning horizon in avoiding imbalances among blocks, and the second phase, determines the number of containers associated with each ship in each period, in order to minimize the transport distance among their storage block and berth. (Zhen et al., 2016) proposes a template planning considering both the yard traffic congestion and the multiple cycle time of the periodicities of ship arrival patterns. The Table 3.6 presents the contribution found in the literature on the yard storage decisions.

Table 3.6: Major contributions to Yard storage decisions

Reference	Type of approach	Modelling (algorithms)	Data size	Main Results
(Wong and Kozan, 2006)	**Optimisation**	Mixed integer programming (Tabu search)	Not mentioned	The model could be used for minimising the total travelling time of yard vehicles, increasing the throughput of the port and reducing the fuel consumption. An integrated approach is also proposed to minimise the penalty on ship service time.
(Kozan and Preston, 2006)	**Optimisation**	Mixed integer programming (Tabu search (TS) – genetic algorithm)	#Storage capacity= 2,306 TEU #Yard vehicles =10 #Tiers =3	This paper outlined a novel iterative search technique to solve an integrated model composed of two sub-models with dependent decision variables. A genetic algorithm is compared with a tabu search/genetic algorithm hybrid. Concluding that GA technique produced better results than the TS/GA hybrid
(Zhang et al., 2003)	**Optimisation**	Linear integer programming (Rolling horizon approach)	-Data from a Hong Kong port	With short computation time the proposed method reduces the workload imbalance in the yard, avoiding possible bottlenecks in terminal operations.
(Zhen et al., 2016)	**Optimisation**	Mixed integer programming (Particle swarm optimisation)	Not mentioned	This paper studies the yard template planning problem for arriving ships. Numerical experiments are also conducted to validate the effectiveness of the proposed model, which can save around 24% of the transportation costs of yard vehicles.
(Henesey, 2004)	**Simulation**	Multi-agent system (Searching, coordinating, communicating, and negotiating	Not mentioned	Provide a simulator to run scenarios (dynamic yard and dynamic berth allocation)

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		with other agents via a market-based mechanism)		
(Jin et al., 2016)	**Optimisation**	-Integer linear programming model (Harmony Search Algorithm)	-Not mentioned	Develop an optimization model able to find very good solutions, whereas the heuristic approach balances the solution quality and computational efficiency, also the integration of the two decision problems not only yields cost reduction, but also is able to find feasible solutions for hard situations where non-integrated planning would easily generate solutions violating YC operational restrictions.
(Talavera et al., 2016)	**Simulation**		#YCs=41 Horizon time=35 weeks	Evaluates and compares two different storage strategies for storing containers in the yard in a real port, showing that applying the marshalling yard policy can have some advantages in comparison to the current system in the port, as well as increasing the rate of ship serving
(Kim et al., 2000)	**Optimisation**	Dynamic programming model (decision tree)	Randomly generated problems	In this study the optimal solution set from dynamic programming is used to construct the decision tree. The performance of the decision tree is evaluated by comparing decisions resulting from it with optimal decisions from dynamic programming. The number of wrong decisions is between 1.0% and 5.5%,. The results of this study can be utilized to reduce the number of relocation movements during ship loading operations, which results in an increase of efficiency of container handling equipment and throughput of berths.
(Jin et al., 2015)	**Optimisation**	Heuristic methods based	Randomly generated problems	Studied the integration of three tactical decision problems: berth template design, yard template

	on column generation		design, and schedule template design. A column generation-based approach is developed to obtain near-optimal solutions, computational experiments show that the enhanced column generation-based method achieves similar solution quality to the Memetic heuristic proposed in literature but gains significant improvement in computational efficiency.

Assumptions

1. Each QC unload all inbound containers before loading any outbound containers (Wong and Kozan, 2006)
2. All YMs are of the same speed; (Wong and Kozan, 2006)
3. The routes of YMs are independent of the job sequence and are determined by the start and end positions. (Wong and Kozan, 2006) (Zhen et al., 2016)
4. A pre-determine loading/unloading plan (Wong and Kozan, 2006) (Zhang et al., 2003) (Zhen et al., 2016)
5. A pre-determined container allocation in the yard(Wong and Kozan, 2006) (Zhang et al., 2003)
6. The containers are of one size (Zhang et al., 2003)
7. The time that containers remain in the yard is random (Zhang et al., 2003)

3.3.2.2 Yard crane scheduling

The service time of ships is indirectly affected by the productivity of yard cranes. As the workload on different storage blocks changes over time, deploying RTG between storage blocks to provide more RTG to blocks with heavier workloads is an issue at the terminal, thus, the problem to solve is the number of yard cranes in each block and the schedule of these (Rashidi and Tsang, 2013). (Li et al., 2009) presents a model for yard cranes scheduling considering realistic operational constraints as interference among cranes. (He et al., 2015a) develops a mixed integer programming model in order to minimize the total completion delay of all yard cranes tasks, considering the energy consumptions of the cranes. The same authors in other publication presents an study about an effective yard crane scheduling developed based on a rolling-horizon technique via objective programming, able to minimize the total delayed, workloads, the number of remaining tasks for handling, and the moves of yard cranes among different blocks(He et al., 2010). (Yu and Yang, 2019) investigates the yard crane scheduling problem of a hybrid storage container terminal whose import containers and export containers are stored together in each block, through the develop of a mixed integer programming model jointly optimizes trucks waiting costs and penalty costs caused by exceeding waiting time thresholds.

Table 3.7: Major contributions to Yard crane scheduling

Reference	Type of approach	Modelling (algorithms)	Data size	Main Results
(Li et al., 2009)	**Optimisation**	Mixed linear integer programming (Rolling-horizon approach)	Not mentioned	Develops an efficient model for container YC work schedules. By applying heuristics and a rolling-horizon algorithm, the model size is greatly reduced systematically and the solution time is shortened from days to seconds. The algorithm yields higher solution quality in a very short time compared to other heuristics used in the literature.
(He et al., 2015a)	**Simulation and optimisation**	Mixed integer programming and simulation-based optimisation (Genetic algorithm – Particle swarm optimisation)	Randomly generated problems	An integrated simulation optimization method is developed, where the simulation is designed for evaluation and the optimization algorithm is designed for global search. Besides provides a novel idea that considering the trade-off between energy-saving and timesaving in the YC scheduling problem. Energy-saving is part of the optimization objective.
(He et al., 2010)	**Simulation and optimisation**	Integer programming (Parallel genetic algorithm)	Randomly generated problems	A systemic, simulation approach is employed considering and evaluating the workload in the yard, then the authors implement an optimisation approach to reduce the operational time in the yard considering the workload.
(Guo et al., 2008)	**Simulation**	Three dispatching strategies (first come first serve, nearest job first, and fixed	# Vehicles: 6 # Yard Cranes:2	Great value in improving Yard Crane performance in three Strategy

		window size with 1,3, 6, 9 jobs)		
(Yu and Yang, 2019)	**Optimisation**	Mixed integer programming (Rolling horizon algorithm)	-Not mentioned	The efficient scheduling of the cranes in hybrid storage blocks can improve the space utilization and operational efficiency of a container yard system.
(Sharif et al., 2012)	**Simulation**	Multi-agent system,	Randomly generated different scenarios	Applied different strategies in order to assign the cranes among blocks at the beginning of a planning period based on the work volume forecast.
(Huynh and Vidal, 2010)	**Simulation**	Discrete event simulation based on agent-based approach	10 trucks per hour arrive according to the Poisson dist. #Yard block= 4 with 40 bays	Simulation results showed that if crane operators choose trucks that are closest to them without requiring the cranes to turn and reverse heading, then the overall system performance in terms of average waiting time and the maximum waiting time of any truck will be better than if there were to choose trucks based on their waiting times.
(Zeng et al., 2017)	**Optimisation**	Mixed integer programming model (backtracking search algorithm)	No mentioned	This paper contributes to research the gantry crane scheduling and storage space allocation problem railway container terminal The stop position of railway train, the handling procedures, no crossing requirement, the safety distance of gantry cranes, and the storage modes in the main area were comprehensively considered in the established model. The proposed algorithm can gain the near-optimal solutions within a reasonable computation time.
(Javanshir and Seyedalizadeh Ganji, 2010)	**Optimisation**	Mixed integer programming model (Genetic algorithm)	#YCs=3 #Slots=20	In this study, the problem of scheduling multiple yard cranes to handle containers within a yard has been studied. A mixed integer program with non-interference constrains between cranes that usually move on the same rail in the yard has been proposed. Numerical comparisons have shown the accuracy and efficiency

	of proposed genetic algorithm in solving the problem.

Assumptions

1. Target times and locations of container moves are assumed known and fixed. The target times can be translated from the QC work list. (Li et al., 2009)
2. The job handling time of an YC is usually 2–4 minutes. The job handling time of all YCs is3 minutes (i.e., 20 moves/hour). (Li et al., 2009) .All yard cranes possess the same capacity of 360 min in a 6-h planning period. (He et al., 2010)
3. 20–30 moves in a 2-hour time window are used in the scenarios tested in this paper (Li et al., 2009).
4. In a ITs, YC–YC interference is usually more serious than prime mover (PM–PM) interference as YCs have more difficulty substituting for each other than PMs during actual operations Thus, generating YC schedules with the assumption that PMs are always available becomes very worthwhile. (Li et al., 2009). Due to the limitation of block size and the potential danger of crane collision, each block is utmost served by two yard cranes at the same time (He et al., 2010)
5. the minimum difference in slot numbers allowed for two YCs at the same time is assumed to be 8 slots. (Li et al., 2009) (Sharif et al., 2012)
6. All tasks of one task group should be at the same block. All tasks of one yard bay should be grouped together. (He et al., 2015a)
7. For export operations, all tasks of one task group should be from or for the same ship and all tasks of one task group should be from or for the same carrier. (He et al., 2015a)
8. The volume of a task group should not be more than the work capacity of one YC from current time to the planned end time. (He et al., 2015a) The workload of each period can be forecasted (He et al., 2010) (Sharif et al., 2012)
9. An uncompleted task group from the previous period should be still treated as a single task group, and its arriving time is set at the beginning time of the current period. (He et al., 2015a) (He et al., 2010) (Sharif et al., 2012)
10. In the YC scheduling problem, only tasks of a single period are considered(He et al., 2015a) (Sharif et al., 2012)
11. The start and end time of yard crane operation is in the same planning

period. (He et al., 2010)

12. Each yard crane can utmost move twice from one to another block in the same period. (He et al., 2010)
13. A truck request can be handled by a YC only if the corresponding truck arrives at its handling location; i.e., each request can only be handled by a YC after the request has been released. (Yu and Yang, 2019)
14. Once a YC starts handling a request, the YC will not handle another request until it completes the request. (Yu and Yang, 2019)
15. The YC moving time between two request locations could be predicted with high accuracy as YC speed is usually quite consistent. (Yu and Yang, 2019)

3.3.3 Landside

3.3.3.1 Gate operations

The increase of the containerization in the last years brought on the one hand a solid source of economic growth for the countries but on the other hand it has evidenced several problems particularly in the external interfaces of the terminals, like the interface with the landside where it is connected to the transport network. Gate operations are affected by operations that occurs inside the terminal i.e., yard operations that generate congestion due to the delay of the teams working there. Added to this, when truckers come to pick up import containers when the container yard is full, there could be multiple movements/shuffles within the terminal to get to the containers. These issues can create a backlog on the shore side operations which affects the productivity of the port/terminal, resulting in the ship on the berth working longer and the ships waiting outside for the berth to wait longer while other ships keep adding to the queue(“Port Congestion - causes, consequences and impact on global trade,” 2020). Several studies has been developed with aim to reduce this gate congestion optimizing the trucks appointment, i.e. (Chen and Jiang, 2016) presents a solution based on the truck- ship service relationship, assigning trucks delivering containers for the same ship one common time window. (Caballini et al., 2018) develops a mathematical model that assign appointments to the different time slots composing the gate opening time in a terminal container that operate with truck appointment system. Similarly, (Zhang et al., 2013) optimized a truck appointment subject to the constraints of adjustment quota, utilizing a Baskett Chandy Muntz Palacios queuing network to describe the queuing process of trucks in the terminal, moreover (Huynh, 2009) considers two types of appointment- strategies from the health sector, to determine the effectiveness of the scheduling strategy, used a simulation model of a container terminal. (Chen, 2013) develops a mathematical formulation for smoothing the peaks in trucks arrival, considering the negotiation process among the truck companies and the terminal operator to smoothing truck arrivals in peak hours.

On the other hand, (Li et al., 2018) deal the disruption among the trucks appointment and the trucks arrival time, utilizing various strategies in order to smooth the impacts of disruptions in the schedules. also develops simulation models to determine the best arrival pattern on trucks arrival. (Azab and Eltawil, 2016)focused his study to determine the how the arrival patterns influence the turn time of external trucks through the simulation model.

Table 3.8: Major contribution to gate operations

Reference	Type of approach	Modelling (algorithms)	Data size	Main Results
(Li et al., 2018)	**Simulation**	Discrete event simulation	Data from container terminal in Shenzhen, China.	Propose different truck service strategies, in order to maintain a good level of truck service.
(Chen and Jiang, 2016)	**Optimisation**	Genetic algorithm-based solution heuristics	#Ships= 14 # Trucks:4798 # Horizon planning= 1 week #Gate processing rate= 40veh/h	Evaluate different strategies in order to optimise the truck arrivals with time windows, based on the truck-ships service relationship.
(Caballini et al., 2018)	**Optimisation**	Integer linear programming	#Trucks=100 #Time windows=10 # 3 different trucks arrival pattern #Horizon planning= 1 working day	The proposed mathematical model seeks to assign appointments to the different time slots composing the gate opening time.
(Zhang et al., 2013)	**Optimisation**	Genetic algorithm based on the Pointwise stationary fluid flow	Data from a terminal of Tianjin.	A model able to optimise appointment quota of each period to minimize the truck turn time consequently the gate congestion.
(Azab and Eltawil, 2016)	**Simulation**	Discrete event simulation	Not mentioned	Provide a simulation run of different scenarios using various truck arrival patterns

(Huynh, 2009)	**Simulation**	Discrete event simulation	Data from Port of Houston's Barbours Cut Terminal #Trucks = 100/day	Provide a simulation run under two types of appointment: individual appointment; block appointment system
(Veloqui et al., 2014)	**Simulation**	Discrete event simulation	Data from Port of Naples	Provide a simulation of various scenarios with the variation of the servers in access gate, improvement the gate performance
(Guan and Liu, 2009)	**Optimisation**	Multiserver queuing model	Data from a Port of New York	Develop a multi-queuing model to analyse gate congestion issues for inbound trucks, quantify truck waiting cost and explore alternatives for gate system optimization.
(Phan and Kim, 2015)	**Optimisation**	Non-linear mathematical model, Decentralized decision-making model (Software Lingo)	Not mentioned	Provides a mathematical formulation for smoothing the peaks in arrivals considering the inconvenience of trucks from changing their arrival times and the waiting cost of trucks in peak hours.
(Chen, 2013)	**Optimisation**	Integer programming (Genetic algorithm and simulated annealing)	Data from a container terminal in Northern China # Gate lanes= 2 Gate processing rate= 20 veh/h Truck arrival= Beta dist (1.29 , 3.25)	Proposes a method called 'vessel dependent time windows to control truck arrivals, which involves partitioning truck entries into groups and assigning different time windows to the groups.
(Rajamanickam and Ramadurai, 2015)	**-Simulation**	Discrete event simulation	#Gates=10 #Trucks=228	The study demonstrates the utility of using traffic micro-simulation to study congestion inside the port. Several alternative scenarios are developed and simulated to get results of the key performance indicators.

(Preston et al., 2020)	**-Simulation**	Discrete event simulation	Data from a Port of Dover	The main result of the research presented here is in discovering and illustrating some guiding principles that can be applied to port more generally, also the analysis confirmed that the ability of the Port to clear traffic out of the system is strongly influenced by vehicle processing times.
(Zehendner and Feillet, 2013)	**Simulation and optimisation**	Discrete event simulation; Mixed integer linear programming model	Data from a Port of Marseille	Results show that a thought-out truck appointment system can reduce delays of trucks, trains, and ships: the terminal can deviate truck arrivals to less busy periods and free straddle carriers for trains, and ships when necessary. Hence the container terminal can smooth out the workload by forwarding or postponing truck arrivals via the appointment system.

(Veloqui et al., 2014) develops a queue model to analyse truck congestion at the gate of a real port, then through a simulation approach they reproduce various scenarios with changes in the servers to decrease congestion at the gate. (Guan and Liu, 2009) applies a multi-server queuing model to analyse gate congestion and to quantify the truck waiting cost. An optimisation model was developed to minimize the total gate system cost.

Assumptions

1. The ship schedule information is known in advance, which includes ship arrival times and the volumes of outbound containers. (Chen, 2013)
2. For a specific ship, a time window is assigned to the related truck entries. The ending point of a time should be no later than the corresponding vessel arrival time. (Chen, 2013)

3. Within the time window, the trucks arrive and wait in a queue at the entrance gate. All trucks are served on a ‘first-come, first-served’ principle. (Chen, 2013)
4. During the waiting time, truckers normally keep their engines idling, because in the queue they frequently move forward. (Chen, 2013)
5. Each truck approaching the terminal is characterized by several features. Specifically, each truck has to perform one or two pick-up and/or delivery operations in the same or in different areas of the terminal. (Caballini et al., 2018)
6. The productivity of the handling resources assigned to each area may vary in the different time slots for two main reasons: Firstly, a different number of containers can be present in the area, thus implying a different number of rehandles (i.e., unproductive movements) that directly impact on the productivity of resources. Moreover, during time slots with high levels of activity in vessels, the terminal can use some handling resources to serve the quay operations, thus reducing the handling productivity in the yard areas. (Caballini et al., 2018)

3.4 Conclusion and research prospects

In this chapter, a systematic investigation of decision-making in container terminals has been carried out. Most of the previous work modelled the decisions with several restrictions and tackled their model with limits in size. The literature done also includes simulations and performance in container terminals. In addition, a summary of the latest research around decisions in some of the container terminals across the world has been made.

A challenge is to integrate the scheduling decisions in container terminal. As an example, suppose that scheduling and routing of vehicles, must be combined with the storage space assignment. Besides the major research needs to find out a suitable and efficient algorithm for the decisions as well as the integration, additional topics may become important. Regarding changes in environments, the approaches for container terminals usually apply scenarios when it comes to consideration of stochasticity. Hence, the area of ‘stochastic optimization and scenario-based scheduling’ could be another further challenge.

This research looks a container terminal from every perspective, whether functional, environmental, economic, etc. However, which can state that from the social-behavioural perspective there is very little research in the international literature that goes into this argument, and at present there is no optimisation model that considers this aspect, which can be seen as a challenge for future research.

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4.Theoretical Framework

4.1 Introduction

This thesis aims to study the modelling and simulation of a container terminal through the combination of the two main known simulation techniques, discrete event and multi-agent approach. As mentioned in the previous chapters, the transport of freights by sea takes place in a competitive context in which it is necessary to research and develop tools capable of supporting container terminal managers in the management of operations and consequently improve their performance. To do this, it is necessary to employ simulation techniques. In this thesis work, the potential of simulation tools in modelling highly complex logistics systems such as container terminals is highlight.

Through a simulation model it is possible to reproduce, in a controlled environment, the operation of a real system in order to analyse its behaviour in different possible conditions. The simulation gives a support not only to make measurements of the performance of existing systems at the variation of structural and/or performance characteristics, but also to evaluate the different behaviours of systems in the design phase at the variation of operating conditions. Therefore, through simulation it is possible:

- Study and analyse interactions between individual components of complex systems;
- Assessing the impact that potential changes of an existing system would have before implemented them;
- Assessing the performance that systems in the design phase would have under different conditions.

In this chapter will focus on simulation and will try to highlight on the main modelling techniques that can be used to reproduce the flow of freights in a container terminal.

This chapter deals the simulation models and the two main approaches used in the container terminal simulation, as well as the main tools used in the market to this purpose. In particular, the simulation tool used in this thesis work (AnyLogic) it's presented, highlight the mains features and application fields.

4.2 Simulation Modelling

Simulation is the creation of a reality model that makes it possible to evaluate and predict the dynamic development of a series of events following the imposition of certain conditions by the analyst or user. To this end, a computer is used to study the behaviour of the system in the present conditions or in modified conditions, but without modifying it.

Since the 1950s, simulation studies have found wide application in many sectors, from industry to the health sector, to improve efficiency, reduce costs or increase profitability in complex situations that are difficult to test except in theory. Nowadays, the use of simulation has developed considerably in the civil and industrial sectors, as well as in the service sector, becoming an indispensable tool for management and development activities. In fact, there are many processes that can be modelled and from whose simulation profit can be derived.

The simulated model therefore imitates reality and reproduces it in laboratory conditions, i.e. in a study environment that can be easily controlled, manipulated and reproduced.

When the relationships that make up the model are sufficiently simple, an analytical solution can be used to describe the model. However, most models that attempt to represent reality are very complex and cannot be represented by exact formulas. Some models must necessarily be analysed using simulation models. The data obtained from simulation do not provide a way of representing reality, only an estimate, which is why it is useful to carry out many simulations and statistically assess what is most likely to happen.

Simulation has weaknesses that have not made its development possible in the past, as they require very powerful computers to enable simulation.

The schematisation of a system in terms of a model is aimed at providing a simplified abstract representation of the system for subsequent analysis. The model must be subjected to the same inputs as the real model to produce similar outputs. In fact, the implementation of models is useful both for forecasting purposes and to simulate the effect of different intervention scenarios and alternative design solutions.

The system that will be represented through a simulation model consists of a set of interacting entities. More generally, depending on the system to be simulated and the data available, there are different types of simulation models:

- Continuous or discrete: they differ in the way the system evolves over time. In a discrete model, the state changes only at a finite number of points on the time axis and the variables assume a well-defined set of values at precise instants of time: the system switches its state only in correspondence with an event. In a continuous model, instead, the state, and therefore the variables, change continuously;

- Static or dynamic: these differ in terms of the role of the variables over time. A static model describes the system at a particular point in time, while a dynamic model represents the temporal evolution of the system under consideration;
- Deterministic or stochastic: they differ in the presence or absence of the random element. Deterministic models do not contain random variables: the evolution of the system and the outputs produced are strictly dependent on the inputs into the system. One speaks of stochastic simulation models, instead, if they contain random variables whose evolution depends both on the input parameters and on the random elements inserted. It should be noted that even systems, which are stochastic by nature, can be described as deterministic, taking the mean values of the individual distributions as sample values.

In this context, the most effective approach to the analysis of a container terminal is through discrete event simulation, hence this chapter will refer to this type of simulation.

In a container terminal, this type of simulation can help to achieve several objectives: overcoming the mathematical limitations of optimisation approaches, allowing a more detailed and realistic representation of the terminal characteristics, supporting decision making in day-to-day processes through the evaluation of "what if" scenarios and making computer generated strategies/policies more understandable. The discretization of the system depends on the case study size (one terminal vs. several terminals), available data (aggregated vs. disaggregated, historical vs. experimental data), on the problem to be addressed (loading/unloading of ships vs. simulation of the whole system) and/or on the planning time horizon (short term vs. medium term).

The introduction of artificial intelligence as a scientific discipline whose aim is to investigate the mechanisms underlying the cognitive faculties of human beings, such as language, reasoning, problem solving, perception, etc., and their reproduction by means of appropriately programmed computers has permitted the creation of software based on artificial intelligence.

The modern view of an artificial intelligence system is to regard it as an agent (or a multiplicity of agents) capable of performing high-level tasks. Lines of research are pursued in terms of the degree to which an 'intelligent agent' is endowed.

The rapid technological evolution of the computer, from its invention to the present day, has enabled contemporary man to avail himself of an essential tool for his research. What was initially a simple calculating machine has been transformed into a computer system with such high capacities that it can manage processes.

With the help of computer tools, it has been possible to describe numerous real processes in order to explain them, study their characteristics and simulate their evolution over time.

Multi-agent simulation makes it possible to create artificial worlds, models of real systems, in which all variables and state parameters can be controlled. This fundamental feature of multi-agent systems allows us to directly experience the consequences of behaviour that differs from the real thing, unexpected events, or alternative theories. Unlike mathematical models, with the use of agent-based models it is possible to represent variations of the real system by simply modifying some parameters or small parts of the program, without requiring, therefore, to intervene on the equations, or heavily on the implemented software. Whole models, or parts of them, are thus reusable in other experiments, and a researcher can come up with his or her own model, without having to program a system from the outset and without having to enlist the help of computer experts.

Agent-based models present themselves as more versatile and user-friendly than classical models, as much as that they have been defined by the Academy of Sciences as the most promising paradigm for the coming years, and this topic will be discussed in detail at the end of this chapter.

The section will be structured as follows: In the first subsection, the discrete event simulation and its application to a container terminal will be discussed in detail. After that, an overview will be given of artificial intelligence and multi-agent models, and finally the different tools that are able to support this type of simulation and its application to a container terminal.

4.2.1 Discrete Event System

A discrete event system is a type of system which the system state and time are discretised to specified values. Discrete event simulation is used to simulate the behaviour and performance of real-world processes. Most of an organisation's processes can be described by a series of separate discrete events, occurring over time, that modify the state of a system. For example, a truck arrives at a distribution centre, goes to the unloading area, unloads, and then leaves the warehouse, or a patient with a certain pathology arrives at a medical care unit, is referred to the appropriate specialist, is treated, and then leaves.

A system is composed by:

- Entities: Individual elements of the system to be modelled, whose behaviour and evolution is traced throughout the system:

    - Class: Groups of entities which are identical or similar in their behaviour.
    - Sets: Temporary groups of entities whose current state is identical or similar
    - Attributes: Internal information of the entities that make them different within a class or set and that influences their behaviour.
- Resources: Elements of the system that are consumed or generated in the processes (not modelled individually).
- Event: Any event capable of altering the state of the system: They can be external events (generated by the environment), able to represent the beginning and (especially) the end of an activity.
- Activity: Process within the system:
    - Has a fixed duration: starts with an event and ends with an event.
    - It leads to a change in the state of the system.
    - It is influenced by the attributes of the system elements.
- System state: Variables that define the state of the system as a whole and its elements in particular:
    - They are modified by events.
    - They in turn influence the sequencing of events.

The discrete event system may also be defined as an interactive set of entities that evolves through different states upon the occurrence of internal or external events. Entities may be physical, conceptual (information flow) or mathematical and may be resident or transitory. Resident entities remain part of the system for long intervals of time; transitory entities enter and leave the system several times. Entities may be characterised by parameters and/or variables. Parameters define static (stationary) characteristics that never change, variables define the state (dynamic characteristics) of each entity and can change over time and can also be classified as deterministic or stochastic. An activity may be associated with each entity, in which case the entity is called active, otherwise passive. An activity represents a specific operation/task performed by the entity. It is triggered by an event and is characterised by a time duration. The duration can be constant or variable and its evolution in time can be modelled as a deterministic or stochastic process. Active entities, residents or transitory, play an active role that influences the evolution of the system; passive entities, residents or transitory, are fundamental in the evolution of the system but do not perform any activity, such as the structures needed to perform an activity (e.g. docks) or what is actually moved by the active entities (e.g. containers).

Entities interact through rules, these could be endogenous or exogenous. Endogenous rules may reflect the hierarchy (spatial or temporal) between entities and derive from the process of building the logical architecture of the system. Exogenous rules may depend on exogenous phenomena and may reflect "human" management actions.

The whole system is characterised by a state that describes the whole system and is fully defined once the entity attributes are known. The state of a system evolves when events occur that change the value of entity attributes and the evolution depends on the logical or physical relationship existing between entities (hierarchy). The figure 4.1 shows an abstract representation of the system evolution, which the events are in a global list within the system, that occurs in a defined period of time (represented by the clock of the simulation environment), after the first event in the list occurs, the state of the system is updated based on the state of the variables that regulate it, then it proceeds with the second event in the list and so on, the state of the system is updated in time instants well defined by the duration of each event (Figure 4.1).

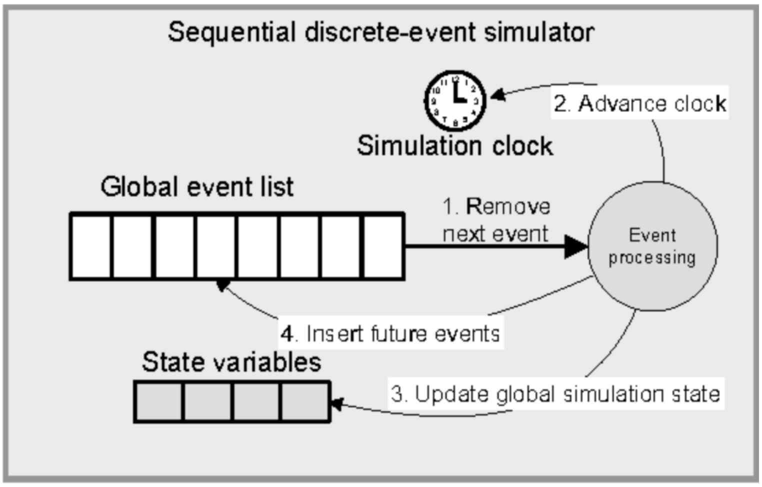


Figure 4.1: Discrete event system(Source:(Juhasz et al., 2003)

4.2.1.1 Discrete Events in a Container Terminal

A discrete event approach allows a good abstraction of the phenomenon, modelling the modularity and graphical representation of the results. In this sense, container terminal operations are a natural application of the discrete event approach, since they can be easily schematised into a finite set of entities (physical or conceptual), have a clear hierarchy and have an internal complexity which other approaches have little effectiveness (e.g. Petri nets or optimisation models).

In a container terminal, entities represent handling equipment, containers and all those physical locations relevant to container terminal operations (dock, yard, gates, etc.).

The handling equipment is a resident and active entity which can be characterised by parameters, variables and activities. The parameters define the main characteristics of each piece of equipment; the variables define the state of the entity, such as occupancy status, location; the activity defines the duration of the task that the entity performs. The duration of time can be deterministic or stochastic and, in both cases, should be estimated on real data. Containers are passive entities. The focus of the simulation is on how they are moved through the terminal by the handling equipment. Containers are characterised only by parameters and variables. Parameters define the type of container (e.g. 20', 40', empty or full); variables define their state (stopped or moving) or their position (through coordinates, storage areas, etc.). Physical positions are identical and passive entities. As for containers, they can be characterised by parameters and variables. Parameters define their geometrical characteristics (e.g. length, available area, number of levels); variables define their status (occupancy, containers/trucks queued, etc.).

In addition to the entities described above, others can be considered. Such entities usually do not move containers but can control / manage the entities managing the containers and can therefore modify their attributes. The modification of such attributes can be driven by simple heuristic rules (e.g. if there are more than four trucks waiting for a reach stacker, use another reach stack) or by sub-models that modify the attributes of entities, trying to optimise the overall terminal performance in real time.

Interaction between entities is possible if events occur. In a container terminal system, events can be exogenous or endogenous. Exogenous events are, for example, ship arrivals, truck arrivals and container arrivals; endogenous events are the start or end of an activity (activity) or events that may occur due to real-time control/management strategies (also departures).

The figure 4.2 shows a compact elementary schematisation of a container terminal, from the layout of a terminal it is possible to construct an abstraction of the logical functional architecture by identifying three main elements: the areas, the activities in each area and the actions, which are simply the events that provide for the interactions between the activities in the different areas.

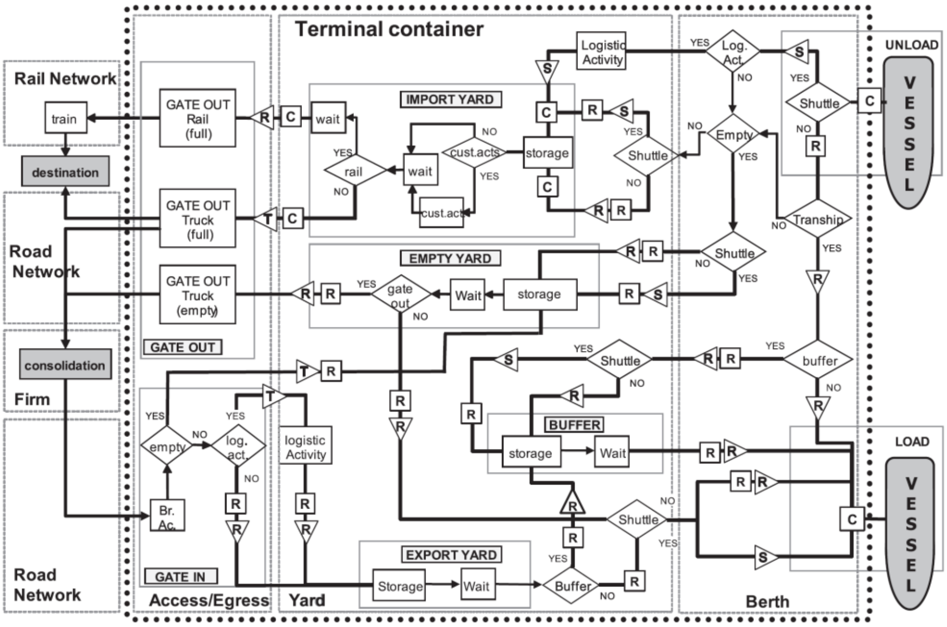


Figure 4.2: Logical architecture of a container terminal (Source:(Cartenì and de Luca, 2012))

4.2.2 Agent-Based System

An agent is an entity characterised by the fact of being, at least partially autonomous, be it a computer programme, a human being, and so on. An agent system is a set of agents located in a certain environment and interacting among themselves through an appropriate organisation.

The agent systems are used to simulate interactions between autonomous agents. Attempts are made to determine the evolution of the system to predict the resulting organisation.

For a better understanding, this section will expand on the study of Artificial Intelligence (AI).

AI is a scientific discipline born around 1950, whose objective was the investigation of the mechanisms underlying the cognitive faculties of human beings and their reproduction by means of appropriately programmed computers.

Over the years, the discipline designated as "artificial intelligence" has been split into two areas, which differ in relation to the meaning of the term "reproduction".

The first area is the called 'strong artificial intelligence', which believes that a suitably programmed computer can indeed be endowed with genuine intelligence, not distinguishable in any important sense from human intelligence. At the basis of this conception is the theory that the human mind is also the product of a complex set of calculation procedures, performed by the brain. It remains, of course, to be established at what level of description brains and computers can be considered the same thing (excluding, at least for the moment, the hardware level); nevertheless, supporters of strong AI are convinced that such a level must exist.

The second area, by contrast, is called 'weak artificial intelligence'. It argues that a suitably programmed computer can only simulate human cognitive processes (or some of them), in the same sense that a computer can simulate the behaviour of an atmospheric event. Therefore, the emphasis here is on what a programme is capable of doing, without making any assumption that the way it does it coincides at some level with human mental processes. On the other hand, there is no claim that a program, complex and efficient, can really be called an example of 'mind'. Obviously, supporters of this form of AI are also interested in the many practical applications of the technologies being developed in their discipline.

The two declinations of artificial intelligence, although profoundly different with respect to their basic philosophical assumptions and aims, share methodologies, instruments, and technologies. Maintain that in order to reproduce and/or simulate intelligent computer behaviour, it is necessary to process information (represented by discrete symbols) through a programme. In this sense, they constitute what is called "classic artificial intelligence".

This is opposed by a new discipline, called connectionism, which argues that in order to reproduce or simulate intelligent behaviour, it is necessary to replicate, using a computer, the functioning of the human brain at the cellular level. This replicates the functioning of individual neurons and simulates the connections that transmit information between one neuron and another. Real-world applications of this technology have given rise to neural networks: systems capable of evolving and learning according to the stimuli they are subjected to.

Finally, it is also important to mention another discipline: cognitive science. This is an area of study that has emerged over the last twenty or thirty years thanks to the convergence of exponents of various disciplines (artificial intelligence, linguistics, philosophy of language and mind, cognitive psychology, neuroscience), and whose subject is the study of intelligent systems, whether natural or artificial. In a certain sense, cognitive science represents the heir of strong AI, especially for the conception that intelligent systems (any of them) are basically information processing systems that interact with a complex environment. On the other hand, the coexistence of different disciplinary traditions has meant that this new area also includes many scholars who are strongly critical of the foundations of AI. From this simple observation, is possible deduce the theoretical foundations that underlie modern AI:

- The idea that reasoning, and in general any kind of activity of the mind, is a calculation;
- The concept of symbol or representation;
- The concept of calculation as the manipulation of symbols according to rules;
- The idea that something like an automatic symbol manipulator could exist.

Some of the concepts that appear in these theoretical propositions are part of the common-sense bag of concepts: calculation, representation or symbol are words that are commonly used.

Generally, we can say that a representation is an object that represents another object. An interesting property of representations is that they are not exact copies of their objects. For example, a picture represents the appearance of a person, but not his tone of voice, the softness of his skin, or the scent of his hair, let alone his character. A representation is therefore always the product of a process of selection from among the many (infinite) characteristics of the object to be represented, in other words, a process of abstraction.

Representations are divided into two classes according to the relationship that exists between the representing object and the represented object. In some cases, such as photos, there is a physical relationship that determines how the object is represented. The light emitted by the object, such as a house, impresses the film, imprinting the image on it. In other cases, such as drawing, it is the representative who chooses how to represent the house, using vertical, horizontal, or oblique lines. However, both the drawing and the photograph maintain a relationship of similarity or analogy with their object. This type of representation is referred to as analogical.

One of the characteristic limits of the computer's formal procedure is that the machine ignores the meaning of the symbols it is manipulating. This is the distinction that exists between a syntactic procedure, made up of undecidable propositions, such as arithmetic properties, and a semantic one, i.e. connected to the meaning of what is being processed. Research on natural language processing is one of the leading sectors of artificial intelligence and is the subject of another discipline called computational linguistics.

One of the most important applications of artificial intelligence, especially at a commercial level, is the creation of expert systems. In synthesis, an expert system is understood as a programme which is able to resolve complex problems which fall within a particular domain, with an efficiency comparable to that of a human specialist in that sector. For example, an expert system might be able to make medical diagnoses by examining the (suitably formalised) medical records of a patient; or it might assess all the risk factors and profit prospects of a particular financial investment.

All expert systems have the following components:

- A specialised knowledge base on a given domain, representing the knowledge needed to address and solve problems in that domain. Obviously, the knowledge base must be appropriately represented in the memory of the computer by means of formalisms;
- An inferential engine that is able to deduce (or infer), starting from the knowledge base, the conclusions that constitute the solution to a given problem in the domain. The inferential engine, which is the real heart of the programme, works by applying to the knowledge base a series of heuristic procedures similar to those developed in the field of problem solving. However, in most cases the general heuristics are complemented by heuristics specific to the topic the system deals with. In fact, in any specialised field a human expert is able to exclude immediately and without evaluation a number of options that are manifestly unproductive.

The modern vision of an artificial intelligence system is that it is an agent capable of performing high-level tasks. An artificial agent does not act in isolation; it must interact with human beings but also with other artificial systems. Research on multi-agent systems deals with the representation of knowledge and reasoning in situations where many agents are present in a system, each with its own knowledge and "point of view" on the world. Particularly important aspects are communication, coordination, and cooperative planning: these are necessary for the multi-agent system to efficiently pursue (by distributing the workload or exploiting the specific capabilities of some agents in the system) a common goal even in environments that may be made hostile by the presence of another team of adversary agents. The study of multi-agent systems and their peculiarities will be dealt with in the next paragraph.

4.2.2.1 Multi-Agent Systems

The technological evolution of the computer, from its invention to the present day, has enabled contemporary man to make use of an essential tool for his research. What began as a simple calculating machine has turned into a computer system with such high capacities that it can manage companies, industrial processes, design machinery or assist in medical analyses.

With the help of computer tools, it has been possible to describe numerous real processes to explain them, study their characteristics and simulate their evolution over time, thus, as to predict possible future scenarios.

Recently, the need has emerged to analyse complex phenomena, which originate from the behaviour of individuals and from choices that are often non-deterministic and therefore difficult to represent mathematically through equations: these phenomena, which have emerged in many areas, for example in the social, economic, and territorial spheres, cannot be explained through the principle of superposition of effects.

In order to respond to these demands, models have been developed that are able to describe mathematically only small parts of a system; they evolve by analysing a phenomenon through the interactions between the elements themselves: these are the agent-based systems (MAS: multi-agent system).

A multi-agent system (MAS) is a computer system consisting of multiple agents interacting with each other within an environment. MAS differ from single systems in that there are several agents that mutually shape their actions and goals (Figure 4.3). Five main issues can be identified in the creation of multi-agent systems:

- Action issues: how can a set of agents operate simultaneously in a partially observable environment, and how does this environment interact in response to the agents? These questions are related to the representation of the environment by the agents, the collaboration between the agents and the planning of the activity of a multiplicity of agents;
- The problem of the relationship with the outside world: everyone in a society of multiple agents must be able to take the action most suited to his or her objectives. This issue also covers the notion of the agent's constraints in relation to a third agent;
- Systems with multiple agents also require the study of the nature of interactions, as a source of opportunities on the one hand, and of constraints on the other. The problem of interaction is concerned with the modes of interaction, the analysis, and the design of the forms of interaction between agents. The notions of collaboration and cooperation are fundamental issues in this field. Applying the knowledge of single-agent systems to multi-agent systems will result in self-interested agents who will not cooperate in any way, thus that the goal of the system will be only minimally achieved;
- Adaptation issues: the agent must have mechanisms to judge the current state of its environment in order to modify its behaviour and make decisions about future actions;
- The effective realisation and implementation of multi-agent systems: the development phase is carried out using different types of programming languages, which vary from formalisation and specification languages to actual implementation languages. Between the two classes are languages for

communication between agents, the description of the laws of the environment and the representation of knowledge.

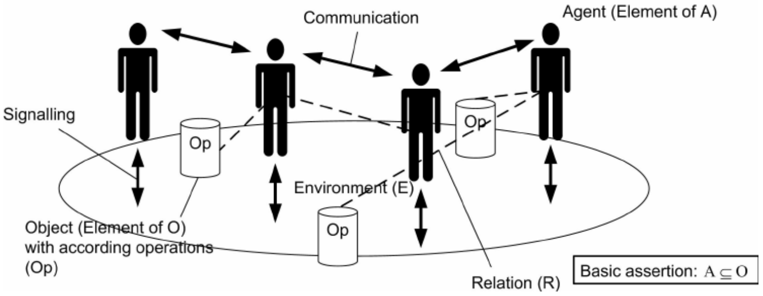


Figure 4.3: Multi-Agent system(Source:(Frantz, 2009)

The architecture of a multi-agent system cannot depend on the problems outlined above, hence will have the following necessary points:

- Agents must be equipped with a variety of decision and planning systems. Operations research, or decision theory, is a discipline entirely dedicated to the study of this subject;
- Agents also need a cognitive model;
- Agents must also be equipped with a communication system;
- The problem of adaptation is a sensitive issue that is currently the subject of much research.

The preferability of the MAS approach with respect to the classical simulation method will be discussed in more detail in the next section. Here it is sufficient to note that it is immediately recognisable that this approach facilitates, in comparison with the traditional method, the introduction of time-varying behaviour of the agents as a consequence of variations in the circumstances in which they find themselves (environment).

4.2.2.2 Agent Based in a Container Terminal

The exponential growth of container transportation has caused to problems in the ports and in the cities close to them, the repercussions of the costs associated with port congestion affects a number of actors related to container terminals, for example:

- Shipping Lines – ship delays, extra costs, missed feeders, etc;
- Terminals – extra manpower, yard congestion, re-handling, etc;
- Trucking Companies and Railways – waiting time, loss of business;
- Shippers – longer lead times.

One of solution to mitigate this problem is to increase the terminals' capacity, which would increase their performance. The capacity could be increased either by physical expansion or by better utilisation of available resources. However, many port, especially the Mediterranean ports, do not have the space to expand their terminals and not have the funds to build new infrastructure. Due to this the container terminals managers are calls to reach for alternative methods to mitigate the problems that weaken the container terminals performance (Henesey, 2004).This thesis focuses on improving the performance by the use of available resources through computer-based support for management decision making.

The management of a container terminal affect the decision of ship lines to use a determined container terminal or another. Hence, it is necessary the satisfaction of a customers by part of container terminals management, such as minimising the ships' operation time. To shorten this time, the managers must spend effort in increasing the productivity in terms of container crane moves per hour, which is regarded to be one measure of performance. The increasing complexity of CT operations requires management to decide allocation of resources but also the sequence and timing of operations (Henesey, 2004).

The complexity of the operation management of a container terminal often requires complex models (combinatorial and non-linear), resulting models are extremely difficult or take too much time for solving problems (Hayuth et al., 1994). That is the reason why the isolated planning is normally used. Nevertheless, the disadvantage of this approach is that it only provides approximated results and requires of the help of the human planner's experience to compensate these approximations in the results.

Multi Agent Based Simulation differs from other kinds of computer-based simulation in that the simulated entities are modelled and implemented in terms of agents. Like other micro simulation techniques, Multi Agent Based Simulation attempts to model the specific behaviours of specific individuals. This is contrast to typical macro simulation techniques in which the characteristics of a population are averaged together, the model in this type of simulation approach, simulates the changes for the whole population by using the averaged characteristics (Henesey et al., 2003), it is therefore not an effective approach to simulate a container terminal, where several resources are involved with well-defined characteristics between each of them.

On the other hand, in micro simulations the structure is viewed as emergent from the interactions between the individuals. (Van Dyke Parunak et al., 1998) compared these approaches and pointed out their relative strengths and weaknesses. They concluded, "…agent-based modelling is most appropriate for domains characterized by a high degree of localization and distribution and dominated by discrete decision."

Thus, given the characteristics of container terminals, Multi Agent Based Simulation seems a promising approach to simulating container terminals.

The management of a container port is a complex process, which involves a high number of decisions. In this context a simulation tool, would be one a great support for terminal container managers to assist in decision-making. There are several studies in literature that try to integrate all the operations within a simulation environment to improve performance indicators in each activity. In this thesis it be focus in the multi agent-based simulation.

In table 4.1 extract of (Abar et al., 2016) provides an overview of some simulation tools currently used in various application fields, including container terminals through the multi-agent paradigm, highlighting the main features of these tools, as well as technical features and specifications that have been taken from the developers' sites where technical guides, manuals and the ABMSs software itself are available for download.

4.2.2.3 Agent Based Modelling and Simulation Tools

An agent is considered an entity, notion, or software abstraction, similar to well-known programming specifications such as objects, methods, procedures and functions, where an abstract object wraps the methods and attributes of a software module. However, an agent presents a higher scale software abstraction that defines a complex software unit in an efficient way (Abar et al., 2016). The most important characteristic of these entities is their ability to decide independently during problem-solving, conflict resolution and decision-making processes to achieve a common goal. Whereby an agent represents an object having control on its execution (Zeid, 2003).

Agent-based modelling and simulation (ABMS) refers to a category of models that invoke dynamic actions, reactions, and the intercommunication form between agents in a shared environment, in order to evaluate their design, performance, and obtain information about their behaviour and properties. From a simulation perspective, the function of an individual entity can range from very basic reactive rules to more cognitively sophisticated models of behaviour.

Agent based modelling is a recent modelling method, since until the early 2000s, this kind of simulation was pretty much an academic topic, actually the adoption of agent based modelling started in 2002 – 2003 motivated by the need of obtain a deep vision about the traditional system that were not well represented by traditional modelling approaches; the development in modelling technology from computer science specifically object-oriented modelling, UML and statecharts; rapid growth in hardware and memory availability (agent-based models are more demanding on both, compared to system dynamics and discrete event models).

In this context it was necessary to develop a user interface that consists of a set of computer modules, thanks to which a human being is able to interact, and to create intelligent agents capable of learning and then training them. Learning allows agents to operate in initially unknown environments becoming more competent than they were at the beginning. Sometimes the user may not be able to know how the system as a whole behaves, what the key variables are and the dependencies between them but can have some idea of how the objects in the system behave individually. Then, one can start building the model from the bottom up by identifying those objects (agents) and defining their behaviours. Sometimes, it is possible to link the agents together and make them interact; other times, it is possible to put them in an environment, which may have its own dynamics. The overall behaviour of the system thus emerges from many competing individual behaviours.

There is no specific language for agent-based modelling. The structure of the agent is created using graphical editors or scripts, depending on the software. However, the behaviour of agents can be specified in a variety of ways, it is important to know that the agent has a notion of state, in which its actions/reactions depend on this. In these cases, behaviour is best defined by state diagrams. Another way, the behaviour is defined in the form of rules that are executed upon special events. In many cases, the internal dynamics of the agent can best be captured using the system dynamics or discrete event approach. In these cases, we can put an action and flow diagram or a process flow diagram inside an agent. Similarly, external agents and the dynamics of the environment in which they live are often modelled naturally using traditional methods. Therefore, a large percentage of agent-based models are multi-method models.

Essentially the ABMS approach consists of modelling and simulating realistic scenarios with a group of autonomous agents as simplistic entities within computer codes or as considerably intelligent objects. In a similar way, to the problem-solving capacity of a human beings with an infinite number of states, beliefs, trusts, decisions, actions, and responses. However, acquiring adequate knowledge of the system in order to build an appropriate conceptual and logical model is one of the most difficult tasks in simulation testing. Over the years, numerous agent-based modelling and simulation tools have been developed, applied to a specific domain, in which each strategy has a particular programming, syntax and semantics for the agents and has a different basis in terms of generality, usability, modifiability, scalability and performance.

In recent years, this type of modelling has aroused great interest in the scientific community where there are several reviews that try to expose the main software on the market that are able to model this type of paradigm, showing the differences, advantages, and disadvantages of each of them as well as their field of application. In this thesis a part of a consistent review by (Abar et al., 2016) it's presented, which covers an extensive study on the latest generation ABMS software addressing modelling as well as simulation capabilities, highlighting several special features of agent-based software that are not covered by other studies in the literature, providing information on the types of agents that can be implemented in each tool, meticulously extracting general details from the documentation or user guides of each individual tool, the various aspects that are analysed are:

- ABMS software tool;
- License/Availability;
- Source code;
- Type of agent simulated based on its interaction behaviour;
- Application Programming Interface for model development;
- Compiler, operating system, implementation platform;
- Model development effort;
- Modelling strength ;
- Scope or application domain.

ABMS is increasingly recognized different scientific disciplines within of these the Science, Technology, Engineering and Mathematics in simulating dynamic large-scale complicated systems and observing emergent behaviours (Macal, 2016) (Marvuglia et al., 2017) (Allan, 2010) . Complex systems might be simplified using a set of interacting agents.

A complex model can be modelled with many interacting agents with certain inherent attributes to establish relationships between them and the system, thus facilitating automated reasoning and problem solving.

Computational tools help users to investigate how the macroscopic behaviour of a system depends on properties, constraints, and rules at the microscopic level. Agents, as objects, are typified by specific states and sets of attributes, properties, and rules, in other words "behaviours" that can trigger special actions through predefined parameters in each of them. In addition, there are agent modelling libraries and tools that help users to build these models(Pignotti et al., 2008).

The notion of ABMS is well suited to social science goals and to the study of systems which exhibit two important properties: one is that the system is constituted by entities interacting for negotiation and conflict resolution; and the other is that the system coordinates emergent attributes prevailing from the dynamic interactions of agents that cannot be inferred by simply aggregating the agents' embodied characteristics.

It is therefore accurate to state that "when agents' interactions depend on past experience, and especially when agents continuously adapt to that experience, mathematical analysis is often very limited in its ability to derive dynamic consequences". In these cases, agent-based modelling is often the only practical method of analysis (Tesfatsion and Judd, 2006). In addition, agent-based modelling can also be interpolated to provide pragmatic solutions to many problems important to the environment, wildlife, health, and finance. In addition, these models are applied to epidemiology.

There are other application areas for ABMS in engineering and science, such as the design of self-organising systems, either continuous or discrete event systems, simulation of fluid flows, immunology, genetic/molecular networks for signalling trajectories, physiological fluctuations, including the ability of systems to react to a trace of environmental impulses/stimuli, analysis of pollutants to formulate policy rules for a greener habitat, transport and logistics, detection and diagnosis of environmental pollutants, detection and diagnosis of the effects of environmental pollution, and the development and implementation of new technologies, including the ability of systems to react to a trace of environmental impulses/stimuli, analysis of pollutants to formulate policy rules for a greener habitat, transport and logistics, fault detection and diagnosis in distributed systems, manufacturing, production, design of safety-critical systems, etc. Increased use and acceptance of ABMS is foreseen in microsimulation and social optimisation problems, such as crowd pattern detection, traffic flow and urban supply chains. With the help of agent-based modelling, users define the interactions between objects/agents in their domain of interest, and then use these models to generate their own models of real-world systems (Perez-Mujica et al., 2014).

An integrated development environment is a stand-alone application programming environment with a typical code editor, compiler, debugger and viewer or interactive graphical user interface builder. What makes this methodology interesting for an user is that models are intuitively visualised in aesthetically appealing user interfaces; more specifically, cases where individuals' tendencies have direct downstream impacts on the universal/macroscale properties of the whole unit. Thus, the users can observe the dynamic interactions between agents and the consequences on each individual agent and thus the impact on the overall system performance (Perez-Mujica et al., 2014).

Table 4.1: Multi-Agent based software tools

Software tool	Source code	Type of agent based in its interaction behaviour	Coding language / application programming interface	Compiler operating system	Model development effort	Modelling strength/ scalability level	Application domain
AnyLogic	Java	Agents/ objects implemented as Java classes	Java; UML (unified modelling language) for real time User-friendly graphical environment for visual model development	Java runtime Environment Windows Mac OS X, Linux	Moderate	High/Large-scale	Manufacturing, business strategy and innovation analysis, transportation, healthcare, social sciences, economics, urban dynamics, supply chains, computer networks, logistics, warehousing, power grids, complex adaptive dynamic/ discrete event systems

FlexSim	Microsoft.NET framework Open GL	Agents/objects implemented as C++ classes	FlexSim's library of standard customizable objects available Drag and drop model building, intuitive controls and dynamically display of outputs statistics as charts and graphs	Microsoft.NET compiler Windows	Simple/Easy	Small-scale Medium-scale	Manufacturing, production, distribution of logistics, supply chains, transportation, oil field or mining process, networking data flow, healthcare, optimization (with optQuest)
NetLogo	Scala code compilation to Java byte-code	Active objects with simple goals implemented as mobile agents	Models library available NetLogo language	Any Java virtual machine with version 5 or later Windows, Mac OS X, Linux, Unix	Simple/Easy	Medium scale Large scale	Simulations in social and natural sciences

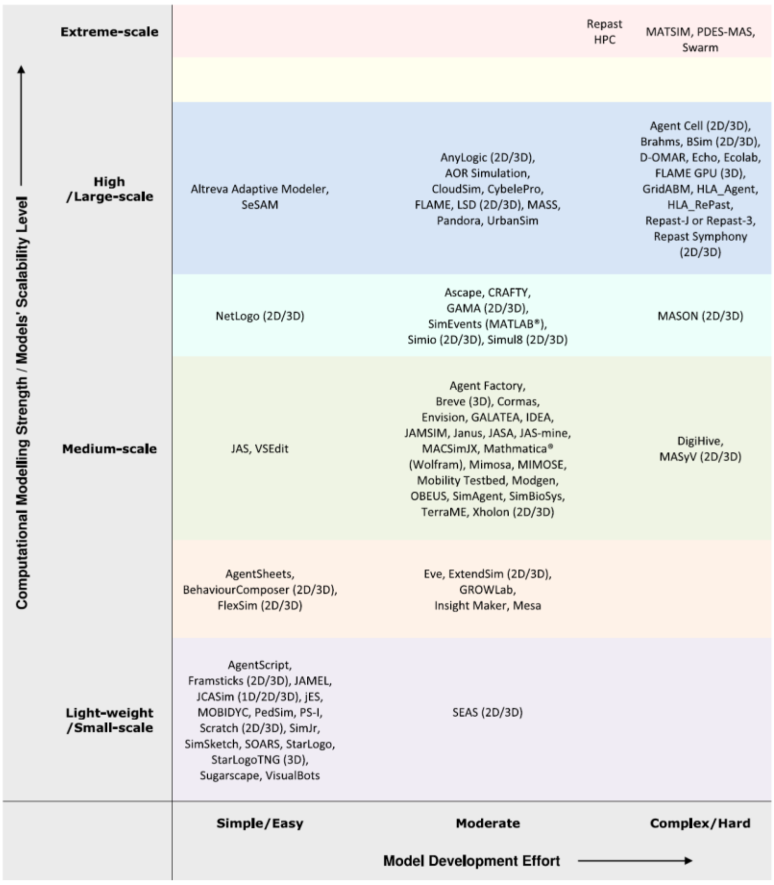
Simio	C#	Agents as objects characterized by properties, states and behaviours	Standard object libraries available Built in graphical programming environment	Windows	Moderate	Medium scale Large scale	Simulation in advanced predictive analysis, tourist flow, manufacturing, military solutions, production, scheduling, transportation, logistics, supply chain, mining industry, healthcare, maritime/ports, airfreight services, optimization with OptQuest

Simul8	Visual logic code	Agents as physical, logical or activity-based objects	Sample templates and libraries of interactive models available Coding: Visual logic Intuitive drag and drop interface	Windows, Mac OS X, Linux	Moderate	Medium scale Large scale	Simulations in educations, healthcare, manufacturing, logistics, contact centre or client-based services, supply chains, capacity planning, administrative workflows, optimization with OpQuest

Although all these software packages (Table 4.1) are capable of simulating container terminal operations, each of them does in a different way, depending on the code source, the modelling development effort, the type of agents being simulated, etc.

4.2.2.4 AnyLogic Simulation Tool

In this thesis work the simulation tool used as support was AnyLogic ("AnyLogic," 2021) , the choice of this software is the flexibility in the simulation of logistics flow, the interface 2D/3D that make more compressive the model representation, the possibility to simulate the dynamic and discrete event systems being an ideal approach for the simulation of the terminal operations, and as show the figure 4.4 the effort to modelling in AnyLogic it's moderate with a high/large-Scale to computational modelling, these features make AnyLogic a user friendly software suitable for complex simulations such as a container terminal.



Computational Modelling Strength / Models' Scalability Level	Simple/Easy	Moderate	Complex/Hard
Extreme-scale			Repast HPC MATSIM, PDES-MAS, Swarm
High /Large-scale	Altreva Adaptive Modeler, SeSAM	AnyLogic (2D/3D), AOR Simulation, CloudSim, CybelePro, FLAME, LSD (2D/3D), MASS, Pandora, UrbanSim	Agent Cell (2D/3D), Brahms, BSim (2D/3D), D-OMAR, Echo, Ecolab, FLAME GPU (3D), GridABM, HLA_Agent, HLA_RePast, Repast-J or Repast-3, Repast Symphony (2D/3D)
	NetLogo (2D/3D)	Ascape, CRAFTY, GAMA (2D/3D), SimEvents (MATLAB®), Simio (2D/3D), Simul8 (2D/3D)	MASON (2D/3D)
Medium-scale	JAS, VSEdit	Agent Factory, Breve (3D), Cormas, Envision, GALATEA, IDEA, JAMSIM, Janus, JASA, JAS-mine, MACSimJX, Mathmatica® (Wolfram), Mimosa, MIMOSE, Mobility Testbed, Modgen, OBEUS, SimAgent, SimBioSys, TerraME, Xholon (2D/3D)	DigiHive, MASyV (2D/3D)
	AgentSheets, BehaviourComposer (2D/3D), FlexSim (2D/3D)	Eve, ExtendSim (2D/3D), GROWLab, Insight Maker, Mesa	
Light-weight /Small-scale	AgentScript, Framsticks (2D/3D), JAMEL, JCASim (1D/2D/3D), jES, MOBIDYC, PedSim, PS-I, Scratch (2D/3D), SimJr, SimSketch, SOARS, StarLogo, StarLogoTNG (3D), Sugarscape, VisualBots	SEAS (2D/3D)	

Figure 4.4: Modelling levels (Source: ("AnyLogic," 2021)

AnyLogic it is a multi-method programming simulation tool developed by AnyLogic company (before XJ Technologies).
At the beginning of the 1990s was a great interest by the mathematic approach to modelling and simulation of the parallel process. The Distributed Computer Network (DCN) research group at the Saint-Petersburg Technical University has developed such software system called COVERS (Concurrent Verification and Simulation), where this system allowed graphical modelling notation to be used for describing system structure and behaviour. At 1998s the DCN founded a new society with aim to develop a new generation tool. The greatest emphasis in development was placed on the application of quantitative methods of simulation, performance analysis, stochastic behaviour, and optimisation. The new software, released in 2000, encapsulated the state of the art in computer science: an object-oriented programming approach, elements of the UML standard, the use of Java, a modern graphic interface, etc.

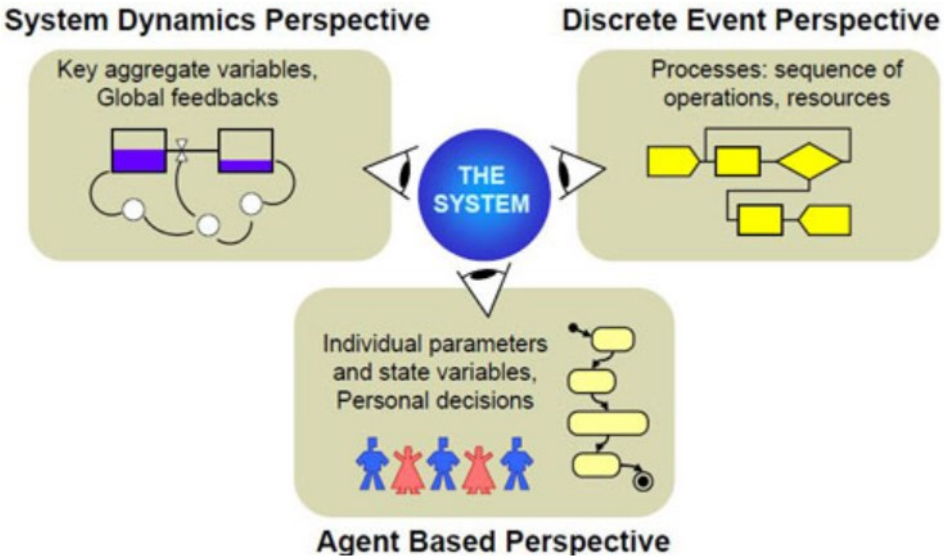


Figure 4.5: Simulation approaches supported by AnyLogic. (Source:(“AnyLogic,” 2021)*)*

The tool was named AnyLogic, due to its ability to support well-known modelling approaches, as well as any combination of these (figure 4.5):

- Oriented to the activity, System Dynamics;
- Oriented to the process, Process-Centric (Discrete Event Simulation);
- Oriented to the agents, Agent Based Modelling.

Then has been a great success with AnyLogic 5, that was focused on the business simulation in different industries:

- Market and competition,
- Health,
- Production,
- Supply Chain,
- Logistics,
- Retail,
- Business processes,
- Social and ecosystem dynamics,
- Defence,
- Project and Asset Management,
- Infrastructure IT,
- Pedestrian dynamics and traffic simulation,
- Aerospace,
- Photovoltaics.

AnyLogic includes a graphical modelling language and allows the user to extend simulation models with Java code, thus it is possible to custom model extensions trough Java code, as well as the creation of Java applets that can be opened with any standard browser. These applets make AnyLogic models, very easy to share or put on websites. These pure Java applications can be a basis for the decision support tool.

AnyLogic models can be based on any simulation modelling paradigms: Discrete Event or Process-Centric (DE), System Dynamics (SD), and Agent-Based (AB).

System Dynamics and Discrete Event are traditional simulation approaches, whereas Agent-Based is a new one. The System Dynamics approach deals mainly with continuous processes, whereas Discrete Event and Agent-Based models work mainly with discrete times, for example the transition from one event to another.

Traditionally, System Dynamics and Discrete Event simulations have been teaching at universities to very different groups of students, such as management, industrial and operations research engineers. As a result, there are two distinct communities of professionals who never talk to each other.

Agent-based modelling has been a purely academic topic. However, the growing demand for optimisation in the global marketplace has led modellers to study combined approaches to gain a knowledge about

System Dynamics, which deals with aggregates, used at the highest level of abstraction. Discrete event modelling is used at low to medium abstraction levels. As with Agent-Based modelling, this technology is used at all levels of abstraction, and the agent may model objects of different nature and scale: at the physical level agents can be, for example, pedestrians, cars, or robots, at the medium level - customers, at the highest level (figure 4.6).

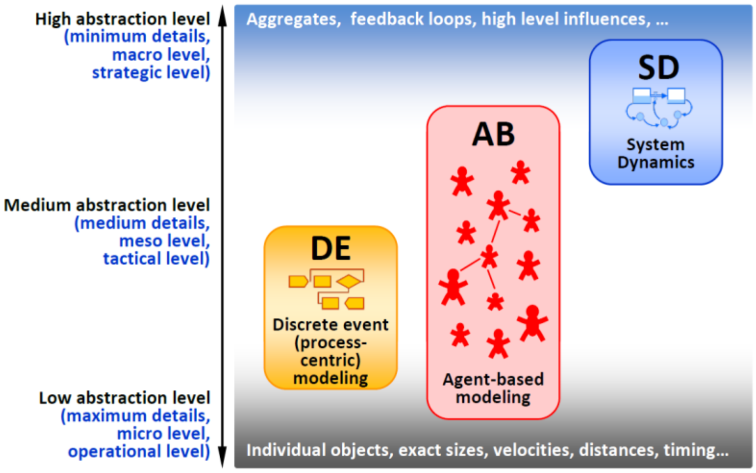


Figure 4.6: Abstraction level in different kind of approaches (Source: ("AnyLogic," 2021)*)*

AnyLogic allows the modeller to combine these simulation approaches within the same model. Thus, for example, one could create a model of a package shipping system in which carriers are modelled as agents acting/reacting independently, while the internal workings of their transport networks and infrastructure can be modelled with Discrete Event simulation. Similarly, consumers can be modelled as agents whose aggregate behaviour feeds a System Dynamics model of capturing flows, such as revenues or costs that do not need to be linked to individual agents. This mixed language approach is directly applicable to a wide range of complex modelling problems, which can be modelled by any approach.

The AnyLogic simulation language consists of the following elements:

- Stock and flow diagrams that are used for System Dynamics modelling;
- State diagrams (statecharts) are mainly used in Agent-Based modelling to define agent behaviour. They are also often used in Discrete Event modelling, for example, to simulate the behaviour of different vehicles and equipment in the terminal container.
- Action diagrams are used to define algorithms. They can be used in Discrete Event modelling, for example, for call routing, or in Agent-Based modelling, for example, for agent decision logic;
- Process flow diagrams are the basic construction used to define a Discrete Event modelling process. Looking at this flowchart you can see why the Discrete Event style is often called Process-Centric.

The language also includes low-level modelling constructs (variables, equations, parameters, events, etc.), presentation forms (lines, polylines, ellipses, etc.), analysis structures (datasets, histograms, plots), connectivity tools, standard images, and the structure of experiments.

Includes the following standard libraries:

The Process Library: designed to support Discret Event simulation in the areas of Manufacturing, Supply Chain, Logistics and Healthcare. Using the objects of the Enterprise Library it is possible to model real systems in terms of entities (operations, customers, products, parts, vehicles, etc.), processes (sequences of operations typically involving queues, delays, resource usage), and resources. Processes are represented through flow diagrams.

The Pedestrian Library: dedicated to simulating pedestrian flows in a physical environment. It allows the creation of models with high pedestrian traffic (such as underground stations, security checkpoints, etc.) or roads. The models support a collection of statistics on pedestrian density in different areas. This ensures acceptable performance of service points with a hypothetical load (of people), estimates the length of stay in specific areas, and detects potential problems caused by internal geometry, such as the effect of adding too many obstacles, and other applications. In models created with the Pedestrian Library, pedestrians move in a continuous space, reacting to different types of obstacles (walls, various areas), as well as to other pedestrians. Pedestrians are simulated as interacting actors with complex behaviour, but AnyLogic's Pedestrian Library provides a high-level interface for the rapid creation of pedestrian models through flow diagrams.

The Rail Yard Library: supports modelling, simulation and visualisation of a railway yard of any complexity and size. Rail yard models can be combined with Discrete Event and Agent-Based modelling related to: loading and unloading, resource allocation, maintenance, market processes, and other transport activities.

The Fluid Library: allows the user to model storage and transfer of fluids, bulk freights, or large amounts of discrete items, which are not desirable to model as separate objects. The library includes blocks such as tank, pipeline, valve, and objects for routing, merging, and diverging the flow. To improve model execution speed, the Fluid Library uses a linear programming solver. The library is designed to improve AnyLogic use in manufacturing, oil, gas, and mining industries. The user can simulate oil pipes and tanks, ore, coal conveyors, and production processes where liquids or bulk materials are involved, for example, in concrete manufacturing.

The Road Traffic Library: allows users to simulate vehicle traffic on roads. The library supports detailed, physical level modelling of vehicle movement. Each vehicle represents an agent that can have its own behavioural patterns inside. The library allows users to simulate vehicle movement on roads, taking into account driving regulations, traffic lights, pedestrian crossings, priorities at junctions, parking lots, and public transport movements. The library is suitable for modelling highway traffic, street traffic, on-site transportation at manufacturing sites, or any other systems with vehicles, roads, and lanes. A special traffic density tool is included to help analyse road network loads.

The Material Handling Library: assists in process simulation in factories and warehouses. The library contains conveyors, transporters, and other elements simplifying the creation of detailed production models

Furthermore, to these standard libraries, users can create their own libraries and distribute them.

The graphical user interface, tools, and library objects provide quick access to model different areas such as manufacturing and logistics, business processes, human resources, consumer, and/or patient behaviour. The object-oriented design model paradigm supported by AnyLogic provides for modular, hierarchical, and incremental construction of large models.

The animation editor is a part of the model development environment. This editor supports a wide variety of graphic shapes, and controls for interface design (sliders, buttons, text input, etc.), as well as the import of images and CAD files as elements and backgrounds. Likewise includes a wide range of data analysis and professional graphics objects, such as bar charts, pie charts, time charts, and histograms. These are designed to make processes efficient and dynamically visualise data changes during simulation execution.

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5. Model Specification and validation

5.1 Introduction

Terminal container simulation models may rely on a wide variety of approaches. Among them Discrete event simulation (DES) models have been widely adopted for container terminal analysis (Cartenì and Luca, 2012), whilst the Multi-Agent (MAM) approach, which several agents interact among them to carry out a task oriented has not been much used. The (MAM) approach provides an interesting way for solving problems (Henesey, 2004). The agents are characterised as modular, decentralised, changeable, Ill-structured, and complex (Van Dyke Parunak et al., 1998), characteristics well identified in a container terminal management: Modular: Each decision maker and the resources employed in the terminal have their own set of state variables different among them; decentralised: A set of actors in a CT can be decomposed into autonomous processes, each of which is able to act without interference from the other actors/processes; changeable: a CT is subject to change, due to the permanent arrival of ships with different requirements and configurations. I-ll structured: It is not possible to obtain complete information on all CT management processes due the use of different systems at the same time, which are not connected to each other. Complex: A CT is seen as a complex system with many entities interacting and uncertainties. (Fajar et al., 2018) compares the DES and MAM with the aim to evaluate the performance in a container terminal, demonstrating that MAM can efficiently manage the communication process, whilst DES is unable to manage it. (Chargui et al., 2020)proposes a reactive MAM in which a simultaneous real-time rescheduling of activities in a container terminal is tested, demonstrating the stability of the logistics flow once a disturbance occurs. (Gerrits et al., 2018)presents the design and implementation of a scalable and flexible MAM to planning and control of automatic guides vehicles in container terminals, the results show an increase of the gross moves per hour and proves the efficiency (in terms of ships turnaround time) on different layout configurations.

Therefore, the DES models allow solving large size problems through discretization, MAMs allow to embed different behavioural logics, thus allowing to simulate complex and different technological contexts. Moreover, the combination of both the approaches, DES and MAM, makes it possible the simulation of a highly not-stationary systems with several interactions between handling means, trailers, human factors, etc.

Finally, both the modelling approaches usually guarantees a time efficient solution, solutions adaptive to changes in problems, and computational stability (Davidsson et al., 2007).

Based on the previous considerations and on what has been stated in chapter four, the development of the simulation model will be followed through these two types of approaches. In the present chapter, the specification of the model will be presented considering a real case study, and then the validation of the model according to environmental and functional criteria will be carried out.

The chapter is divided into four sections, the first one deal about the modelling framework carried out in the model specification, then, a brief introduction about the case study analysed is presented, after that the model specification is deeper defining the various functions inserted in the simulation model, and finally the model validation is presented specifying the functional and environmental validation.

5.2 Modelling Framework

In this thesis a hybrid DES and MA model was developed for the assessment of the global energy consumption and the emissions of a real container terminal.

Through the discrete event simulation, the system is represented in its evolution over time, with variables that instantaneously change their value at well-defined instants of time, these are those in which the events occur. The agent defined by agent-based modelling is an entity endowed with partial autonomy, intelligence and mobility that assesses its state and makes decisions according to a set of rules that define its behaviour within the simulation environment, and the multi-agent system is a set of these agents located in a certain environment and interacting with each other through an appropriate organisation. This results in a hybrid model that combines the advantages of both simulation methods.

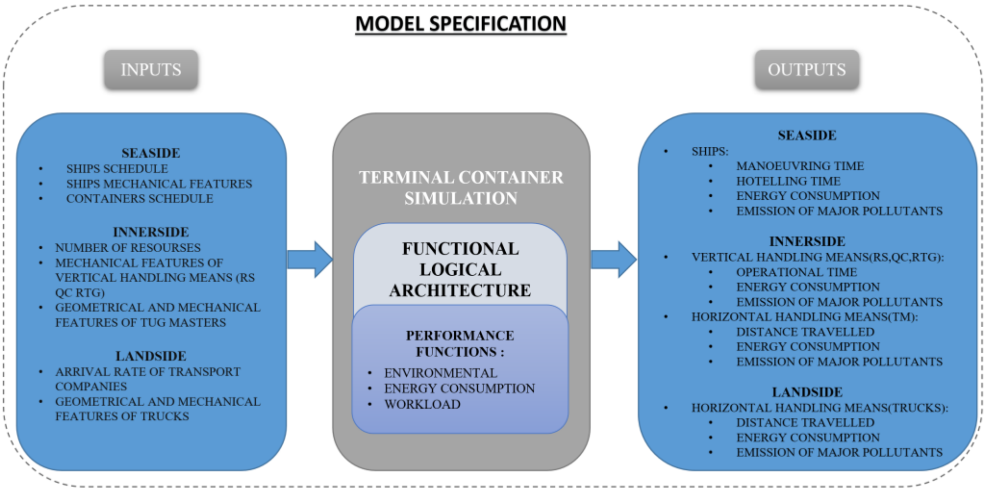


Figure 5.1: Model specification process

The methodological path to the specification model is presented in the figure 5.1, which requires the prior specification of the logic and functional architecture of the terminal, then the identification of the agents, finally the calibration of proper performance functions able to reproduce the activity time of each agent and the corresponding impacts, if any.

To this aim the Salerno CT was considered as case of study, which was divided into three different operational areas: seaside, innerside and landside, then logistic activities occurring in each area were identified and properly schematized in a graph model. Nodes represent all the possible activities involving container movements: physical (service nodes simulating handling activities, buffer nodes simulating buffer zones, where queuing may occur), conceptual (e.g. logical conditions) and mathematical (models that represent the movements time, waiting time, etc.). Links represent the connections between nodes and make it possible to identify the different sequence of activities that may be carried out to accomplish the specific logistic operation. Finally specific performance functions were associated to each node/activity.

In the following sections, the model's architecture is detailed.

5.3 Case Study

5.3.1 The port of Salerno

The port of Salerno, located in the gulf of the Tyrrhenian Sea and registered in the I class of the II category of maritime ports, the boundary extends from the municipality of Vietri sul Mare to “Molo 3 Gennaio” with a total of 24 berths. It is located in the northern part of the city, in a part of the territory between the urban area of Salerno (east), the Amalfi coast(west), and the territory of the Agro Nocerino Sarnese (north). It is one of the largest national ports and plays an important role in the industrial and commercial system of the centre-south of the country. The port is characterised by fast connections with a number of primary road infrastructures including the A3 motorway, the E841 Salerno-Avellino and with the secondary road network comprising of suburban and urban roads that ensure penetration movements towards the local network.

The port of Salerno is of artificial nature, and it is delimited by the “Molo di Ponente”, about 1100 metres long, to the south-west and the “Molo di Levante”, about 1500 metres long, to the east, which together delimit the area under the jurisdiction of the Port Authority. The commercial port is developed on three large quays: “Manfredi, “Roberto il Guiscardo” and “Guimario IV Quay”. The “Banchina Ligea” is intended for the fishing fleet (Figure 5.1). Ships access the port through a single entrance, about 70 metres wide and with a depth in the access channel of about 12 metres. There are 14 berths for ships, with depths at the quays ranging from 9 to 11 metres.

Port traffic in Salerno can be attributed to three main types (Figure 5.2):

- A) Various freights;
- B) Containers;
- C) Motor vehicles.

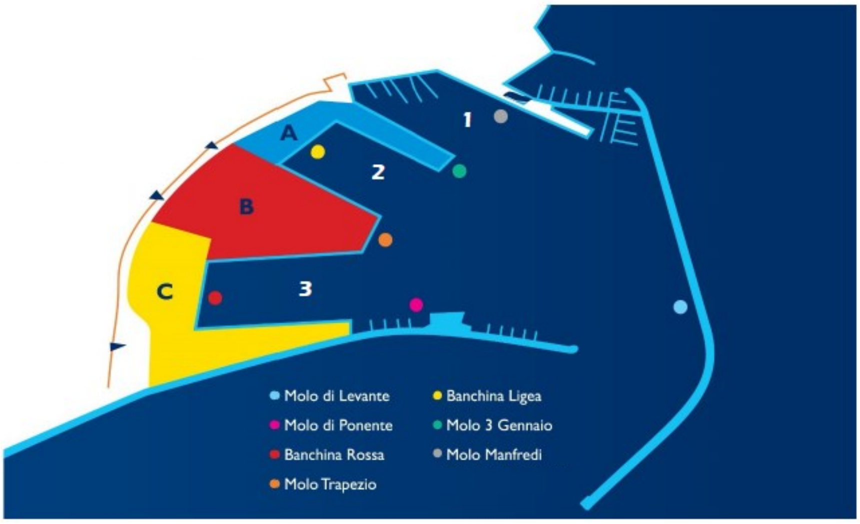


Figure 5.2: Piers of the port of Salerno (Source:("Home ~ ADSP Mar Tirreno Centrale," 2021))

<u>Ponente Pier (Molo di Ponente)</u>

It has a single approach face, with depths of up to 11.5 m and a high degree of manoeuvrability. As for the apron, it has an approximately triangular shape and is only adequately wide in the root part of the pier.

This pier is suitable for:

- Vehicles: requiring considerable storage areas and berths for RO-RO type ships.
- Various freights: of lesser spatial requirements, they require easy moorings, favoured by the good depth, and storage areas adjacent to the quay.

<u>Red Quay (Banchina Rossa)</u>

In this case there is only one berthing face. The Red Quay is suitable for mooring medium-sized ships. The yard, located along the quay and with a very regular shape, is particularly suitable for housing of vehicles.

<u>Trapezium Pier (Molo Trapezio)</u>

It has three approaches and good depths. The head berth can only accommodate medium-sized ships, while the others are long enough to berth large ships. The root berth on the western side of the pier faces the exotic fruit storage facility, which prevents the use of the berth for any other type of traffic due to its proximity to the sidewall. The existing harbour road system divides the pier into regular, wide, and deep storage yards. Those at the root of the pier do not have direct access to the quayside. Due to the characteristics described above, the Trapezium Pier is therefore suitable for handling containers. Indeed, containers require moorings adapted to large ships and large and close together handling and storage yards to allow efficient and safe use of the mechanical equipment necessary for terminal operators in this sector. In the Trapezium Pier there are also some structures able to repair the mechanical equipment and containers.

Ligea Quay (Banchina Ligea)

A quay with a single approach face and smaller draughts, which, added to its overall length of 250 m, limits the two moorings present to the accommodation of medium-sized ships. As for the storage area, this is subdivided into regular, practically rectangular squares for the storage of various freights and, to a lesser extent, motor vehicles.

Pier 3 January (Molo 3 Gennaio)

It has a main approach front, with moorings characterised by good depths and relative ease of manoeuvre. This berth is not affected by commercial moorings and is assigned to the fishing fleet. The long, narrow storage yard has a modest planimetric extension and the head area is connected to the opening at the root of the Trapezium pier by a short route with no intersections. These characteristics make Pier 3 January suitable for general cargo traffic, except for the head area which supports the traffic of the "Motorways of the Sea".

There are three access points to the commercial area:

- At the root of the western pier, at the roundabout at the base of the Via Gatto viaduct;
- At the root of the Trapezium pier, with access onto Via Ligea;
- At the root of the three January pier, with access onto Via Porto.

The only gate currently open to vehicles is the one at the root of the western pier. The access road to Molo Manfredi is located at the end of the road of the same name. The port of Salerno ranks 7th in terms of container handling, behind Gioia Tauro, Genoa, La Spezia, Taranto, Livorno and Cagliari. As mentioned above, its activity is not limited to the transport of containers, as some quays are also suitable for the transport of vehicles and various freights.

On 20 December 2004, the port committee of Salerno approved a plan to change the current use of the wharves and quays, inspired by the organisation of the airport terminals. This plan excludes the Manfredi pier, which will be used for cruise traffic. In particular, the port has been divided into three terminals (Figure 5.3) A, B and C:.

- Terminal A: corresponding to the Ponente pier and the Rossa Quay, it will be used exclusively for rolling stock and motorways of the sea. In particular, for the motorways of the sea there will be a 300 m2 ferry terminal and a 4,415 m2 area at the end of the western pier. All the rest of area A is intended for the handling of cars, for which it is planned to build a driveway deck on the red quay of 27,075 m2. in essence, a raised deck will be built to accommodate cars destined for export.

- Terminal B: this corresponds to the Trapezium pier and, with the exception of a 16,325 m2 area for refrigerated miscellaneous freights, is intended for container traffic. Terminal B, which has three quays (head, west and east), covers an area of 114,855 m2.
- Terminal C: corresponding to the Ligea quay and quay 3 January, will be used for miscellaneous freights, whose activities will have a total area of 35,550 m2. Along the perimeter of the Ligea quay there will be an area of 1,380 m2 for a building intended for services, a buffer area for the building and for the access road and car park (680 m2), a car park and an area intended for services (1,550 m2), two parking areas for semi-trailers (2,095 m2) and an area intended for a company (3,110 m2). On quay 3 January, there will also be an area for fishing boats (1,610 m2) and an area for an incinerator and waste collection (1,300 m2), activities which are currently carried out on the Manfredi quay. Finally, the General Warehouses are also to be relocated to the Ligea quay, in order to free up the Manfredi for cruise traffic.

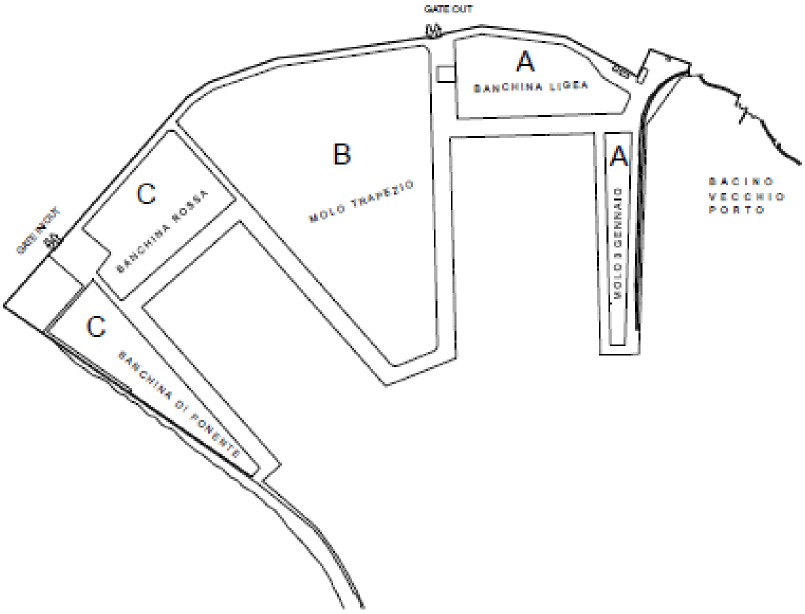


Figure 5.3: Overview of the three terminals in the port of Salerno (Source:(“Home ~ ADSP Mar Tirreno Centrale,” 2021)

5.3.2 Salerno Container Terminal

In this thesis the Salerno Container Terminal (SCT) is analysed, it’s located in the port of Salerno. SCT is one of the companies that make up the Gallozzi Group, which has been active in the maritime transport sector for over 60 years and has its headquarters in the city of Salerno.

The Gallozzi Group company was founded in 1952 by Sir Giuseppe Gallozzi, M.B.E. (Member of British Empire), with the intention of offering booking and management services for the transport of freight from the port of Salerno to customers located in central and southern Italy.

The company has evolved over the years from a small local agency to a consolidated group of over 25 companies, handling shipping, forwarding, logistics and terminal activities, with offices in Salerno, Shanghai, London and the United States.

In 1991 Salerno Container Terminal was founded as an equal joint venture between the Gallozzi Group and ContshipItalia to develop a private and independent terminal in the south of Italy to meet the strong growth in demand for transport by sea from local industries.

In 1994 the Gallozzi group took over 35% of the shares owned by ContshipItalia, becoming the majority shareholder of S.C.T. with about 85% of the shares.
Over the years the terminal has built a strong reputation for its efficiency, reliability and customer care. The terminal guarantees everyone docking on arrival of the ship, high productivity and performance indices, and sailing schedules that are always respected and in line with the requirements of the shipping companies.
In July 2010, in Lisbon, the port of Salerno was named the best European port for cargo and passenger handling in relation to available space. Furthermore, the European Commission expressed its appreciation for the security level of the port of Salerno and selected it as the only port in Italy for a continental conference on port security and to present its Port Security Plan. The port of Salerno was also chosen, along with 13 other Italian port authorities, to participate in the Shanghai Expo 2010 with a multimedia stand set up by Assoporti, the Association of Italian Ports.
It should also be pointed out that for years the port has taken part in Cruise Shipping Miami with its own exhibition space. In 2013, it was included among the 319 European ports considered key by the EU.
In the last 20 years, the Port of Salerno has consolidated its position as a regional port in Italy as well as in Mediterranean area, increasing in 40% (before the pandemic period) its volume of containerized handled (Figure 5.4).

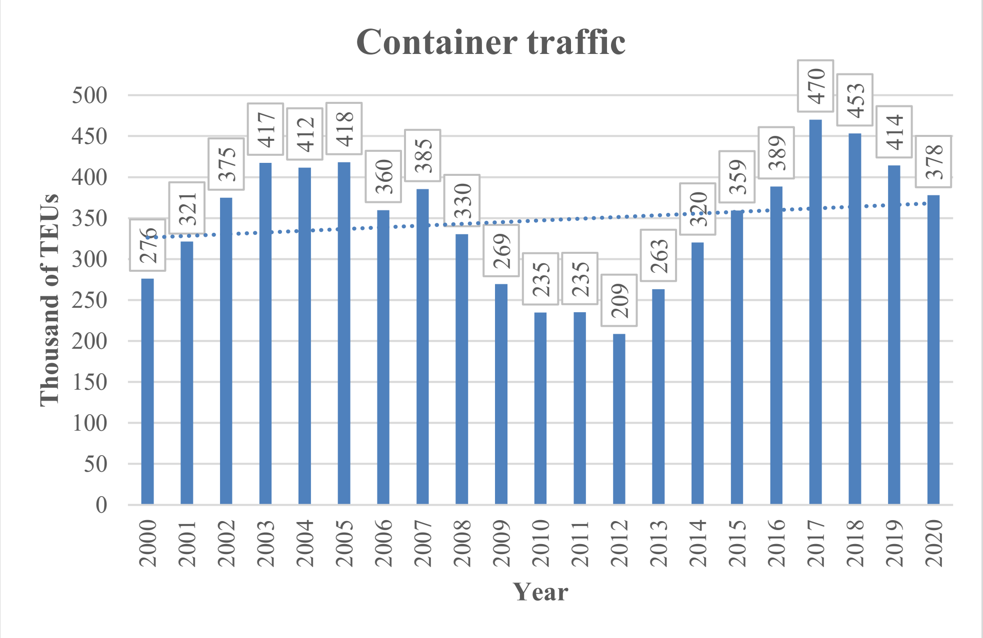


Figure 5.4: Container traffic in the Port of Salerno

For most freights transported to and from central and southern Italy, the port of Salerno is the best solution in terms of proximity to markets and service times.

Recently, major quay consolidation and dredging works have been carried out to allow ships with a high draught to access the port, including ships over 300 metres.

At present, the quays available to the terminal are:

- East side: 380 m.
- Western side: 380 m.
- South side: 130 m.

5.3.2.1 Terminal description

SCT is a major private CT operator in southern Italy (Figure 5.5) and is both small and very efficient: The SCT set up is based in two quays of 380 m. and one of 140 m. the terminal handles close to 0.45 MTEUs per year in 11 ha (110,000 m2), which amounts to 41 kTEUs/ha. offering non-stop round the clock operations, 365 days per year. These figures should be compared with terminals such as HIT and COSCO-HIT in Hong Kong which handle 6.6 MTEUs in 122 ha (2008), or 54 kTEUs/ha, and Delta Terminal in the Netherlands which handles 2.5 MTEUs or 9 kTEUs/ha (2008). In addition, the location of Salerno harbour does not allow the terminal area to be extended. Hence the chances of any improvement to keep pace with increasing demand will depend on operation management enhancements rather than an increase in land occupation.

The area under concession for the conduct of terminal activities is the so-called "Trapezium Pier". This name was given on the basis of its geometric shape. The Trapezium pier has three berthing fronts and good water depths. The head berth can only accommodate medium-sized ships, while the others are long enough to berth large ships. The root berth on the western side of the pier is opposite the exotic fruit storage facility.

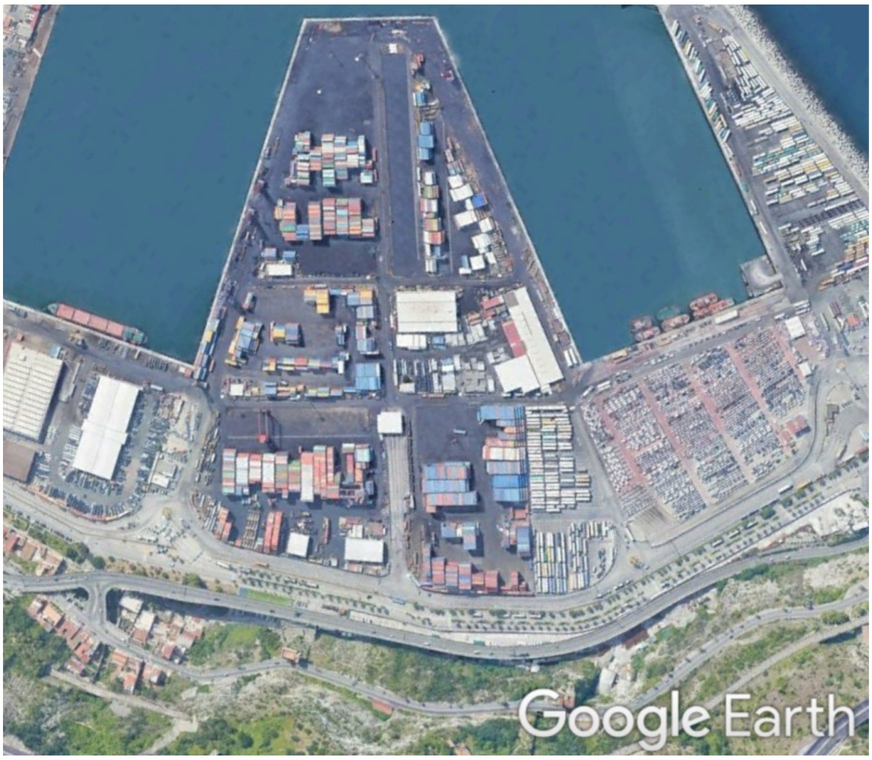


Figure 5.5: Salerno Container Terminal (Source: ("Google Earth," 2021))

Inside the terminal, several zones are identified, each with a precise and predefined purpose and identified graphically with different colours (Figure 5.6).

The entrance to the terminal is represented by the area where entry operations take place.

The Levante zone (upper left side) is for export traffic only (blue and pink). On the other hand, the Ponente zone (upper right side) is destined both for export and import traffic (blue), just like the Ponente zone.

The pink buffers are used to store containers belonging to the export cycle that are temporarily in custody awaiting transfer to the export area to be loaded onto ships. The green colour represents the storage place for REEFER containers where the freight needs a certain temperature to be kept in good condition. Behind the trapezium pier, in an area close to the gate operations area, there are two storage areas for empty containers (light blue colour) and for full containers coming from the import cycle (blue colour). The containers stored are subdivided according to the company they belong to.

Figure 5.6: Terminal layout

5.3.2.2 Terminal Activities and handling equipment

The main activity of the terminal includes port operations, loading, unloading, transhipment, storage, movement of freights and any other material carried out within the port.

In order to carry out its activities, the terminal receives a concession from the port authority for areas within the port of Salerno, as provided for in Article 18 of Law 84/1994: "The port authority and, where not established, or before its establishment, the port organisation or the maritime authority grant concessions for state-owned areas and quays within the port area to the companies referred to in Article 16, paragraph 3, for the performance of port operations, without prejudice to the use of buildings by public administrations for the performance of functions relating to maritime and port activities".

That is, the execution of the activities in all the different phases of the handling of freights both in the cycle of unloading/import and in the cycle of loading/export. Reference could be made to all the other activities that are carried out in parallel to these activities to ensure the completion of the previous ones. For example, deliveries of complete exports, complete imports and unloading for subsequent exports, completion of customs documentation and a port call service linked to the storage of containers within the port of Salerno.

The yard operations management organises the best possible layout of containers in the areas under concession for container storage and works in close coordination with the ship operations management, before, during and after container loading and unloading operations. Within the yards, the management supervises with yard inspectors, since it is important to distinguish between the two main activities that take place in the storage areas of freights in the port: the export cycle and the import cycle. The mechanical vehicle repair and maintenance workshop plans its work by timing the stop of mechanical vehicles for ordinary maintenance and periodic checks on the correct functioning of mechanical parts and work safety and protection devices. It also intervenes directly in cases of breakdowns that can be resolved in real time. The refrigerated container management department regularly checks that the variable value settings of the refrigerated container correspond to the company's customer requirements. It is also in charge of managing problems relating to the services connected with this activity.

The activities are linked to two major operation cycles which are planned for the completion of the activities to be analysed. The ship cycle which includes all activities related to the loading and unloading of containers from and to the ship, also there is the truck cycle which carries out all activities of the truck for the delivery of unloaded containers and the reception of containers for future loading.

The SCT can be divided into three subsystems: enter/exit port gates (landside), container yards (innerside), and berths (seaside) as show the Figure 5.7. Container handling equipment comprises storage cranes (GC) or RTG, loading/unloading cranes MHC), and reach stackers (RS).

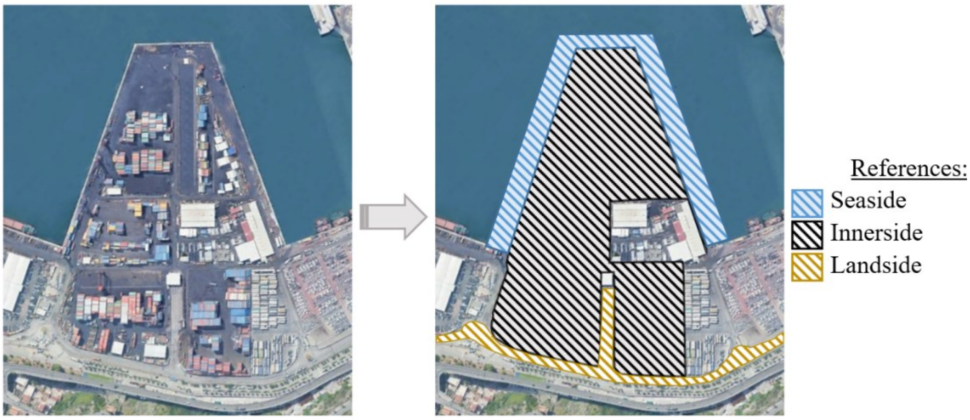


Figure 5.7: Container terminal layout and its operational areas (Source: own elaboration based on(“Google Earth,” 2021)*)*

Mobile harbour cranes (MHCs)

The MHCs operating in the SCT are three Gottwald HMK 260 and three Liebherr LHM 550 which work on internal combustion and are mounted on rubber-tyres (Figure 5.8); these are particularly popular in ports and terminals frequented by feeders and other ships. In particular, the Liebherr cranes are post panamax and able to handle ships up to 17 containers across at 30 t. and/or 18 containers at 25 t. This equipment is also suitable for twin-lift (2 × 20′ full) containers cargo. MHC activities are mainly devoted to loading/unloading containers to/from berthed ships and loading/unloading container to/from tug masters.

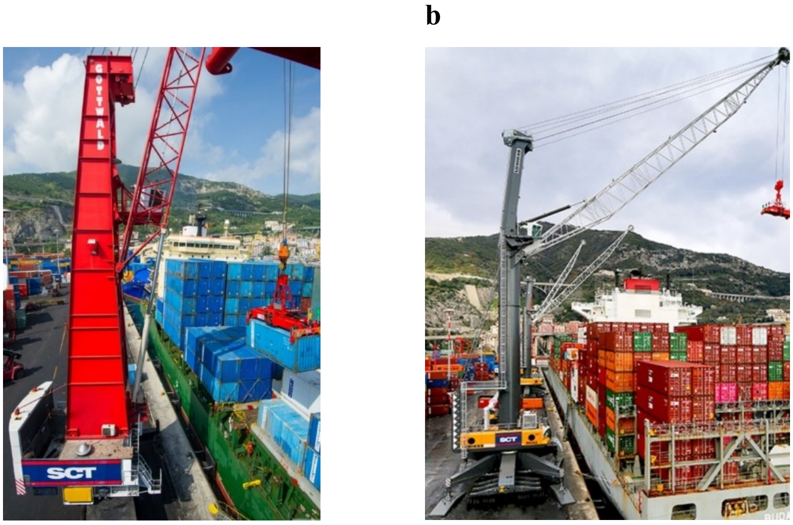


Figure 5.8: (a) Gottwald HMK260. (b) LiebherrLHM 550 Mobile Harbour Crane

Gantry Cranes (GCs)

The GCs operating in the SCT are 2 rubber-tyred gantry cranes (RTG) (Figure 5.9) used both for movement/storage of containers and for loading of tug masters/trucks, specifically are Fantuzzi Reggiane Noell model that work on internal combustion. This crane type usually consists of three separate movements for container transportation. The first movement is performed by the hoist, which raises and lowers the container. The second is the trolley gear, which allows the hoist to be positioned directly above the container for placement. The third is the gantry, which allows the entire crane to be moved along the working area.

Figure 5.9: Rubber Tyred Gantry Crane

Reach stackers (RSs)

Ten RSs operate in the Salerno Container Terminal distributed in various models to internal combustion, Ferrari and Liebherr (Figure 5.10), equipped with a twin-lift spreader able to move two full 20′ containers. They are used both to transport containers very quickly over short distances and to pile/stow them in various rows.

Figure 5.10: Reach Stackers

The basic activities occur simultaneously and interactively and can be grouped into four main operations: receiving (gate–yard), delivery (yard–gate), loading (yard–berth) and unloading (berth–yard).

Planning of the SCT includes berth planning, yard planning, storage planning and logistics planning. Berth planning controls container loading and unloading. Yard planning optimally allocates storage areas for import, export, and eventually transhipment containers. Storage planning assigns storage locations to the containers in the ships bay. Logistics planning assigns and coordinates the operations of container handling equipment such as quay cranes (QC), gantry cranes (RTG), and yard tractors (TM) for transferring containers between ships bay and the container yard.

Three different macro-activities are carried out in SCT: import, export, and transhipment.

In export operations, containers enter at CT from the landside through the road network and, after gate-in activities, are stacked in the export yard, where they wait for their turn to be loaded on the corresponding ship. Each container may be loaded directly or with a buffer area. In the other case, containers can reach the corresponding berth on a RS or on a TM. In the latter case, containers are stacked in a specific area and moved to the berths through RS. Once they have arrived at the berth, containers are directly loaded onto the ship, if on the TM, or left on the dock, if on RS, and subsequently loaded on the ship.

In import operations, containers are unloaded on the berth and moved towards the import yard, if full, or towards the empty yard, if empty containers. Empty containers are loaded to TM through RS and are stacked in the empty yard through RS. Full containers may reach the import yard through RS or through TM and they are stacked with a RTG. Once stacked, full containers may pass through customer activities or just wait to leave the terminal. Containers can leave the terminal by rail or road; in the other case they are transferred onto railway cars and leave the terminal after the train has been composed; in the latter case they are directly displaced on trucks and leave the terminal immediately.

In transhipment operations (unusual in the CT analysed), containers are unloaded on the berth and can be directly loaded on a ship or moved towards a specific buffer area. In both situations reach stackers, TM or a combination can be used.

5.4 Model Specification

Seaside: Model architecture

The seaside area includes all the activities that are carried out inside of container terminal, with the aim of handling of containers from the ships that has arrived at the port. The agents involved in this area are the ships that should be loaded and unloaded by the quay cranes. For each agent, the inputs and the output variables are reported in Table 5.1, whilst Figures 5.11 and 5.12 schematizes the logic architecture in this area.

Table 5.1: Agents, inputs, and outputs for seaside area.

Agents	Inputs	Outputs
Ships	-Arrival time -Speed in the manoeuvring phase -Main and auxiliary power engines (EP) -Load factor (manoeuvring/hoteling phase) (LF) -Engine's emission factors (EF) -Containers to handling	-Manoeuvring time (t_{man}) -Hotelling time (t_{hot}) -Energy consumption (EN) -Emissions of the major pollutants (EM)

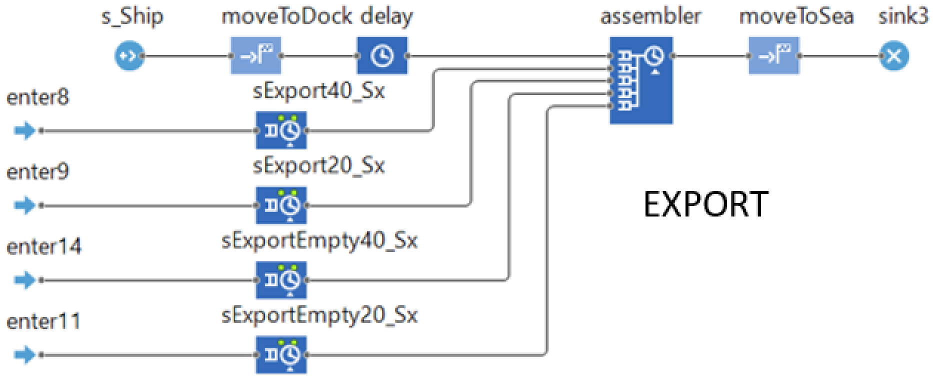


Figure 5.11: Seaside area. Export logical architecture.

With respect to Figure 5.11, it is possible to identify the following functions that represents the **export cycle** in this operational area:

- **s_Ship:** generates the ships arrival. Which are set by a schedule, since the terminal operator knows in advance the ships arrival and their loads;
- **moveToDock:** moves the ship from harbour entrance to mooring point in the dock. Once provided the origin and destination points of each ship, an average speed of 1 knot is set, which has been estimated on experimental data;
- **delay:** keeps the ship docked until all loading/unloading operations are completed. Clearly, the delay's time will be subject to the loading/unloading activities of the quay cranes. The unloading operations (import) are described in the next paragraph (see Figure 5.12);
- **enter8, enter9, enter14 and enter11:** simulates the entrance of export containers from the terminal's yard, each enter block represents one container kind: 40' full, 40' empty, 20'full and 20'empty;
- **sExport40_Sx, sExport20_Sx:** performs the load operation time of containers 40' full and 20' full by the quay cranes from the dock onto the ship, this time is simulated through a stochastic performance function specifically calibrated on the case study, which a gamma distributions function was adopted for each type of container: 40'full and 20'full;
- **sExportEmpty40_Sx, sExportEmpty20_Sx:** performs the load operation time of containers 40' empty and 20' empty by the quay cranes from the dock onto ship, as in the previous case this time is simulated by a stochastic performance function specifically calibrated on the case study, which a gamma distributions function was adopted for each type of container: 40'empty and 20'empty;
- **assembler:** represents the deck of the ship, which the containers are grouped in this buffer until all loading operations are completed;
- **moveToSea:** this function moves the ship to out the harbour with the same speed at which entered in it;
- **sink3:** this function is used to remove the ships from the model.

The **import cycle** (Figure 5.12) begins once the **delay** function (Figure 5.11) is called, and the following functions are implemented:

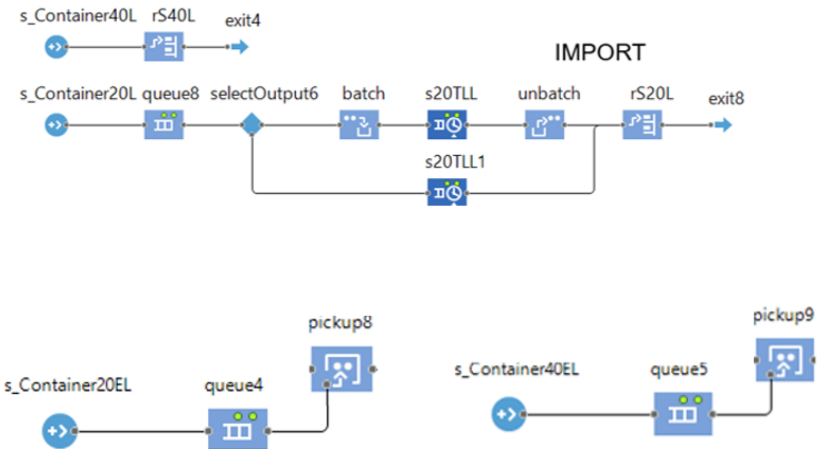


Figure 5.12: Seaside area. Import logical architecture.

- **s_Container40L:** represents the 40’ full containers (on the ship) that will be unloads from the ship. The number of these it’s knows in advance by the terminal operator;
- **rS40L:** performs the unload operation time of containers 40’ full by the quay cranes from the ship onto the dock, this time is simulated through a stochastic performance function specifically calibrated on the case study, which a gamma distributions function was adopted;
- **exit4:** represents the container placed on the quay waiting to be loaded onto a tug master by a reach stacker;
- **s_Container20L:** represents the 20’ full containers (on the ship) that will be unloads from the ship. The number of these is knows in advance by the terminal operator;
- **queue8:** it is a "virtual" FIFO (First In - First Out) queue in which containers are grouped before to be unloaded;
- **SelectOuput6:** selector configured to differentiate the unloading 20' full containers that can be unloaded one at time (bottom exit), or two containers at the same time (top exit);
- **batch, unbatch:** represents the crane spreader that takes 2 containers at the same time (**batch**) and releases these in contemporaneous (**unbatch**);
- **s20TLL, s20TLL1:** performs the unload operation time of containers 20’ full, both the single container (**s20TLL1**) that two containers in contemporaneous (**s20TLL**) by the quay cranes from the ship onto the dock, this time is simulated through a stochastic performance function specifically calibrated on the case study, in which a gamma distributions function was

adopted for each type of unload operations;

- **rs20L:** puts the containers on the dock;
- **exit8:** represents the container on the quay, attending to be loaded onto a tug master by a reach stacker;
- **s_Container40EL, s_Container20EL:** represents the 20' and 40' empty containers that will be unloads from the ship. The number of these is knows in advance by the terminal operator;
- **queue4, queue5:** it's a "virtual" queue of type FIFO (First In – First Out) queue in which containers are grouped before to be unloaded;
- **pickup8, pickup9:** simulates the containers moving from the ship onto the tug masters by quay cranes.

Innerside: Model architecture

The innerside area is divided in different zones, each one composed by a block of containers usually placed in six lanes and stacked in four or five tiers. This area serves as a temporary buffer for inbound and outbound containers.

The outbound containers (export) arrive at the port by road, after gate-in activities they are assigned to a specific stocking area in the yard. Once arrived, the reach stackers and yard cranes move the containers to the final (but temporary) position in the yard stacks.

The inbound containers (import) are unloaded from the ship onto tug masters and moved to the designated storage area block, where reach stackers place them in the final position.

Generally, the yard operations take place within the 24 hours of the day, hence, it is necessary to work permanently with the aim of locating the containers in the most convenient way in order to facilitate the loading and unloading operations. The agents involved in this area are the quay cranes, reach stackers, tug masters, and yard cranes. For each agent the inputs and the output variables are reported in Table 5.2, whilst the logic architecture is reported in Figure 5.13 and Figure 5.14.

Table 5.2: Agents, inputs, and outputs for inner-side area.

Agents	Inputs	Outputs
Reach Stackers	- Number of Reach Stackers - Movement time of each container type - Power engine (EP) - Emission factors (EF)	- Operational time (t) - Energy consumption (EN) - Emissions of the major pollutants (EM)
Quay Cranes/Mobile Harbour Cranes	- Number of Quay Cranes by Ship - Movement time of each container type - Power engine (EP) - Emission factors (EF)	- Operational time (t) - Energy consumption (EN) - Emissions of the major pollutants (EM)
Rubber Tyred/Gantry Cranes	- Number of Gantry Cranes - Movement time of each container type - Power engine (EP) - Emission factors (EF)	- Operational time (t) - Energy consumption (EN) - Emissions of the major pollutants (EM)
Tug Masters	- Number of Tug Masters - Geometrical and mechanical parameters - Emission factors (EF)	- Distance travelled (D) - Energy consumption (EN) - Emissions of the major pollutants (EM)

In the next figure, it is possible to identify functional blocks that represents the **import cycle** in innerside area. Inside the import cycle several operations have been identified, these are repeated two times, which the single diagram is broken down to distinguish in the upper part the process dedicated to full containers (20’, 40’) that are unloaded from the ship, and will be stored in the yard, whilst the lower one to empty containers (20’, 40’) that come from the sea-side and will be stored in the yard (Figure 5.13).

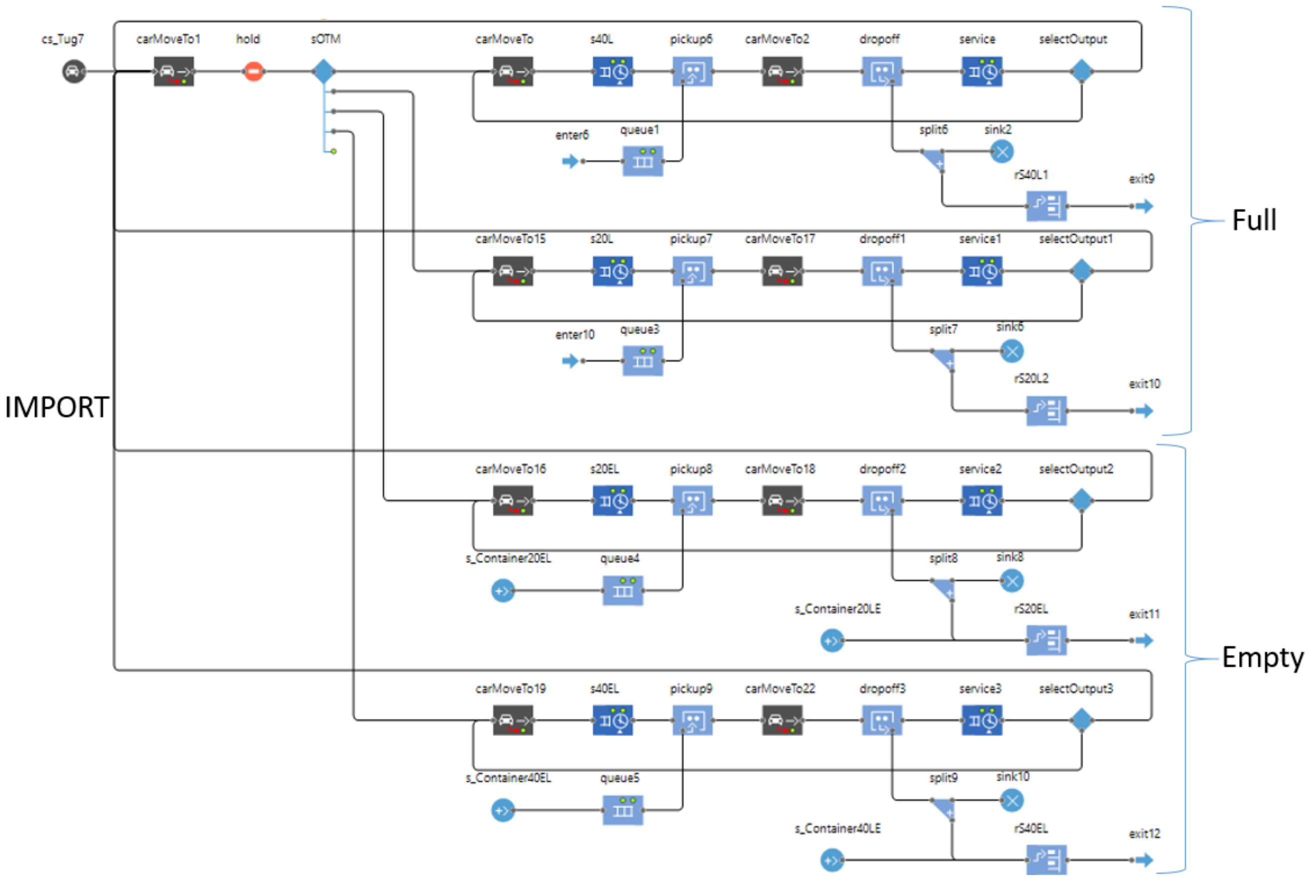


Figure 5.13: Inner-side area. Import logical architecture.

From a logical point of view, this cycle involves the following functions:

- **cs_Tug7:** which generates the tug masters as soon as the simulation starts, is necessary get few parameters as:
  - Average speed: 30 km/h
  - Acceleration: 1.8 m/s2
  - Deceleration: 4.2 m/s2
- **carMoveTo1:** moves the tug master to its parking point, located in a specific point in the terminal;
- **hold:** block that keeps the tug master parked at the parking point while there are no containers to transport; as soon as containers enter at the queue blocks the hold turns green and lets the tug master pass;
- **sOTM:** is a selector that assigns the output of the tug master to one of the 4 block outputs, representing 4 different operations depending on the type of container.

In the next paragraph the logical architecture for incoming containers it is presented, differentiating among full and empty containers (Figure 5.13):

Full containers logic diagram:

- **carMoveTo, carMoveTo15:** guides the tug master from the parking to the loading area (dock);
- **s40L, s20L:** used to modelling the waiting time with relative loading time used by the reach stacker for load the tug master, this time has been calibrated on the case study, which a gamma distributions function was adopted both for the 40’ full (**s40L**) than 20’full(**s20L**);
- **queue1, queue3:** represent the virtual queues, which the containers represented by **enter6**(40’full containers) and **enter10**(20’full containers) are waiting on the dock to be takes by a reach stacker;
- **pickup6, pickup7:** used to takes a container that comes from the virtual queues (**queue1/queue3**) and deposit these onto the tug masters. **pickup6** for 40’ full containers and **pickup7** for 20’ full containers;
- **carMoveTo2, carMoveTo17:** moves the loaded tug masters from the dock to their specific unloading point;
- **dropoff, dropoff1:** removes the container from the system and replace it with the new identical one generated by the **split6** and **split7** blocks;
- **service, service 1:** performs the unload operation time of containers 40’ full (**service**) and 20’ full (**service1**) by the reach stackers from the tug masters onto the yard stack, this time is simulated by a stochastic performance

function specifically calibrated on the case study, which a gamma distributions function was adopted for each type of container;

- **rS40L1, rS20L2:** pick-up the container from the tug masters using the reach stacker as resource, and places it in the import yard, as soon as the picking operation finishes the tug is free to leave the block;
- **exit9, exit10:** represents the container on the yard waiting for their recovery;
- **SelectOutput, SelectOutput1:** this function gives indications on the next tug master operation, if still there are containers to be picked up in the queues, it returns to the loading point near the dock and repeats the whole cycle, if there are no more containers, it returns to the parking and remains there until the hold block remains red.

Empty containers logic diagram:

- **carMoveTo16, carMoveTo19:** guides the tug master from the parking to the loading area (dock);
- **s20L, s40L:** used to modelling the waiting time with relative loading time used by quay cranes for load the tug master (Figure 5.13), this time has been calibrated on the case study, which a gamma distributions function was adopted both for the 20’ empty(**s20L**) than 40’empty(**s40L**);
- **queue4, queue5:** represent the virtual queues, which the containers (**s_Container20EL, s_Container40EL**) are attending on the dock to be takes by a reach stacker (Figure 5.12);
- **pickup8, pickup9:** takes a container that comes from the virtual queues (**queue4/queue5**) and deposit these on the tug masters. **pickup8** for 20’ empty containers and **pickup9** for 40’ empty containers;
- **carMoveTo18, carMoveTo22:** moves the loaded tug masters from the dock to their specific container unloading point;
- **dropoff2, dropoff3:** removes the container from the system and replace it with the new identical one generated by the **split6** and **split7** blocks;
- **service2, service 3:** performs the unload operation time of containers 20’ empty (**service2**) and 40’ empty (**service3**) by the reach stackers from the tug masters onto the yard stack, as in the previous case this time is simulated by a stochastic performance function specifically calibrated on the case study, in which a gamma distributions function was adopted for each type of container;
- **rS20EL, rS40EL:** pick-up the container from the tug masters using the reach stacker as resource, and places it in the import yard, as soon as the

picking operation finishes the tug is free to leave the block;

- **exit11, exit12:** represents the container on the yard waiting for their recovers;
- **SelectOutput2, SelectOutput3:** this function gives indications on the next tug master operation, if still there are containers to be picked up within the queues it returns to the loading point near the dock and repeats the whole cycle, if there are not more containers, it returns to the parking and remains there until the hold block remains red.

The **export cycle** in the innerside module is presented below (Figure 5.14), several operations have been identified, these are repeated two times, the upper part concerns to 20’ and 40’ empty containers that are loaded onto the ship, whilst the lower one to 20’ and 40’ full containers that are loaded onto the ship.

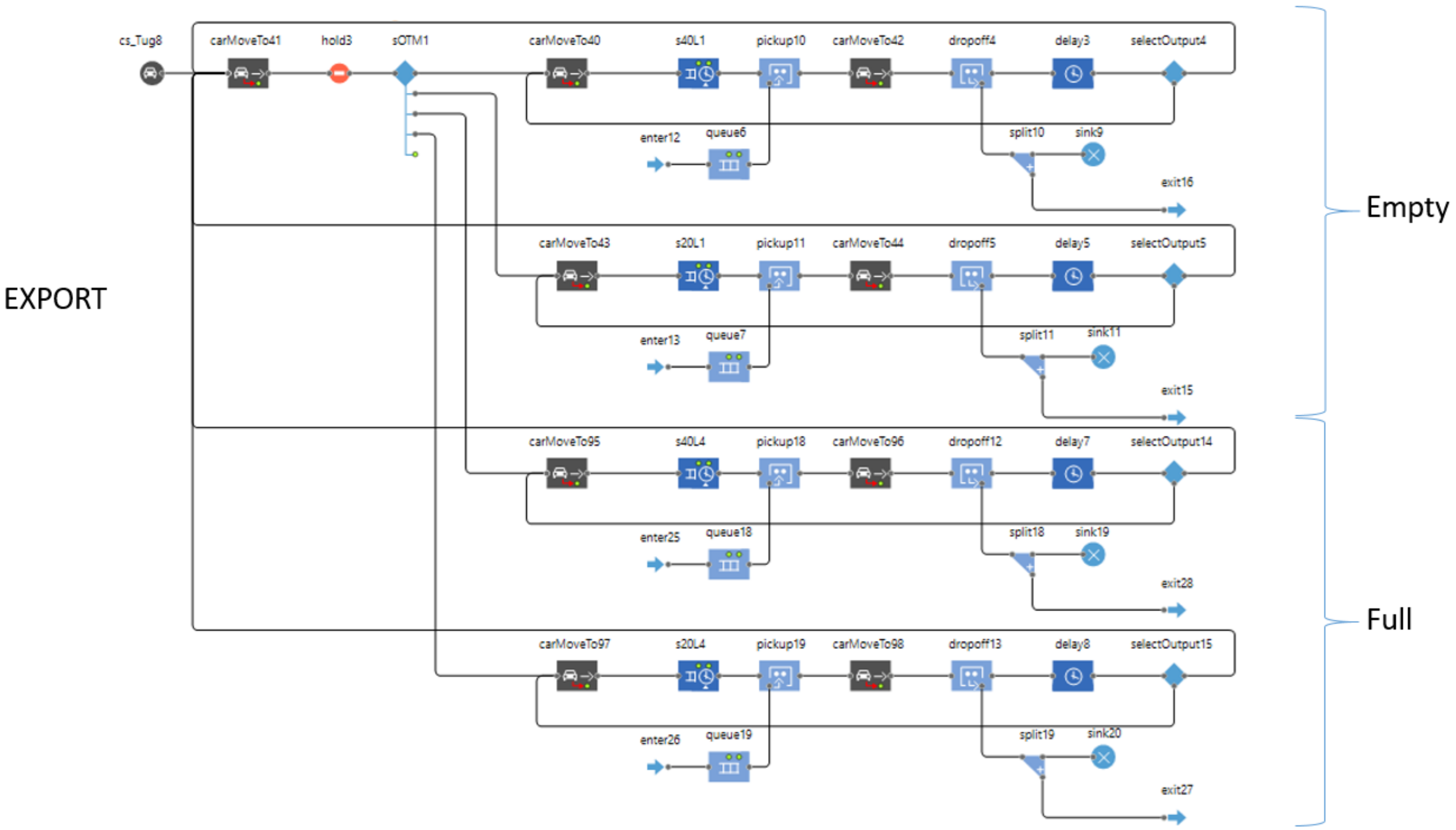


Figure 5.14: Innerside area. Export logical architecture.

From a logical point of view, this cycle comprises the following functions:

- **cs_Tug8:** which generates the tug masters as soon as the simulation starts, is necessary get few parameters as:
  - Average speed: 30 km/h
  - Acceleration: 1.8 m/s2
  - Deceleration: 4.2 m/s2
- **carMoveTo41:** moves the tug master to its parking point, located in a specific point in the terminal;
- **hold3:** keeps the tug master parked at the parking point until there are no containers to transport, as soon as containers enter at the queue blocks the hold turns green and lets the tug master pass;
- **sOTM1:** is a selector that assigns the output of the tug master to one of the 4 block outputs, representing 4 different operations depending on the type of container.

The logical architecture of the outbound containers is presented below, differentiating between full and empty containers (Figure 5.14):

<u>Empty containers logic diagram:</u>

- **carMoveTo40, carMoveTo43:** that guides the tug master from the parking to the loading area (export yard);
- **s40L1, s20L1:** used to modelling the waiting time with relative loading time employed by the reach stacker for load the tug master, this time has been calibrated on the case study, which a gamma distributions function was adopted both for the 40' empty (**s40L1**) than 20' empty (**s20L1**);
- **queue6, queue7:** simulated a virtual queue, which the containers represented by **enter12**(40'empty containers) and **enter13**(20'empty containers) are waiting on the correspond yard stack to be takes by a reach stacker;
- **pickup10, pickup11:** used to takes a container that comes from the virtual queues (**queue1/queue3**) and deposit these on the tug masters. **pickup10** for 40' empty containers and **pickup11** for 20' empty containers;
- **carMoveTo42, carMoveTo44:** moves the loaded tug masters from the export yard to the dock;
- **dropoff4, dropoff5:** removes the container from the system and replace it with the new identical one generated by the **split10** and **split11** blocks;

- **delay3, delay5:** performs the moves operation time of containers 40’ empty (**delay3**) and 20’ empty (**delay5**) by quay cranes from the tug masters onto the ship’s deck (described in the seaside area), in which a gamma distributions function was adopted for each type of container;
- **exit16, exit15:** represents the container exit of this diagram and enter of the sea-side module diagram through **enter14** and **enter 11** (Figure 5.11);
- **SelectOutput4, SelectOutput5:** this function gives indications on the next tug master operation, if still there are containers to be picked up within the queues it returns to the loading point and repeats the whole cycle, if there are no more containers, it returns to the parking and remains there until the hold block remains red.

Full containers logic diagram:

- **carMoveTo95, carMoveTo97:** guides the tug masters from the parking to the loading area (export yard);
- **s40L4, s20L4:** used to modelling the waiting time with relative loading time used by the reach stacker for load the tug master, this time has been calibrated on the case study, which a gamma distributions function was adopted both for the 40’ full (**s40L4**) than 20’ full (**s20L4**);
- **queue18, queue19:** simulated a virtual queue, which the containers represented by **enter25**(40’full containers) and **enter9**(20’full containers) are waiting on the correspond yard stack to be takes by a reach stacker;
- **pickup18, pickup19:** used to takes a container that comes from the virtual queues (**queue18, queue19**) and deposit these on the tug masters. **pickup18** for 40’ full containers and **pickup19** for 20’ full containers;
- **carMoveTo96, carMoveTo98:** moves the loaded tug masters from the yard to the dock;
- **dropoff12, dropoff13:** removes the container from the system and replace it with the new identical one generated by the **split18** and **split19** blocks;
- **delay7, delay8:** performs the moves operation time of containers 40’ full (**delay7**) and 20’ full (**delay8**) by quay cranes from the tug masters onto the ship’s deck (described in the sea-side module), in which a gamma distributions function was adopted for each type of container;
- **exit28, exit27:** represents the container exit of this diagram and enter of the seaside area diagram through **enter8** and **enter 9** (Figure 5.11);
- **SelectOutput14, SelectOutput15:** this function gives indications on the next tug master operation, if still there are containers to be picked up within the queues it returns to the loading point and repeats the whole cycle, if there

are no more containers, it returns to the parking and remains there until the hold block remains red.

Landside: Model architecture

This area is the external interface of a container terminal, which links it with the land transport system, and it is the last component of the import cycle, as well as represent the beginning of the export cycle.

The main operations are the gate-in and gate-out of transport companies, which refers to the pick-up of containers (full/empty) coming from the sea, delivery of containers to be loaded onto ships, also the empty containers to be returned to the terminal. The agents involved in this area are the Trucks of the transport companies. For each agent the inputs and the output variables are reported in Table 5.3, whilst the logic architecture is reported in Figure 5.15 and 5.16.

Table 5.3: Agents, inputs, and outputs for land-side area

Agents	Inputs	Outputs
Trucks	-Arrival time -Geometrical and mechanical parameters -Emission factors (EF) -Containers to carry	-Distance travelled (D) -Energy consumption (EN) -Emissions of the major pollutants (EM)

The next figures show the land-side module in the model, divided by export cycle (Figure 5.15) and import cycle (Figure 5.16), showing for each type of container and operation their logical architecture.

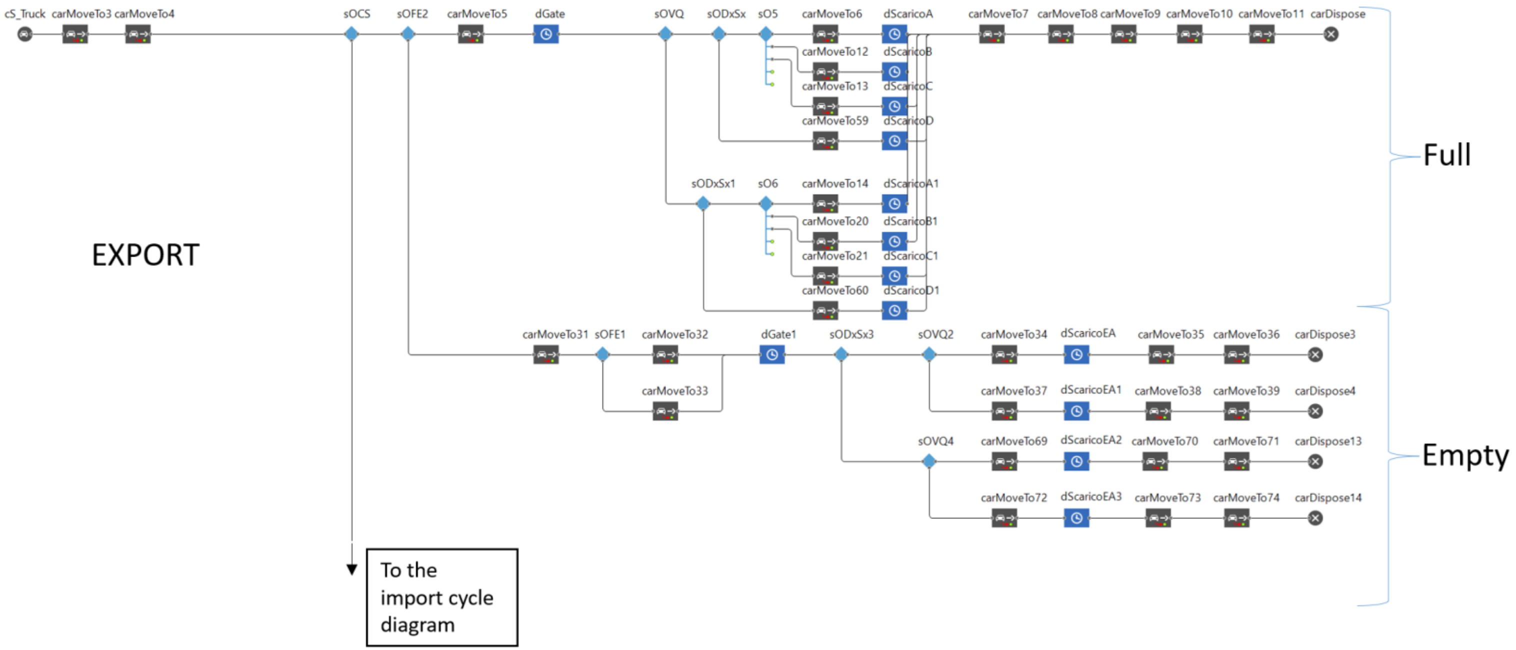


Figure 5.15: Landside area. Export logical architecture.

It is a linear scheme and consists in the following functions:

- **cs_Truck:** generates the trucks entrance outside the port according to an arrival rate (45 per hour), guaranteeing a limited container storage times in the port, this hypothesis is consistent considering the high level of coordination between the terminal operator and the carriers.
- **carMoveTo3, carMoveTo4:** guides the truck from its origin to the entrance gate. For a real representation is necessary to give a few parameters:
  - Speed: 30 km/h;
  - Acceleration: 1.8 m/s2;
  - Deceleration: 4.2 m/s2.
- **sOCS:** represents a selector, which divides the trucks flow considering their operation kind (Import or Export).

In this point of diagram is possible to identify the functional blocks that represents the export cycle in the landside area (Figure 5.15) and the functional blocks that represents the import cycle in the landside area (Figure 5.15).
Respect the export cycle, the first process refers to 20/40 full containers to be loaded onto the ships, and the second one refers to empty delivery at the terminal.

Full containers logic diagram:

- **sOFE2:** this function separates the trucks flow carrying full containers (top exit) from those carrying empty containers (bottom exit);
- **carMoveTo5:** directs of trucks with full containers to the corresponding gate;
- **dGate:** simulates the operational time at the gate, this follows a triangular function, using as function parameters (0.5, 1, 1.5) minutes;
- **sOVQ:** divides trucks carrying 20' containers (bottom exit) from those carrying 40' containers (top exit);
- **sODxSx, sO5:** divides the containers (40'full) according to the specific point inside the export yard where they should be unloaded;
- **carMoveTo6, carMoveTo12, carMoveTo13, carMoveTo59:** these functions are used to guide the trucks to their respective unloading point;
- **sScaricoA, sScaricoB, sScaricoC, sScaricoD:** performs the time taken by the reach stackers to unload the containers (40'full), from the truck onto the yard, which a gamma distributions function was adopted for each type of container;

- **carMoveTo7, carMoveTo8, carMoveTo9, carMoveTo10, carMoveTo11:** guides the trucks to the exit point, then their exit from the model through a **carDispose**;
- **sODxSx1, sO6:** divides the containers (20'full) according to the specific point within the export yard where they should be unloaded.
- **carMoveTo14, carMoveTo20, carMoveTo21, carMoveTo60:** guides the trucks to their respective unloading point;
- **sScaricoA1, sScaricoB1, sScaricoC1, sScaricoD1:** performs the time taken by the reach stackers to unload the containers (20'full), from the truck onto the yard, in which a gamma distributions function was adopted for each type of container.

Empty containers logic diagram:

- **carMoveTo31:** directs trucks with full containers to the corresponding gate;
- **sOFE1:** this function separates the flow of trucks carrying empty containers;
- **carMoveTo32, carMoveTo33:** directs trucks carrying empty containers to the corresponding gate;
- **dGate1:** simulates the operational time at the gate, this follows a triangular function, using as function parameters (0.5, 1, 1.5) minutes;
- **sODxSx3:** divides the containers (20/40'empty) according to the specific point inside the export yard where they should be unloaded;
- **sOVQ2:** separates the trucks carrying containers 20’ empty of these that carrying 40’ empty that will be unloaded on the Levante side;
- **carMoveTo34, carMoveTo37:** directs trucks with empty containers to the corresponding point of unload;
- **dScaricoEA, dScaricoEA1:** represent the time taken by the reach stackers to unload the containers 40'empty(**dScaricoEA**) and 20’ empty (**dScaricoEA1**), from the truck onto the yard, which a gamma distributions function was adopted for each type of container;
- **carMoveTo35, carMoveTo36, carMoveTo38, carMoveTo39:** guides the trucks to the exit point, after that they go out the model through a **carDispose3** e **carDispose4**;
- **sOVQ4:** separates the trucks carrying containers 20’ empty of these that carrying 40’ empty that will be unloaded on the ponente side;
- **carMoveTo69, carMoveTo72:** directs trucks with empty containers to the corresponding point of unload;
- **dScaricoEA2, dScaricoEA3:** represent the time taken by the reach stackers

to unload the containers 40'empty(**dScaricoEA2**) and 20’ empty (**dScaricoEA3**), from the truck onto the yard, in which a gamma distributions function was adopted for each type of container;

- **carMoveTo70, carMoveTo71, carMoveTo73, carMoveTo74:** guides the trucks to the exit point, after that they go out the model through a **carDispose13** e **carDispose14**;

Regard to the import cycle, the containers arrive from the sea, then are carried by the transport companies (trucks) and transferred to their final destination. The import cycle diagram is divided in two parts: full containers and empty containers.

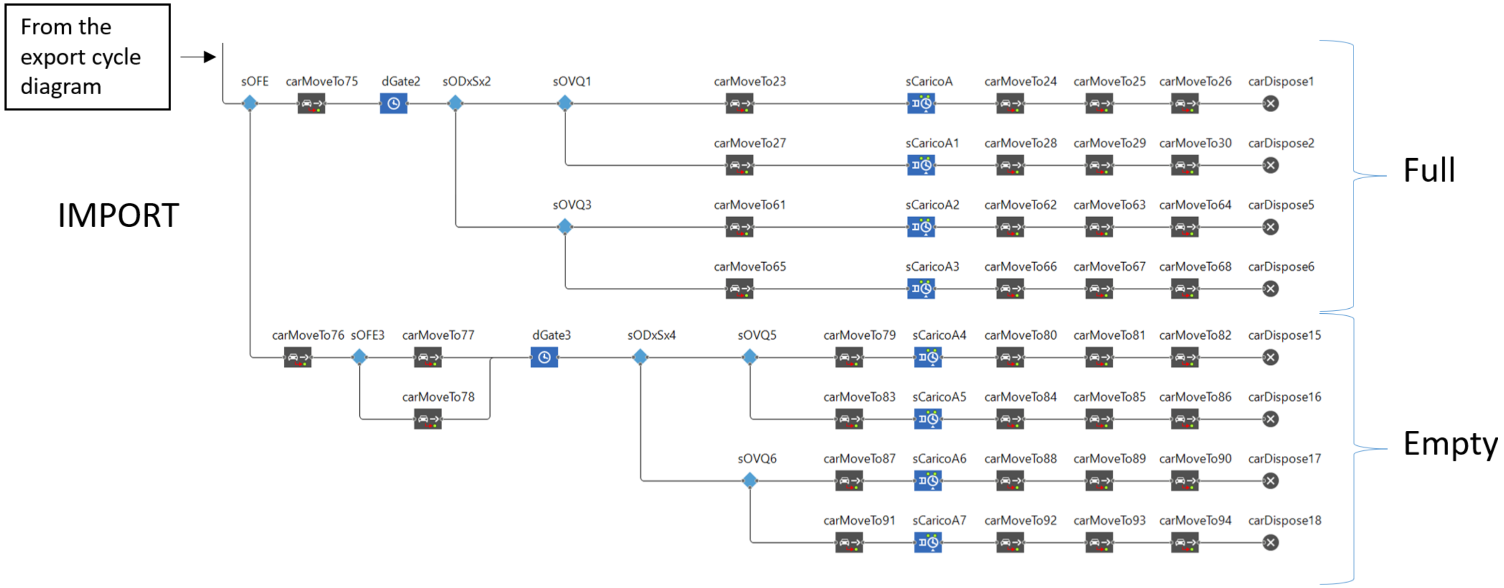


Figure 5.16: Landside area. Import logical architecture.

- **sOFE:** this function separates the trucks flow in two: by top exit the trucks carrying full containers, and by bottom exit those carrying empty containers;

Full containers logic diagram:

- **carMoveTo75:** directs trucks with full containers to the corresponding gate;
- **dGate2:** simulates the operational time at the gate, this follows a triangular function, using as function parameters (0.5, 1, 1.5) minutes;
- **sODxSx2:** separates the trucks flow according to where in the import yard the container to be picked up is located, these should be south side of the terminal (**sOVQ1**) or the north side of the terminal (**sOVQ3**);
- **sOVQ1:** divides the trucks that go to pick up containers 40'full (top exit) and containers 20’ full (bottom exit);
- **carMoveTo23, carMoveTo27:** guides the trucks to their respective loading point;
- **dCaricoA, dCaricoA1:** performs the time taken by the gantry crane (south side) to load the containers 40'full(**dCaricoA**) and 20’ full(**dCaricoA1**), from the yard storage onto the trucks, in which a gamma distributions function was adopted for each type of container;
- **carMoveTo24, carMoveTo25, carMoveTo26, carMoveTo28, carMoveTo29, carMoveTo30:** guides the trucks to the terminal exit point, after that they go out the model through a **carDispose1** e **carDispose2**;
- **sOVQ3:** divides the trucks that go to pick up 40'full containers (top exit) and 20’ full containers (bottom exit);
- **carMoveTo61, carMoveTo65:** guides the trucks to their respective loading point;
- **dCaricoA2, dCaricoA3:** performs the time taken by the gantry crane (north side) to load the containers 40'full(**dCaricoA2**) and 20’ full(**dCaricoA3**), from the yard storage onto the truck, in which a gamma distributions function was adopted for each type of container;
- **carMoveTo62, carMoveTo63, carMoveTo64 carMoveTo66, carMoveTo67, carMoveTo68:** guides the trucks to the terminal exit point, after that they exit of the model through a **carDispose5** e **carDispose6**;

Empty containers logic diagram:

- **carMoveTo76:** directs trucks with empty containers to the corresponding gate;
- **sOFE3:** this function separates the flow of trucks that goes to pick up empty

containers;

- **carMoveTo77, carMoveTo78:** directs trucks to the corresponding gate;
- **dGate3:** simulates the operational time at the gate, this follows a triangular function, using as function parameters (0.5, 1, 1.5) minutes;
- **sODxSx4:** separates the trucks flow according to where in the import yard the container to be picked up is located, these should be Levante side of the terminal (**sOVQ5**) or the ponente side of the terminal (**sOVQ6**);
- **sOVQ5:** separates trucks that should pick up 20' empty containers from those looking for 40' empty containers on the Levante side;
- **carMoveTo79, carMoveTo83:** guides the trucks to their respective loading point.
- **dCaricoA4, dCaricoA5:** represent the time taken by the reach stackers to load the containers 40'empty(**dCaricoA4**) and 20' empty(**dCaricoA5**), from the yard storage onto the truck, in which a gamma distributions function was adopted for each type of container;
- **carMoveTo80, carMoveTo81, carMoveTo82, carMoveTo84, carMoveTo85, carMoveTo86:** guides the trucks to the terminal exit point, after that they exit of the model through a **carDispose15** e **carDispose16**;
- **sOVQ6:** separates trucks that should pick up 20' empty containers from those looking for 40' empty containers on the ponente side;
- **carMoveTo87, carMoveTo91:** guides the trucks to their respective loading point.
- **dCaricoA6, dCaricoA7:** represent the time taken by the reach stackers to load the containers 40'empty(**dCaricoA6**) and 20' empty(**dCaricoA7**), from the yard storage onto the truck, in which a gamma distributions function was adopted for each type of container;
- **carMoveTo88, carMoveTo89, carMoveTo90, carMoveTo92, carMoveTo93, carMoveTo94:** guides the trucks to the terminal exit point, after that they exit of the model through a **carDispose17** e **carDispose18**;

5.4.1 Energy Functions

Seaside

The energy consumption of a container ship depends mainly on the ship's size, as it is closely related to the power of the engines and the load factor of the engines.

The main characteristics, such as the total installed power and mechanical characteristics of these engines, are known and can be found in appropriate databases. Two of these databases have been widely used in the literature: the IHS

Fairplay Ship Register (formerly known as Lloyd's Register of Ships provided by Lloyd's Register Fairplay)("IHS Fairplay," 2021) and the Lloyd's List Intelligence database (formerly known as Lloyd's Marine Intelligence Unit's LMIU database)("Home :: Lloyd's List," 2021).

Ships consumption (MWh) have been estimated distinguishing the manoeuvring and the hotelling phase. They depend on the following factors:

- EP: power of the main and/or auxiliary engines (kW);
- LF: engine load factor (%);
- t_{man}: manoeuvring time, considering both entrance and exit (h);
- t_{hot}: hotelling time (h);
- TO: main engine time of operation (%);
- number of moorings.

Table 5.4: Load factor and main engine time of operation

Phase	LF_{main}	LF_{aux}	TO_{Main}
Manoeuvring	20%	50%	100%
Hotelling	20%	40%	5%

In particular the load factor information and main engine time of operation are available in the open literature (Bacalja et al., 2020).

By the seaside area, the calculations relative to both the hotelling and manoeuvring phases are reported in the chapter 6.

The explicit formulation for the net energy consumption in the **manoeuvring phase** is the following:

$$EN_{main,man.} = EP_{main.} * LF_{main,man.} * t_{man.} * n_{moorings} * TO_{main,man.} * 10^{-3} \quad (5.1)$$

$$EN_{aux,man.} = EP_{aux.} * LF_{aux,man.} * t_{man.} * n_{moorings} * 10^{-3} \quad (5.2)$$

$$EN_{tot,man.} = EN_{main,man.} + EN_{aux,man.} \quad (5.3)$$

For the **hotelling phase**:

$$EN_{main,hot.} = EP_{main.} * LF_{main,hot.} * t_{hot.} * n_{moorings} * TO_{main,hot.} * 10^{-3} \quad (5.4)$$

$$EN_{aux,hot.} = EP_{aux.} * LF_{aux,hot.} * t_{hot.} * n_{moorings} * 10^{-3} \tag{5.5}$$

$$EN_{tot,hot.} = EN_{main,hot.} + EN_{aux,hot.} \tag{5.6}$$

Innerside

Regards to the handling means, a variety of sources including data sheets from vehicles manufacturing companies (Liebherr, Gottwald, Sennebogen, Terberg etc.), literature data (Iris and Lam, 2019), and analytical evaluations were referenced to assess energy consumption.

Reach Stackers

For Reach Stackers, the most common type on the market is diesel powered, although recently some companies have developed hybrid models. The energy consumption (MWh), in one year, is dependent on the following factors:

- EP: engine power (kW);
- t: working time (h).

Explicit formulation for the energy consumption:

$$EN_{RS} = EP_{RS} * t_{RS} * 10^{-3} \tag{5.7}$$

Quay Cranes

For the Quay Cranes, apart from the diesel-fuelled ones, some companies have developed innovative powered models with electric lifting unit. The energy consumption in one year (MWh) is dependent on the following factors:

- EP: engine power (kW);
- t: working time (h).

Explicit formulation for the energy consumption:

$$EN_{QC} = EP_{QC} * t_{QC} * 10^{-3} \tag{5.8}$$

Rubber Tyred Gantry

For the RTG, the energy consumption (MWh), in one year, is dependent on the following factors:

- EP: engine power (kW);
- t: working time (h);
- Cm: consumption per move (kWh/TEU);
- Number of moves (TEU/h).

The energy consumption for the diesel powered is expressed as:

$$EN_{RTG} = EP_{RTG} * t_{RTG} * 10^{-3} \tag{5.9}$$

Regard to electric powered:

$$EN_{RTG} = Cm_{RTG} * t_{RTG} * n_{moves,RTG} * 10^{-3} \tag{5.10}$$

The consumption per move for the electric RTG is provided by (Iris and Lam, 2019).

Tug Masters

The Tug Masters, the energy consumption (MWh), in one year, is dependent on the following factors:

- Cd: consumption per kilometre (kWh/km);
- D: distance (km).

The energy consumption, both for electric and conventional mean, is expressed as:

$$EN_{TM} = Cd_{TM} * D_{TM} * 10^{-3} \tag{5.11}$$

The diesel-powered Tug Master, the consumption per kilometre is obtained through the product of fuel consumption per kilometre (l/km) and the conversion factor (kWh/l). For the electric one it has been assumed a reduction of the 58% for the energy consumption with respect to the conventional one.

Landside

Trucks

The development in terms of calculation for Trucks is similar to Tug Masters.

The energy consumption (MWh), in one year, is dependent on the following factors:

- Cd: consumption per kilometre (kWh/km);
- D: distance (km).

The energy consumption, both for electric and conventional truck, is expressed as:

$$EN_{TR} = Cd_{TR} * D_{TR} * 10^{-3} \tag{5.12}$$

The diesel-powered Trucks similarly to what is obtained from the data relating to the TM, the consumption per kilometre is obtained through the product of fuel consumption per kilometre (l/km) and the conversion factor (kWh/l) and by the electric one it has been assumed a reduction of the 58% for the energy consumption with respect to the conventional one.

5.4.2 Environmental Functions

Seaside

The explicit formulation for the calculation of emissions is directly linked to the emission factors provided by the (European Commission, 2005).

Table 5.5: Emission factors for hotelling and manoeuvring phase

NO_x (g/kWh)		**SO_2 (g/kWh)**		**CO_2 (g/kWh)**		**HC (g/kWh)**		**PM (g/kWh)**	
Hotel.	*Man.*	*Hotel.*	*Man.*	*Hotel.*	*Man.*	*Hotel.*	*Man.*	*Hotel.*	*Man.*
11	11.9	1.4	12	696	705	0.5	1.18	0.5	1.73

These are distinct with respect to the type of Ship and the phase:

$$EM_{tot,man.} = EN_{tot,man.} * EF_{j,man.} * 10^{-3} \tag{5.13}$$

$$EM_{tot,hot.} = EN_{tot,hot.} * EF_{j,hot.} * 10^{-3} \tag{5.14}$$

Where j is the generic pollutant or greenhouse gas. A similar approach is used in (Saraçoğlu et al., 2013).

Innerside

Reach Stacker

For the emission calculation (ton), the emission factors related to the air pollution are referred to (Li et al., 2019), with respect to a power engine between 130 and 560 kW and the Tier III, while for the CO2 the reference is the specific data sheet of the handling mean:

Table 5.6: Emission factors for Reach Stackers

CO_2 (kg/l)	**NO_x (g/kWh)**	**PM_{10} (g/kWh)**	**$PM_{2,5}$ (g/kWh)**	**CO (g/kWh)**	**HC (g/kWh)**
2.67	2.8	0.18	0.16	3	0.8

$$EM_{RS} = FC_{RS} * t_{RS} * EF_{j,RS} * 10^{-3} \tag{5.15}$$

$$EM_{RS} = EN_{RS} * EF_{j,RS} * 10^{-3} \tag{5.16}$$

Where j is the generic pollutant or greenhouse gas.

Equation 5.15 is referred just to the CO2 emission since the emission factor, in this specific case, is referred to the fuel consumption, FC, expressed in l/h. Compared to the conventional diesel vehicle, for the hybrid one, both consumption and emissions are reduced by about 30%.

Quay Cranes

For the emission calculation (ton), regard to air pollution, the same reference of the Reach Stacker is assumed, considering a power engine between 130 and 560 kW and the Tier III, while for the CO2 the reference is the specific data sheet of the handling mean:

Table 5.7: Emission factors for Quay Cranes

CO2 (kg/l)	**NOx (g/kWh)**	**PM10 (g/kWh)**	**PM2,5 (g/kWh)**	**CO (g/kWh)**	**HC (g/kWh)**
2.65	2.8	0.18	0.16	3	0.8

$$EM_{QC} = FC_{QC} * t_{QC} * EF_{j,QC} * 10^{-3} \tag{5.17}$$

$$EM_{QC} = EN_{QC} * EF_{j,QC} * 10^{-3} \tag{5.18}$$

Where j is the generic pollutant or greenhouse gas.

Equation 5.17 is referred just to the CO2 emission since the emission factor, in this specific case, is referred to the fuel consumption, FC, expressed in l/h.

The data provided by the companies shows a reduction in consumption of about 5%.

For the emissions of the electric Quay Crane, the result is equal to zero

Rubber Tyred Gantry

For the emission calculation (ton), the same references of the previous handling means are considered.

Table 5.8: Emission factors for RTGs

CO2 (kg/l)	**NOx (g/kWh)**	**PM10 (g/kWh)**	**PM2,5 (g/kWh)**	**CO (g/kWh)**	**HC (g/kWh)**
2.65	2.8	0.18	0.16	3	0.8

$$EM_{RTG} = FC_{RTG} * t_{RTG} * EF_{j,RTG} * 10^{-3} \tag{5.19}$$

$$EM_{RTG} = EN_{RTG} * EF_{j,RTG} * 10^{-3} \tag{5.20}$$

Where j is the generic pollutant or greenhouse gas.

Equation 5.19 is referred just to the CO2 emission since the emission factor, in this specific case, is referred to the fuel consumption, FC, expressed in l/h.

The data provided by the companies shows a reduction in consumption of about 67% in the electric RTG. The emissions of the electric RTG, the result is equal to zero.

Tug Masters

Inside of the simulation model it has been included the emission factors of CO2 and other pollutants with respect to the values provided by COPERT, a software developed in coordination with EEA ("EMEP/EEA air pollutant emission inventory guidebook 2019 — European Environment Agency," 2019). This was made both for Trucks and Tug Masters.

Table 5.9: Emission factors for Tug Masters

CO2 (g/km)	NOx (g/km)	PM10 (g/km)	PM2,5 (g/km)	CO (g/km)
983	6.51	0.25	0.19	1.79

Regard to the emission calculation (ton):

$$EM_{TM} = D_{TM} * EF_{j,TM} * 10^{-6} \tag{5.21}$$

The electric Tug Master produces zero emissions

Trucks

Table 5.10: Emission factors for Trucks

CO2 (g/km)	NOx (g/km)	PM10 (g/km)	PM2,5 (g/km)	CO (g/km)
626	3.16	0.16	0.11	0.90

The emission calculation (ton)

$$EM_{TR} = D_{TR} * EF_{j,TR} * 10^{-6} \tag{5.22}$$

The electric truck produces zero emissions.

5.4.3 Workload Functions

In intermodal terminals, container handling and the number of accidents still depend on a wide range of human errors, many of them due to mental fatigue of the operators. For this reason it is important to increase the knowledge of the factors that influence the propensity of operators to make mistakes, thus increasing the possibility of accidents occurring(Fadda et al., 2015).

Some studies have been carried out to relate fatigue to performance. Moreover, these studies can link the working environment and conditions not only with reduced performance, but also with a potential risk to health, both physical and mental. One of the most relevant studies in this field is "Processing and analysis of ship-to-shore gantry crane operator performance curves in container terminals" (Fancello et al., 2008). Fatigue, among other characteristics, has physiological roots and is mainly influenced by sleep and the sleep-wake cycle. In fact, it is known that lack of sleep or poor sleep patterns attenuate psychophysical functions such as cognitive processes, alertness, coordination, decision-making, etc.

Moreover, working conditions can affect operators' performance if they are not optimised. In this context, the literature provides interesting insights including the formulation of operator fatigue curves, such as the Yerkes-Dodson (Y-D) curve for quay and yard cranes (Figure 5.17).

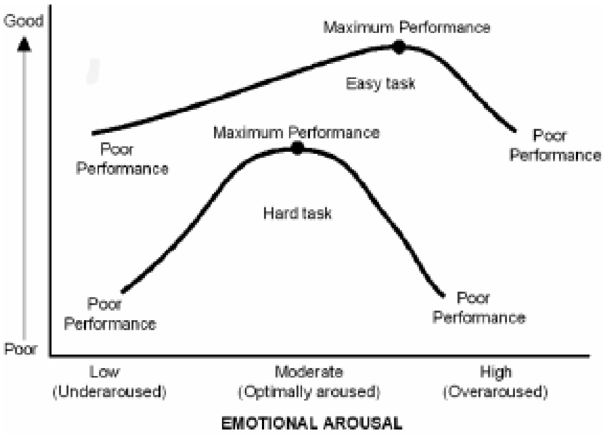


Figure 5.17: Yerkes-Dodson curves. Source(Fancello et al., 2008)

In this thesis, an analysis of the fatigue of the quay crane operators is carried out, based on the Y-D law, using as a starting point data referred to a week of work of the cranes in SCT, then the curves of each crane in their corresponding work shifts were graphed considering the movements carried out. Finally, the average number of movements of each crane was calculated and, through interpolation techniques, the equation of the average curve of movements over the hours of the work shifts was obtained. More detail on this analysis will be given in the next chapter where a workload scenario is evaluated.

On the other hand, for the remaining handling means such as yard cranes and reach stackers, Gamma distribution curves were used, which represent the movement time of each container, according to its size and its state (full/empty). These curves were calibrated in a previous study on the container terminal in study and is reported in the following article(Cartenì and De Luca, 2010). These curves are a measure of operator fatigue as they are created from the movement times of each container during work shifts. Unlike the curves presented above (Y-D) these curves also represent unforeseen or delayed movements since they are based on the variable movement time, in contrast to the Y-D curves which are based on the number of movements per work shift.

For the RTGs the gamma distribution and its mean and variance parameters are shown in Table 5.11. In this case for the unloading operation there were no substantial time differences between the various container types and therefore the "undifferentiated" time was taken. However, this simplification did not lead to any practical feedback within the model as RTGs are only used for container loading operations on trucks and not for unloading operations.

Table 5.11: Gamma distribution values for RTG (in minutes) (Source:(Cartenì and Luca, 2012))

Activity time (min)	**Undifferentiated**		**20’**		**40’**	
			Full		**Full**	
	μ	**σ**	**μ**	**σ**	**μ**	**σ**
Loading (from stack)	0.752	0.406	0.741	0.311	0.796	0.457
Unloading (to stack)	0.766	0.352	n.a	n.a	n.a	n.a
Loading (from stack) – tier 1	1.022	0.449	1.011	0.353	1.060	0.561
Loading (from stack) – tier 2	0.687	0.250	0.658	0.222	0.712	0.256
Loading (from stack) – tier 3	0.668	0.323	0.659	0.246	0.673	
Loading (from stack) – tier 4	0.592	0.325	0.583	0.261	0.606	
Loading (from stack) – tier 5	0.571	0.355	0.560	0.280	0.584	
Unloading (from stack) – tier 1	1.097	0.231	No significant differences with respect to undifferentiated containers			
Unloading (from stack) – tier 2	0.703	0.308				
Unloading (from stack) – tier 3	0.671	0.256				
Unloading (from stack) – tier 4	0.638	0.245				
Unloading (from stack) – tier 5	0.613	0.240				

n.a.= not available

Finally, for the Reach Stackers, once again the distribution that best reproduced the behaviour was a range, the values of which are shown in Table 5.12. The decision was made to use the average stacking time and not the specific stacking time for each tier, since the differences were minimal.

Table 5.12: Gamma distribution values for Reach Stackers (in minutes) (Source:(Cartenì and Luca, 2012)

Activity time (min)	**Undifferentiated**		**20'**		**40'**	
			Full		**Full**	
	μ	**σ**	**μ**	**σ**	**μ**	**σ**
Loading to shuttle/truck	0.307	0.170	0.304	0.311	0.796	0.457
Unloading from shuttle/truck	0.186	0.074	0.144	0.056	0.200	0.087
Stacking time	0.260	0.146	n.a	n.a	n.a	n.a
Stacking time – tier 1	0.185	0.056	n.a	n.a	n.a	n.a
Stacking time – tier 2	0.167	0.071	n.a	n.a	n.a	n.a
Stacking time – tier 3	0.212	0.086	n.a	n.a	n.a	n.a
Stacking time – tier 4	0.334	0.118	n.a	n.a	n.a	n.a
Stacking time – tier 5	0.542	0.140	n.a	n.a	n.a	n.a

n.a.= not available

5.5 Model Validation

Model validation has been carried out through of traditional validation approaches based on the level of service supplied by the terminal and/or the specific activities, but also through a secondary validation approach based on the emissions emitted by the terminal and derived from the statistical data given by the Port Authority.
The combination of both the approaches(Figure 5.18), give robustness of the overall methodology, and it represents an element of originality.

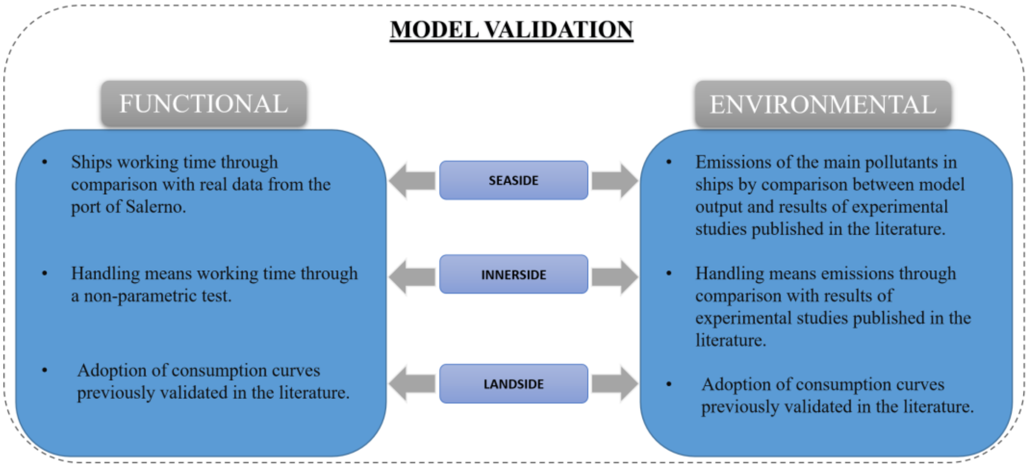


Figure 5.18: Model validation process

5.5.1 Functional Validation

Seaside

The validation of the Ship hotelling time was conducted through data provided by the Salerno Container Terminal (SCT) and the Port Authority of Salerno. These data include the number of TEUs loaded and unloaded by the Ship and the time required to perform the entire number of movements. A comparison was made with the times obtained from the model, in which the same number of movements provided by the real data was imposed.

The comparison showed that the times returned by the simulation are very close to the real ones.

Table 5.13: Ships hotelling time validation.

		Ships working time (min)		
Date	**Moves**	**SCT Data**	**Model**	**Difference (%)**
6 June	170	309	325	**5%**
7 June	304	366	417	**12%**
8 June	233	345	344	**0%**
9 June	246	329	348	**5%**
			Mean	**6%**

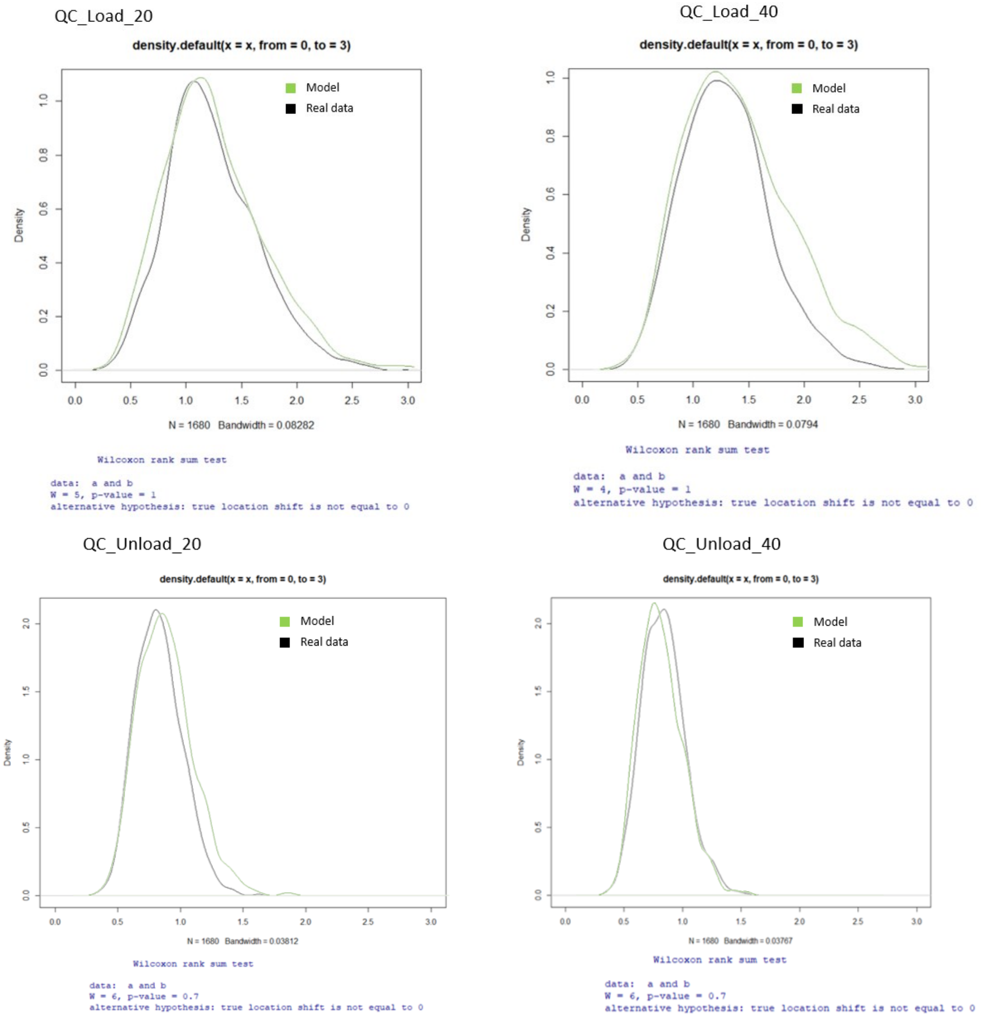
Innerside

The validation phase for the innerside area was carried out on the single operations of each vehicle working inside the terminal to lift and stock the containers: the QCs, the RTGs and the RSs. To conduct the validation, it has been used the R software for statistical analysis ("R: The R Project for Statistical Computing," 2021).

The data to be validated is the average operation times for loading/unloading containers depending on the type, the state of the containers and the type of handling equipment. Since all the input distributions are gamma ones, obtained from (Cartenì and De Luca, 2012), the most effective test to perform the validation is the Wilcoxon-Mann-Whitney test. Wilcoxon tests and the Mann-Whitney test (also known as Wilcoxon rank sum-test) are two of the most powerful non-parametric tests to check, in the presence of ordinal values from a continuous distribution, if two statistical samples come from the same population through the comparison the averages of the values of two groups that do not follow a normal distribution. It is the equivalent of the t-Student test for independent samples. It is easily implemented in R.

The first step was a graphical comparison between the gamma distribution generated by the model and the gamma distribution generated from the real data collection, then an analytical comparison using the Wilcoxon test. the QCs, RSs, and RTGs validation are presented in the following figures.

Quay cranes:



```
        Wilcoxon rank sum test

data:  a and b
W = 5, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

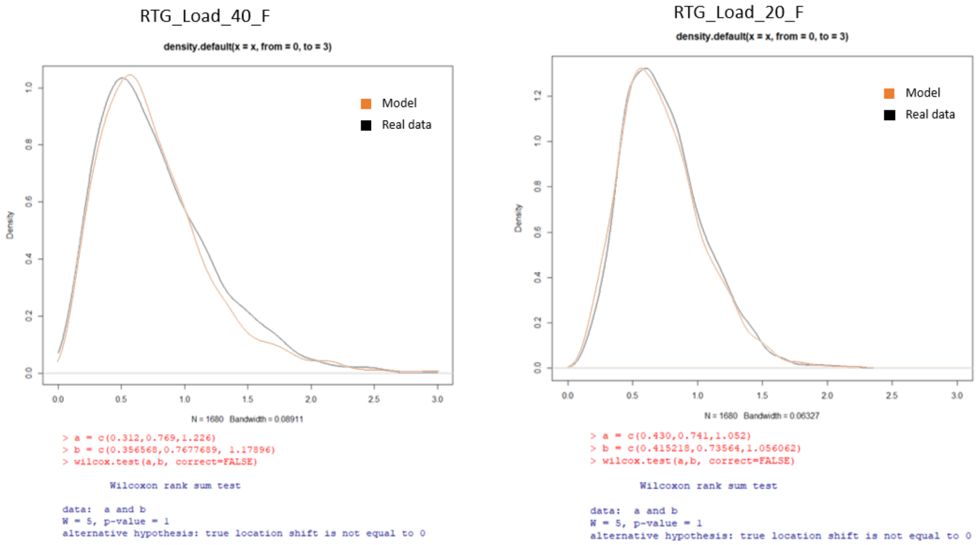
```
        Wilcoxon rank sum test

data:  a and b
W = 4, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

```
        Wilcoxon rank sum test

data:  a and b
W = 6, p-value = 0.7
alternative hypothesis: true location shift is not equal to 0
```

```
        Wilcoxon rank sum test

data:  a and b
W = 6, p-value = 0.7
alternative hypothesis: true location shift is not equal to 0
```

Figure 5.19: Quay cranes - Gamma distribution curves comparisons.

Reach Stackers


RTG_Load_40_F

RTG_Load_20_F

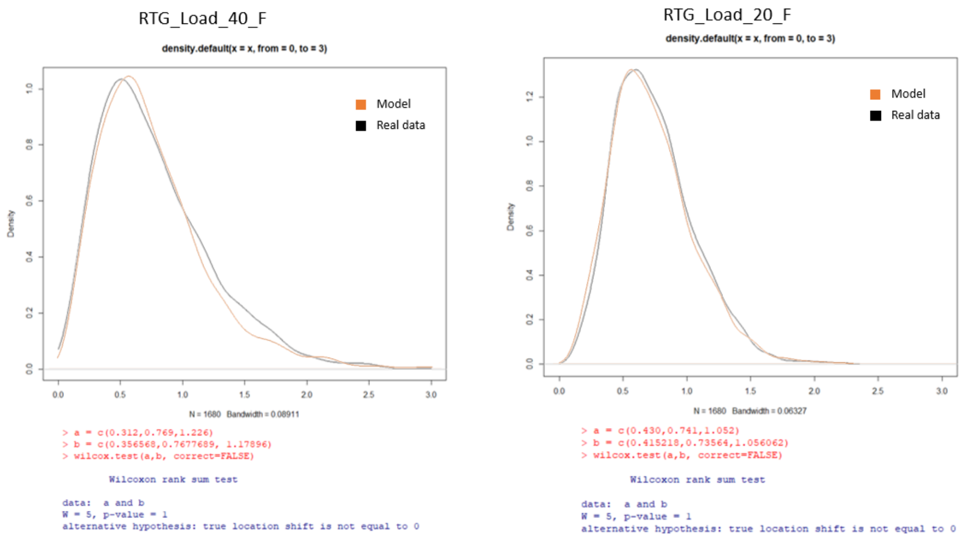
```
> a = c(0.312,0.769,1.226)
> b = c(0.356568,0.7677689, 1.17896)
> wilcox.test(a,b, correct=FALSE)

        Wilcoxon rank sum test

data:  a and b
W = 5, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

```
> a = c(0.430,0.741,1.052)
> b = c(0.415218,0.73564,1.056062)
> wilcox.test(a,b, correct=FALSE)

        Wilcoxon rank sum test

data:  a and b
W = 5, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

Figure 5.20: Reach stackers - Gamma distribution curves comparisons.

The unloading time could not be validated because the unloading time (in the real case) depends on the level of storage in which they have to be deposited after unloading, but instead the developed model takes an average unloading time of containers in each operation.

Rubbed Tyred Gantry


RTG_Load_40_F

RTG_Load_20_F

```
> a = c(0.312,0.769,1.226)
> b = c(0.356568,0.7677689, 1.17896)
> wilcox.test(a,b, correct=FALSE)

        Wilcoxon rank sum test

data:  a and b
W = 5, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

```
> a = c(0.430,0.741,1.052)
> b = c(0.415218,0.73564,1.056062)
> wilcox.test(a,b, correct=FALSE)

        Wilcoxon rank sum test

data:  a and b
W = 5, p-value = 1
alternative hypothesis: true location shift is not equal to 0
```

Figure 5.21*: Rubbed tired gantry - Gamma distribution curves comparisons*

For each distribution, if the p-value of the Wilcoxon test is >0.05, the H0 hypothesis of significant equality of the means of the two groups is accepted. In other words, the hypothesis of belonging to the same distribution is accepted, hence, the loading/unloading operations carried out by means of manipulation have been validated. The following table (Table 5.14) shows the parameters calculated of each gamma distribution.

Table 5.14: Gamma parameters

Operation	**Case**	**Shape(α)**	**Scale(β)**
RTG_Load_40_F	Real	2.831524211	0.271585176
	Model	3.02812618	0.253545876
RTG_Load_20_F	Real	5.676957434	0.130527665
	Model	5.270930722	0.139565991
RS_Load_40_F	Real	2.736560661	0.113646302
	Model	3.255313151	0.094265425
RS_Load_20_F	Real	3.846659729	0.079029605
	Model	3.873192164	0.07866894
QC_Unload_40_F	Real	19.72682775	0.004238144
	Model	13.03318978	0.060592186
QC_Load_40_F	Real	10.26548848	0.125468944
	Model	6.352659909	0.205127496
QC_Unload_20_F	Real	20.32383768	0.040592727
	Model	12.71559713	0.061697433
QC_Load_20_F	Real	9.343965859	0.132491922
	Model	7.604062609	0.160898307

Landside

Regard the landside area has been adopted a consumption curves vs speed that has been previously developed and validated in literature (Huboyo et al., 2017). Based on the consumption of the trucks of the transport companies, the emissions have been estimated. This consumption was calculated from the consumption curve (shown in Figure 5.22) knowing the speed of the vehicle. In this curve, the specific fuel consumption is calculated as a function of the speed profile over time, and it is described according to the following polynomial equation:

$$Specific\ Fuel\ Consumption \left(\frac{l}{km}\right) = a * v^2(t) + b * v(t) + c \tag{5.23}$$

In particular, the values of parameters a,b and c are given in (Huboyo et al., 2017) for a large Truck.

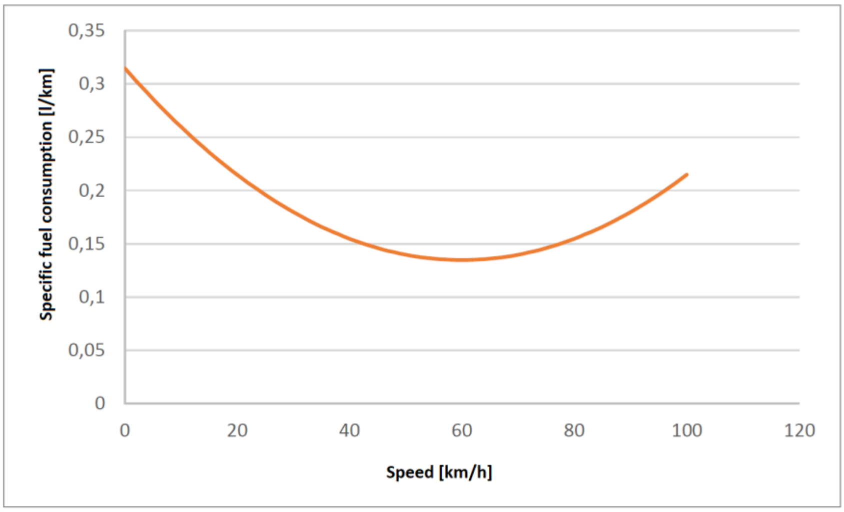


Figure 5.22 Specific fuel consumption as a function of speed. Source:(Huboyo et al., 2017).

Vehicle speed has been evaluated starting from real driving cycles collected in the city of Naples (Figure 5.23), this approach allows a more reliable estimation of the consumption because the real conditions of traffic flow and driving behaviour can be considered (Fiori et al., 2020)(Fiori and Marzano, 2018) (Fiori et al., 2019).The speed profile in the real case is therefore characterised by frequent start & stop phenomena with acceleration and deceleration phases that are not considered when estimating the consumption of a vehicle on a route based only on average consumption value (Fiori et al., 2020, 2019; Fiori and Marzano, 2018).

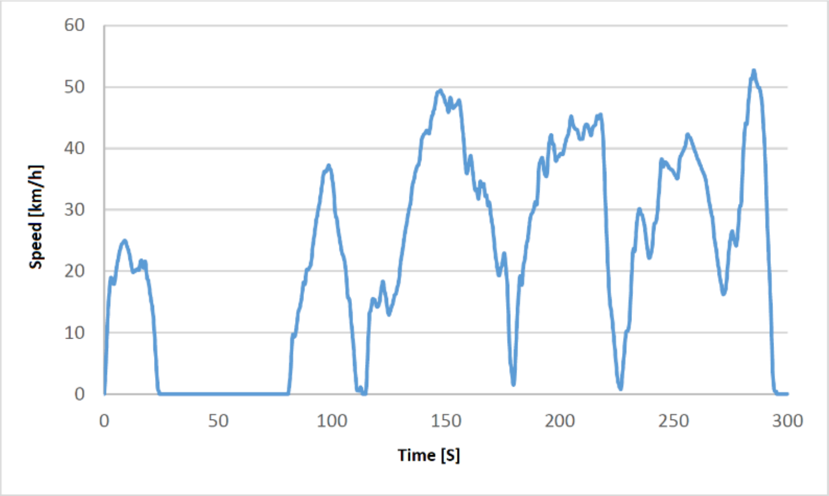


Figure 5.23: Real speed profile on an urban cycle in the city of Naples (Fiori et al., 2020, 2019; Fiori and Marzano, 2018).

5.5.2 Environmental Validation

Seaside

For the environmental validation, the reference used is a feasibility study "Smart Green Port" (SGP) on the Port of Salerno performed in 2012.

Firstly, the database regarding the number of ships passed through the port of Salerno in that year, the gross tonnage and the emission factors associated to each ship were reconstructed. From these data, an average gross tonnage and average emission factors were calculated to use them in the simulation model.

The gross tonnage influences the power of the main and auxiliary engines, according to (Trozzi, 2010).

Table 5.15: Medium gross tonnage calculation.

Container Ships	Number of Ships	Medium gross tonnage (ton)	Main engine power (kW)	Auxiliary engine power(kW)
Gross tonnage >20000	28	17037.5	12715.4	3433.2
Gross tonnage 10000<x<20000	40			
Gross tonnage <10000	31			

It has been considered a temporal horizon such as to have in the model the same number of Ships foreseen in the study.

Table 5.16: Number of Ships within the model and the Study.

	Ships/day	Days considered	Ships/year
SGP	1.6	360	572
Model	2	286	572

It has been evaluated the emission in tons of NOx per year, both for the manoeuvring and hotelling phases.

Regard to the complete database of the various Ships involved in the study, the emission factor is also provided. Depends on the year of construction of the ship, being higher for older ships. The range is from 9.6 to 13.6 g/kWh.

In order to proceed with the calculation an average NOx emission factor of 12.5 g/kWh has been used.

The results obtained (Table 5.15) allowed to verify the reliability of the model.

Table 5.17: NOx Emissions validation.

Manoeuvring phase					
	Manoeuvring time (h/day)	**NOx (kg/day)**	**NOx (kg/year)**	**NOx (ton/year)**	**Difference (%)**
SGP	3.2	171.30	61668	61.67	**1%**
Model	4.09	217.97	62340	62.34	
	3.17	170.54	61394	61.39	
Hotelling phase					
	Hotelling time (h)	**NOx (kg/day)**	**NOx (kg/year)**	**NOx (ton/year)**	**Difference (%)**
SGP	19.72	1010.40	363744	363.74	**4%**
Model	11.61	569.13	204887	204.89	
	19.72	966.93	348094	348.09	

Innerside

Regard the environmental validation in the innerside area, a comparison was made between the emissions reported in Smart Green Ports study (SGP) and the simulation model. To carry out this comparison, the inputs of the model were modified by inserting the same inputs as the above-mentioned study, these inputs are referred to mechanical characteristics of all handling means of the terminal, number of handlings means, emission factors and number of hours worked, in order to be able to make a reliable comparison between the emissions reported in the model and the SGP. On the other hand, it is necessary to clarify that the only pollutant considered for this environmental validation was CO2, since the SGP study does not report any other pollutants regarding the handling means working in the innerside area. The comparison showed (Table 5.18) that the times returned by the simulation are very close to the real ones.

A table with the results of the comparison is presented below, followed by graphs for each handling mean.

Table 5.18: Comparison between SGP and simulation model

CO2 emissions (t/year)			
	Reach Stackers	**Quay Cranes**	**Rubbed Tyred Cranes**
Smart Green Ports	1418	870	146
Model	1404.3	862.3	147
Difference	1%	1%	1%

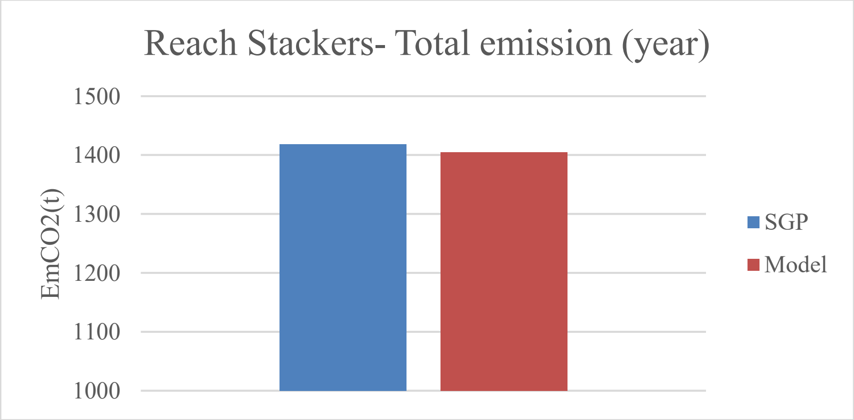


Figure 5.24: Reach stackers emissions comparison

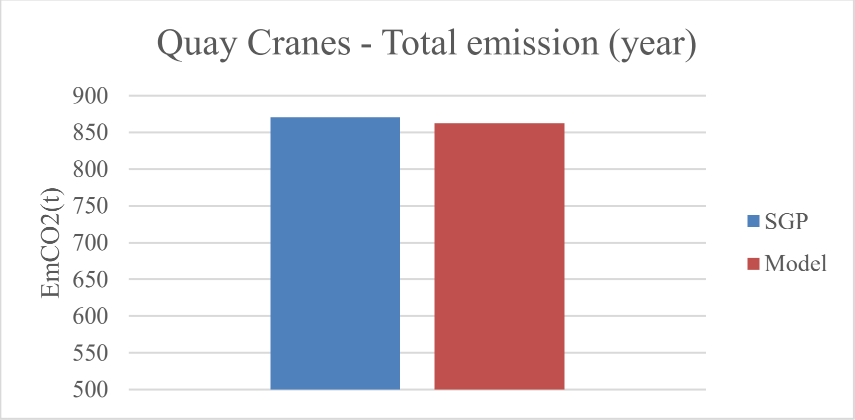


Figure 5.25: Quay cranes emissions comparison

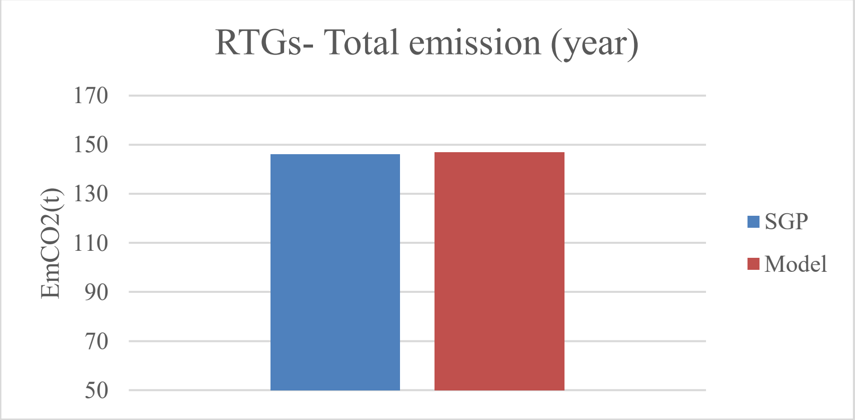


Figure 5.26: Rubbed tyred gantry cranes emissions comparison

Landside

Concerning the landside area, once the consumption of Trucks has been estimated (see section 5.5.1), the emissions produced have been estimated according to the emission factors reported in the section 5.4.2 (emission factor values reported by the European Environment Agency (EEA) and also reported in the COPERT tool ("COPERT Documentation," 2021)).

Therefore, it is not possible to make a comparison of emissions as in the seaside or innerside cases, because there is no source/study on the landside emissions of the case study.

5.6 Conclusions

In this chapter, the specification and validation of an integrated simulation model of a container terminal has been carried out through a hybrid discrete event and multi-agent approach. The aim of this analysis is to simulate the operational logic considering human factors, energy consumption and environmental factors.

The results show that, using a combination of the main simulation techniques currently known, it is possible to model an extremely complex system such as a container terminal. Moreover, the model obtained can correctly simulate 1 week of activity in about 70/80 seconds, thus becoming a possible real-time management system for port activities. The specification and validation of the model was centred on the layout of the port of Salerno, in order to reproduce the performance of the terminal and assess the flexibility and robustness of the developed tool. However, the logical-functional architecture was designed to simulate a generic container terminal, thus it is possible to modify the specification to simulate any container terminal. Furthermore, the validation carried out in comparison with Smart Green Ports and other studies in the literature shows that the model is effective in calculating functional and environmental indicators.

At present, the simulation model is able to provide:

- Support in the design of a Container Terminal;
- Support in the optimisation of the Container Terminal;
- Real-time control;
- An evaluation of the performance of a Container Terminal including human factors.

In the following figure it is possible to appreciate a moment of the model running by reproducing every activity in the terminal in study, moreover it is possible to identify some functional and environmental indicators taken out in real time and shown through dynamic graphs.

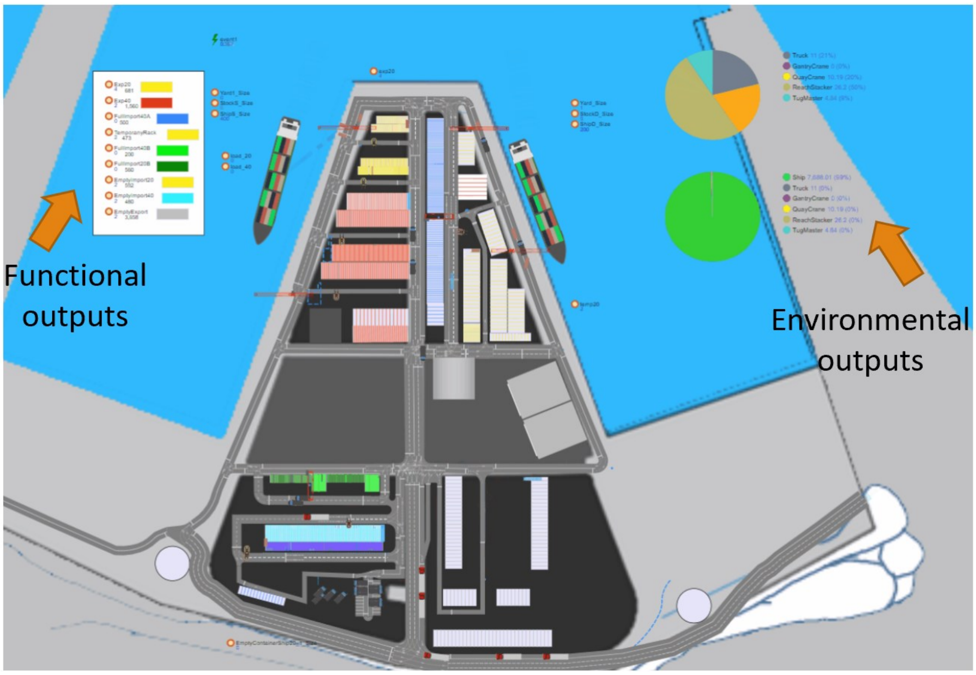


Figure 5.27: Model running

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6. Mono-criteria Scenarios Application

6.1 Introduction

Once the model has been validated, the next step is the model implementation through the analysis of various and different scenarios.

The comparison is not aimed at their economic evaluation, this is meant to demonstrate the many variables that can be acted upon once the model is built and validated. Then, the scenarios will be analysed individually, showing both their input conditions and output results, In the following sections a numerical analysis will be carried out through an environmental and energy assessment of each scenario, using the indicators measured in each of them. The scenarios considered were:

- scenario 0/ do-nothing scenario, used as the basic (real) scenario of the model;
- scenario 1/workload scenario, in which a specific representation of fatigue curves for quay crane operators was performed;
- scenario 2/electrified scenario, in which electrification of all terminal handling equipment was implemented;
- scenario 3/cold ironing scenario, keeping the electrical handling equipment is added to the dock electrification (Cold-Ironing).

Through the simulation model was possible to quantify some indicators. These include functional indicators, such as ships operation time, and others related to environmental impacts, i.e. emissions from ships, horizontal handling means, cranes and trucks, and finally the energy consumption generated by all the means operating inside of the terminal operational areas.

The chapter is divided into two parts: the first part deals with the analysis of the scenarios, explaining the specification of each simulation scenario and its implementation in the simulation model; the second part deals the numerical results of the scenarios simulation considering a complete analysis well to wheels, and at the end of the chapter a summary of these results and the conclusions are presented.

6.2 Scenario analysis

A simulation model, as discussed in chapter four, is an accurate representation of the reality of the system to be simulated, which will allow the dynamic development of a series of events to be evaluated and predicted after the imposition of certain conditions by the analyst. To this end, the model was built based on the investigation of real data as well as the geometrical and functional configuration of the terminal in study.

The arrival of 3 ships per day was simulated according to the real data and technical features of the ships, provided by the website Marine Traffic((“MarineTraffic,” 2021)), by the year 2019, and evaluations regarding the freight traffic of the same year, which were related to the results of the feasibility study ("Smart Green Port") carried out in 2012. This study returned an average number of 1.6 ships per day with around half the freight traffic in 2019. This renders the assumption consistent.

From the data provided by the terminal operator of the port of Salerno ((“SCT - Salerno Container Terminal,” 2021)) an average value was calculated for each type of container (empty/full, 20'/40', loading/unloading) in reference to each ship for one week in June 2019 (Table 6.1). The results were extended to one year (Table 6.2) and compared with the data provided by the Port Authority of Salerno, returning results consistent with the approximation considered.

Date	Condition	IN (unload)		OUT (load)		Total
		20'	40'	20'	40'	
4-Jun	Empty	0	74	0	0	74
	Full	25	2	26	65	118
	Total	25	76	26	65	
5-Jun	Empty	0	62	0	0	62
	Full	24	48	13	23	108
	Total	24	110	13	23	
6-Jun	Empty	0	0	0	9	9
	Full	5	22	23	46	96
	Total	5	22	23	55	
7-Jun	Empty	40	0	10	8	58
	Full	109	54	19	64	246
	Total	149	54	29	72	
8-Jun	Empty	0	0	32	26	58
	Full	89	15	16	55	175
	Total	89	15	48	81	
9-Jun	Empty	0	0	4	0	4
	Full	62	74	67	39	242
	Total	62	74	71	39	

Table 6.2: Comparison of annual movements among the model and real data

Annual average values (TEUs)						
Condition	Model		AdSP data		Difference %	
	IN (unload)	OUT (load)	IN (unload)	OUT (load)	IN (unload)	OUT (load)
Empty	56160	23760	67537	27502	17%	14%
Full	133920	134640	142464	163871	6%	18%

The following table (Table 6.3) shows the fuel types/technologies used for the vehicles in the various Scenarios.

Regard to seaside area, calculations for both the hotelling and manoeuvring phases are reported, although the hotelling phase is the only one for which technological solutions are proposed to reduce consumption and emissions at port level and therefore variations will be observed between the different scenarios. For this reason, the results will only be commented on in relation to the hotelling phase.

Table 6.3: Operational means at the container terminal

Operational Area	**Means involved**	**Scenario 0**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Innerside	**Reach Stacker (RS)**	Diesel	Diesel	Hybrid	Hybrid
	Quay Crane (QC)	Diesel	Diesel	Electric	Electric
	Rubber Tyred Gantry (RTG)	Diesel	Diesel	Electric	Electric
	Tug Master (TM)	Diesel	Diesel	Electric	Electric
Landside	**Truck (TR)**	Diesel	Diesel	Electric	Electric
Seaside	**Ships (Hotelling)**	Marine Diesel Oil	Marine Diesel Oil	Marine Diesel Oil	Cold Ironing
	Ships (Manoeuvring)	Marine Diesel Oil	Marine Diesel Oil	Marine Diesel Oil	Marine Diesel Oil

6.2.1 Scenario 0: Do-nothing scenario

The no intervention scenario is representative of the current situation of the Port of Salerno. The indicators assessed in this scenario should be used as a benchmark respect to those assessed in the next scenarios.

In particular, the model returns in output the time values of all means of both horizontal and vertical movement, as well as the stationing and manoeuvring times of the ships; it also returns the values of the emissions(tons) of some types of pollutants, and finally the energy consumption of all handling means including the ships. Assuming 3 average berths per day. The calculations were extended to all ships passing through the port in one year. The following tables are a summary of the simulation model outputs.

Table 6.4 shows the values of the ships, regarding their operation time in the port (hotelling) as well as the manoeuvring time for enter and leave the port area, manoeuvring time is an average entry time of about 1 hour and it is assumed that the same time is used for leaving the port, these times include the time taken to perform port services, both the pilotage service and the service of towing and mooring the ships. In addition, annual emissions are reported for both the manoeuvring and hotelling phases.

Table 6.4: Emissions and ships' operational time. Scenario 0

Emissions and ships' operational time by year		
Operational time (h)	Hotelling time	5652
	Manoeuvring time	2170
Emissions (t)	HC	15
	$PM_{10/25}$	20
	SOx	123
	NOx	203
	CO2	12421

Below, the data referring to the working hours of the different handling equipment (Reach Stacker, Quay Crane, RTG) and the distances covered within the terminal by Tug Master and Trucks are reported.

Table 6.5: Working times and distances travelled by trucks, tug masters and handling equipment. Scenario 0

Transport mean	**Quantity**	**Working time by year (h)**	**Distance travelled by year (km)**
Reach Stacker	10	15418	-
Quay Crane	4	6307	-
RTG	2	5584	-
Camion	-	-	566753
Tug Master	10	-	388564

Based on the distances travelled by trucks and tug masters, the product of the emission factors (g/km) gives the emissions of various pollutants in one year, as shown in the following table (Table 6.6).

Table 6.6: Annual emissions from trucks and tug masters. Scenario 0

Emissions	**TM**	**Trucks**
	t/year	
CO2	382.0	354.8
NOx	2.5	1.8
PM_{10}	0.1	0.1
$PM_{2.5}$	0.1	0.1
CO	0.7	0.5

For Reach Stacker, Quay Crane and RTG the calculation is not based on distances, instead it is based on working hours, which are multiplied by the power (kWh) of their engine, and by the emission factors (g/kWh) by each pollutant (Table 6.7).

Table 6.7: Emissions Reach Stacker, Quay Crane, RTG. Scenario 0

Emissions	**RS**	**QC**	**RTG**	**Total**
	t/year			
CO2	499.3	417.9	148.0	1065.2
NOx	9.3	11.3	5.7	26.3
PM_{10}	0.6	0.7	0.4	1.7
$PM_{2.5}$	0.5	0.6	0.3	1.5
CO	9.9	12.1	6.1	28.2
HC	2.6	3.2	1.6	7.5

Regarding energy consumption, the next table shows the energy consumption of each terminal handling equipment extended to one year of work.

Table 6.8: Energy consumption by all transport means. Scenario 0

Energy consumption (MWh/year)	
Means involved in terminal activities	**Scenario 0**
Reach Stacker	3546
Quay Crane	4037
RTG	2044
Tug Master	1117
Truck	1765
Ships (Hotelling)	18846

Finally, a summary table of the energy consumption for each operational area of the terminal is presented.

Table 6.9: Energy consumption by area. Scenario 0

Energy consumption (MWh/year)	
Area	**Scenario 0**
Innerside	10744
Landside	1765
Seaside (Hot.)	18846

6.2.2 Scenario 1: Workload

Port efficiency may be achieved through an effective organization of the logistic process, using effective handling unit, and adopting advanced technologies. Nevertheless, the human factors continue, and will continue, to play a central role, in particular, the human fatigue due to the workload is a crucial issue which must be care-fully considered and carefully managed in daily activities.

Fatigue may have significant impacts on the port operations efficiency, but also on the safety of each single workers and on the "safety" of the whole terminal.

To this aim, the workload scenario has been implemented in this thesis following two approaches:

- the first one (1a) on deterministic base;
- the second one (1b) through the application of the Yerkes-Dodson law.

Scenario 1a

In the first approach a deterministic logic that simulates the fatigue curve of crane operators is presented. There are various studies in the literature that build human performance curves as a function of time, the Gamma distribution implemented in the model (Cartenì and de Luca, 2012), considers time due to fatigue, however in this scenario attempt to give to the fatigue a more central role. In AnyLogic® it was assumed as a deterministic value variable in the time. Assuming that the shift time is 6 hours, it was decided to divide the shift into 3 parts: (i) the first, two hours of maximum efficiency where the operating time is given by the average (μ) minus the standard deviation(σ), (ii) the two central hours of medium attention where the processing time is equal to the average(μ), and (iii) the last two hours with a high level of fatigue where the processing time is given by the average(μ) plus the standard deviation (σ) (Figure 6.1).

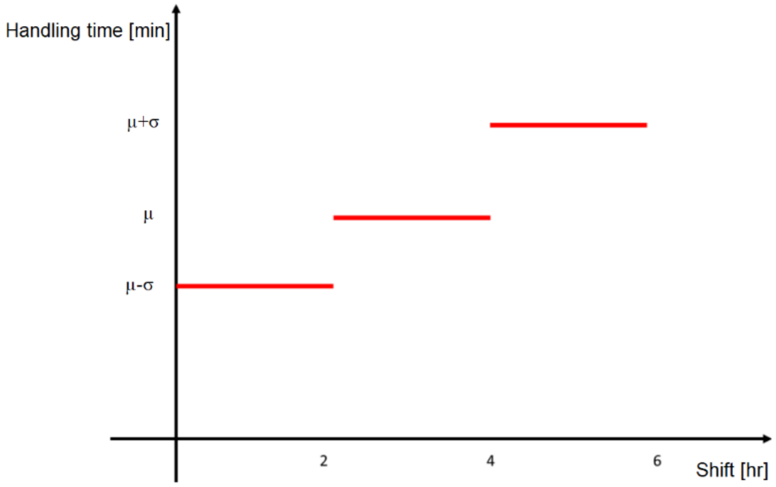

Figure 6.1: Performance curve as function of time.

Clearly, this hypothesis is a considerable simplification since a human task does not follow a deterministic time, however having reduced the time interval from 6 to 2 hours it is more likely that the values assumed are close to the average. In order to implement this logic, a state chart to three-stages has been constructed (Figure 6.2). Cyclically, every 120 minutes, it passes from one stage to the next, modifying the processing times (Table 6.10). Since the ships usually arrive at the beginning of the shift, this strategy takes advantage of the best moment of the workers by unloading most of the containers in the shortest time possible, then when the operator gets tired there are only a few containers left to process.

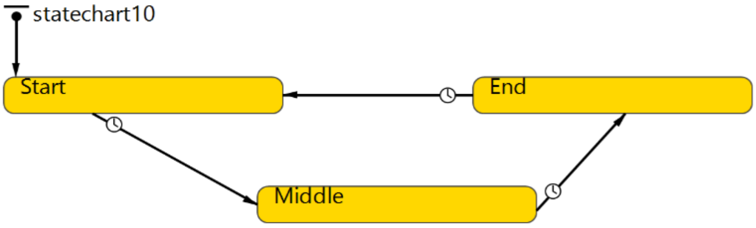

Figure 6.2: Three stages state-chart.

Table 6.10: Three stages processing times

Activity	Start(min)	Middle(min)	End(min)
Unloading_Crane_Time_20_Full	0.642	0.825	1.008
Unloading_Crane_Time_40_Full	0.647	0.835	1.023
Unloading_Crane_Time_20_Empty	0.525	0.664	0.803
Unloading_Crane_Time_40_Empty	0.588	0.788	0.988
Loading_Crane_Time_20_Full	0.833	1.238	1.643
Loading_Crane_Time_40_Full	0.886	1.288	1.690
Loading_GC_Time_20_Full	0.430	0.741	1.052
Loading_GC_Time_40_Full	0.312	0.769	1.226
Unloading_RS_Time_20	0.088	0.144	0.200
Unloading_RS_Time_40	0.113	0.200	2.870
Loading_RS_Time_20	0.149	0.304	0.459
Loading_RS_Time_40	0.123	0.311	0.499
Stacking_RS_Time	0.114	0.260	0.406

The comparison is made only on the functional part, in relation to the average processing time per year, which is no more than the hotelling time since the processing time of each terminal handling equipment impacts on this ship operating time rather than the manoeuvring time. The results of the ship times extended to one working year are shown in Table 6.11.

Table 6.11: Ships' operational time. Scenario 1a

Ships' operational time by year		
Operational time (h)	Hotelling time	5765
	Manoeuvring time	2170

It is noted that the average is greater than the result measured in the base case, by 5652 hours as expected (Table 6.4), however, the difference in this case is 2%, it is closer to the actual result, although in a marginal proportion, clearly this approach does not show a significant increase in time in operations due to fatigue.

Scenario 1b

In the second approach, the performance was implemented according to the Yerkes-Dodson curves, which states that the optimal motivation for task performance decreases with increasing task difficulty (Figure 6.3), also defined in literature as the inverted U model of arousal (Figure 6.4). It states that at low arousal, performance is poor; it improves up to its highest point corresponding to the optimal level of arousal.

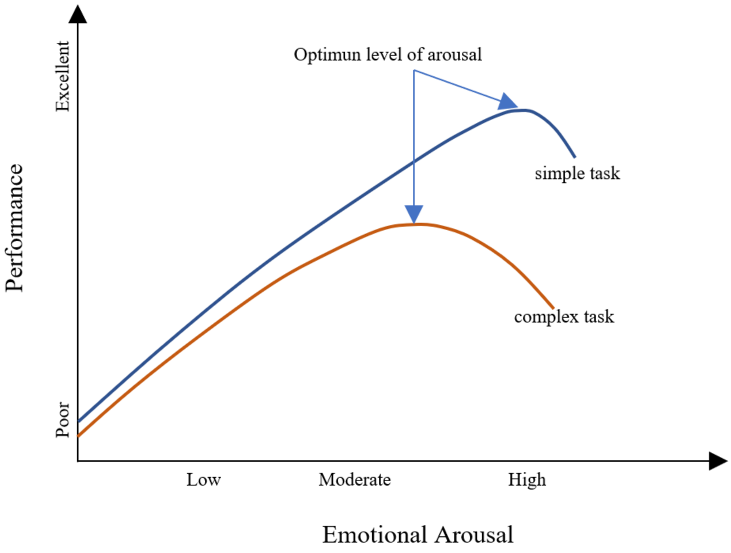

Figure 6.3: Original Yerkes-Dodson law (Source: own elaboration based on (Curry et.al, 2013)).

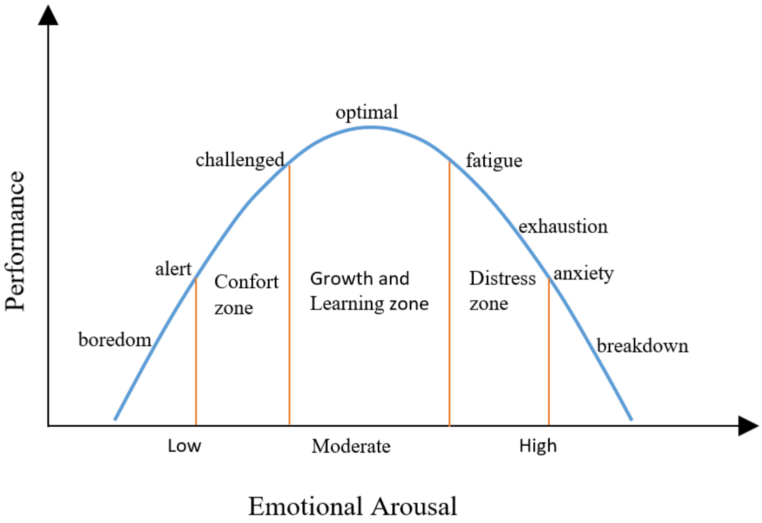

Figure 6.4: Yerkes Dodson curve: Relationship between performance task and arousal/stress state (Source: own elaboration based on (Bodeker et.al,(2021)).

The left side of the curve represents low emotional arousal, whilst the right side represents high emotional arousal and in the middle is a medium level of it. The vertical line on the left side goes from low performance (at the bottom) to maximum performance (at the top). The optimal state of emotional arousal and performance is located in the centre of the curve.

Therefore, different curves are expected for each shift, as the stimulation differs between shifts, especially at night. As can be seen in (Figure 6.5), the average performance curve for different shifts and different days constructed from data provided by Salerno Container Terminal has a maximum point almost halfway of the shift, with an increasing part to the left and a decreasing part to the right that is more pronounced than the previous one, indicating a strong influence of fatigue. The hypothesis described in deterministic scenario (1a) is not analogous to the idea presented in the theory of fatigue, which predicts maximum performance not at the beginning, instead after receiving the precise stimulation. Upon receiving more stimulation, in this case, performance tends to decrease more rapidly than it had increased.

The curve is represented by a second-order polynomial, and defined through equation (6.1).

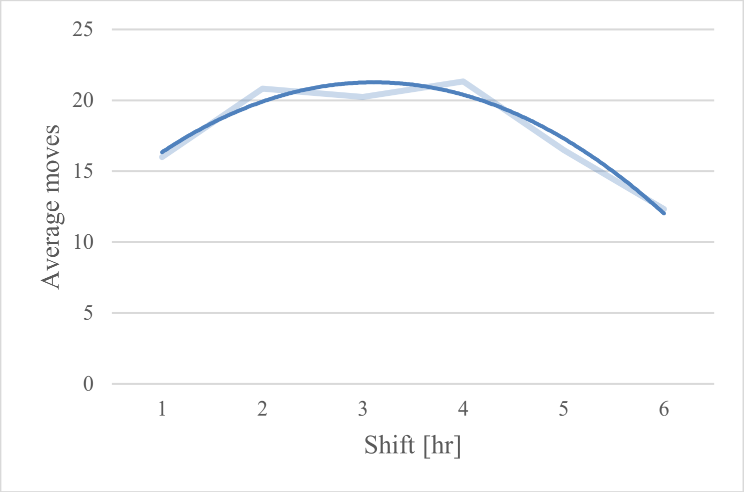

Figure 6.5: Y-D curve created from the data of the average number of movements ***per*** *shift.*

$$Y = -1.107x^2 + 6.8857\,x + 10.567 \tag{6.1}$$

The coefficient of determination (R2) of the (6.1) is equal to 0.94, and therefore resulted a good reliability in reproducing the phenomena.

In this case, this behaviour is implemented in the simulation model in a similar way to scenario (1a) but using representing data that reproduces the trend described above. Corresponding values are then given to proportion the times that the quay cranes take per hour; these proportion values are higher the more fatigue is felt (Figure 6.6).

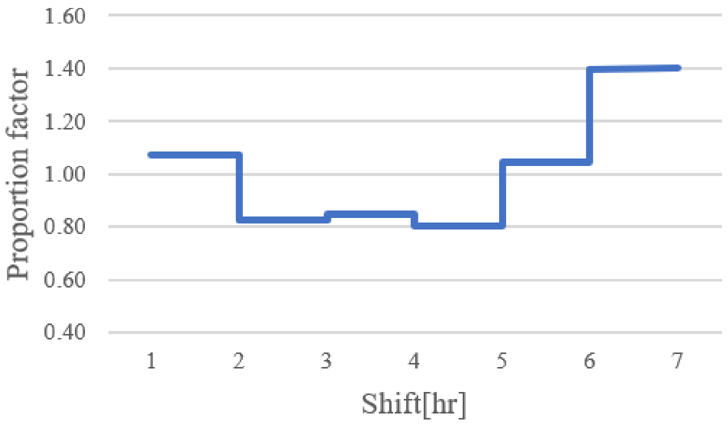

Figure 6.6: Quay cranes working time proportion factors.

Table 6.12: Three stages processing times

Agents	**Operation**	**Average(min)**	**Shift hours**					
			1	2	3	4	5	6
			1.076	**0.827**	**0.850**	**0.807**	**1.044**	**1.3960**
Quay Crane	Load20E	1.084	1.167	0.896	0.922	0.807	1.131	1.513
	Load40E	1.101	1.185	0.910	0.936	0.889	1.149	1.537
	Unload20E	0.664	0.715	0.549	0.565	0.536	0.693	0.927
	Unload40E	0.835	0.899	0.690	0.710	0.674	0.871	1.166
	Load20	1.238	1.332	1.023	1.053	0.999	1.292	1.728
	Load40	1.288	1.386	1.065	1.095	1.040	1.344	1.798
	Unload20	0.825	0.888	0.682	0.702	0.666	0.861	1.152
	Unload40	0.835	0.899	0.690	0.710	0.674	0.871	1.166

The results are shown below

Table 6.13: Ships' operational time, scenario 1b

Emissions and ships' operational time by year		
Operational time (h)	Hotelling time	5313
	Manoeuvring time	2170

As can be seen in the results of scenario 1b, the processing time of ships in one year is even lower than that measured in scenario 0.

In this case, the error is approximately 6%, practically twice that of scenario 0 and three times that of scenario 1a. This should be related to the fact that when implementing this curve, the effect of fatigue is specifically taken into account, but not other events that have an influence on the total time of the ships, such as contingencies, failures, delays, etc. have been considered, whereas the Gamma distribution, implemented before, considered them.

Finally, the poor performance of this configuration compared to scenario (1a) can be explained by the fact that, although the configuration (1a) appears to be too simplified, nevertheless, by considering the time increasing through the standard deviation, the influence of other factors not taken into account by the other approach, is included.

6.2.3 Scenario 2: Electrified means

In the second simulation scenario it has been decided to make a substitution of the handling equipment in the innerside and landside areas in the terminal (Table 6.14), where the substitution will be made by changing the internal combustion engines used in the cranes, tug masters and trucks for electric engines, instead for the reach stackers the substitution will be with a hybrid engine, since at the moment there are no fully electric engines that can maintain the same working performance for this handling equipment.

On the seaside, the operating hours and emissions of the ships maintain a non-significant change (Table 6.14), as they work with the same demand as in scenario 0, therefore the times are similar as well as the emissions.

Table 6.14: Emissions and ships' operational time. Scenario 2

Emissions and ships' operational time by year		
Operational time (h)	Hotelling time	5753
	Manoeuvring time	2170
Emissions (t)	HC	15
	PM	20
	SOx	123
	NOx	205
	CO2	12527

Regarding the emissions of the handling equipment, in the table 6.15 reported below, shows a considerable change, this is due to the fact that the vertical handling equipment works with electric motors producing zero pollution in the course of operations, therefore the only handling equipment that brings a minimum of pollution are the reach stackers, as they work with hybrid motors.

Table 6.15: Emissions Reach Stacker, Quay Crane, RTG. Scenario 2

Emissions	**RS**	**QC**	**RTG**	**Total**
	t/year			
CO2	380.4	0	0	380.4
NOx	7.1	0	0	7.1
PM_{10}	0.5	0	0	0.5
$PM_{2.5}$	0.4	0	0	0.4
CO	7.6	0	0	7.6
HC	2.0	0	0	2.0

As in the case of cranes, horizontal transport means, in this case tug masters and trucks, report a total decrease in emissions as internal combustion engines are replaced by electric motors (Table 6.16).

Table 6.16: Annual emissions from trucks and tug masters. Scenario2

Emissions	**TM**	**Trucks**
	t/year	
CO2	0	0
NOx	0	0
PM10	0	0
PM2,5	0	0
CO	0	0

Regarding energy consumption, there is a considerable reduction in energy consumption in all vehicles working in the terminal (Table 6.17).

Table 6.17: Annual energy consumptions from all handling means. Scenario 2

Energy consumption (MWh/year)	
Means involved in port activities	**Scenario 2**
Reach Stacker	2429
Quay Crane	3849
RTG	675
Tug Master	469
Truck	749
Ships (Hotelling)	19184

Finally, a summary table on energy consumption per work area is given.

Table 6.18: Energy consumption by area. Scenario 2

Energy consumption (MWh/year)	
Area	**Scenario 2**
Inner-side	7421
Land-side	749
Sea-side (Hot.)	19184

6.2.4 Scenario 3: Electrified means - Cold Ironing

Scenario 3 relates to the implementation of cold ironing, keeping the electric vehicles working in the terminal.

Cold-Ironing refers to the replacement of conventional technology, which involves propulsion engines using MDO/MGO type fuels, by an electrified one. Substantially consists in the possibility of directly provide the electric energy to the Ships, at the dock, allowing the switching off the Ship's auxiliary engines. The direct consequence is a strong reduction in local air pollution, noise and vibration impact [(Ballini and Bozzo, 2015) (Entec U.K. Limited, 2005)]. European Commission has promoted the provision of shore-power to its member states via an official recommendation (European Commission, 2006).

Allowing the engines to be turned off in the stationary phase for both large ships and small ships and is therefore aimed at reducing CO2 emissions and improving the environmental quality of the ports and surrounding areas. The on-board electrical system is powered from the shore-based network to allow gradual disconnection of the auxiliary generators. At the moment, it is not yet widespread due to high implementation costs. However, with a view to achieving the objectives of efficient management and use of natural and human resources, ensuring a more environmentally friendly, safe, and efficient transport system, and making a significant contribution to climate change mitigation and adaptation, the use of this technology is expected to grow. The success of this type of initiative requires the development of a wide-ranging collaborative network involving different categories of stakeholders (shipping companies, terminal operators, seaport system authority, technology and equipment suppliers, research and development centres, etc.).

In addition to the massive reduction of CO2, the electrical infrastructure of the port docks produces significant benefits in terms of reducing nitrogen and sulphur oxides, fine particles, and noise pollution, however, the costs are about 2.5 million euros to power point, and this could be a limiting factor in some ports, especially those with reduced capacity.

Returning to the description of the scenario implemented in the simulation model, a total grid connection/disconnection time of 20 minutes (10 per phase) was considered. This has been included within the standby time.

The following table (Table 6.19) shows the significant reduction in emissions for some of the ships, this is a consequence of switching off the engines in the operation phase of the ships and connecting them to ensure the operation of the auxiliary engines in the time remaining in the terminal.

Table 6.19: Time and ship emissions. Scenario 3

Emissions and ships' operational time by year		
Operational time (h)	Hotelling time	5668
	Manoeuvring time	2170
Emissions (t) (Manoeuvring phase)	HC	11
	PM	16
	SOx	111
	NOx	110
	CO2	6519

The information on vertical handling equipment, trucks and tug masters is reported in scenario 2 since the same innovative equipment is still considered from the point of view of its electric and hybrid propulsion. The same applies to the emissions and energy consumption of Reach Stacker, Quay Crane and RTG (see Table 6.15, Table 6.16, Table 6.17).

Regard to energy consumption, there is a large decrease by part of the ships, with about 50% reduction compared to scenario 0 in the hotelling phase (Table 6.20).

Table 6.20: Annual emissions from all handling means. Scenario 3

Energy consumption (MWh/year)	
Means involved in port activities	**Scenario 3**
Reach Stacker	2429
Quay Crane	3849
RTG	675
Tug Master	469
Truck	749
Ships (Hotelling)	9450

Finally, a summary table on this simulation scenario is given, with the aim of showing the energy consumption generated per area of operation in one working year. The analysis and comparison between scenarios will be done in the following section.

Table 6.21: Energy consumption by area. Scenario 3

Energy consumption (MWh/year)	
Area	**Scenario 3**
Inner-side	7421.3
Land-side	748.7
Sea-side (Hot.)	9450.3

6.3 Numerical Analysis

The numerical analysis of the scenarios is carried out through the comparison between scenario 0 (do nothing scenario), scenario 2 (electrified means) and scenario 3 (cold ironing), considering a complete well-to-wheels analysis (Figure 6.7).

The energy consumption of different technological solutions is observed, the CO2 emissions is used as key indicator for the environmental assessment performed throughout a Well-to-Wheels analysis (WTW). This last is composed of a Tank-To-Wheels TTW (from the tank to the wheels) analysis which considers the in-use consumption and emissions of the vehicle, and of a Well-To-Tank WTT (from well to tank) analysis which considers the extraction, conversion and transport processes of the energy carrier used (Figure 6.7).

In order to evaluate the WTW is of kernel importance to identify the technology of the handling means and the energy carrier used. Three different scenarios with a higher level of electrification of the technology involved are analyzed. In Scenario 0 or "Do-Nothing" Scenario all handling means are conventionally fueled; in Scenario

2 or “Electrified Means” Scenario all handling means are electric or hybrid and, finally, in Scenario 3 or “Electrified Means and Cold-Ironing” Scenario, in which all handling means are electric and cold ironing is used to power the ships during ship operations instead of using the ships fuel.

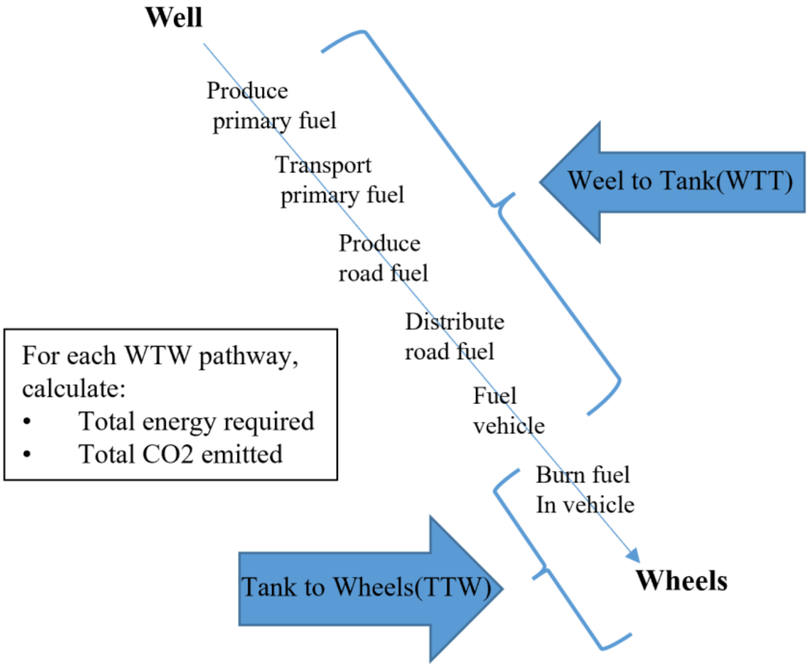

Figure 6.7: Well to wheels analysis: (Source: own elaboration based on “Sustainable transport systems: Energy and environmental issues”, 2021)

6.3.1 Well to tank analysis

The following figure shows the results in tonnes of CO2 produced in a year by the single handling mean, for the Well-to-Tank (WTT) analysis in the 3 Scenarios considered.

The very strong increase in the Well-to-Tank emissions in the transition from conventional vehicles (Scenario 0) to electric/hybrid ones (Scenarios 2 and 3) is evident. The ratios of Scenarios 2/3 compared to Scenario 0 go from 5:1 in the case of Tug Masters (186 ton/year vs 28 ton/year) and Trucks (297 ton/year vs 45 ton/year), and to 15:1 in the case of Quay Cranes (1528 ton/year vs 104 ton/year).

In the Ships case, the transition from Scenario 0/2 (about 500 ton/year) to Scenario 3 (about 3750 ton/year) there is an increase of emissions of about 7 times.

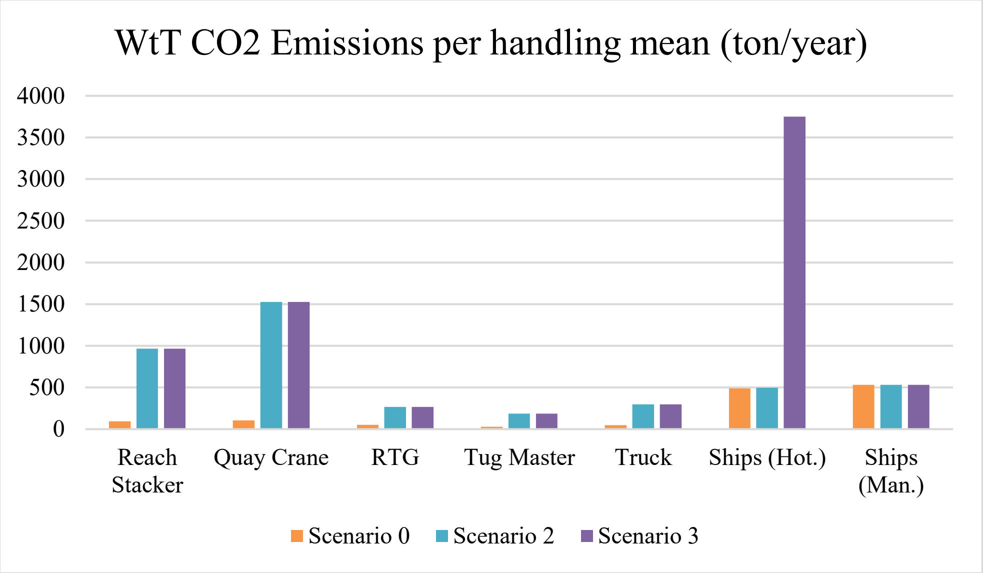

Figure 6.8: WtT CO_2 emissions per handling mean.

The calculation by operational area is presented in the figure 6.9.
Since landside and seaside area coincides with Trucks and Ships from the previous figure, the ratios remain the same.
For the innerside area the ratio of Scenarios 2/3 compared to Scenario 0 is about 10:1 (2946 ton/year vs 278 ton/year).

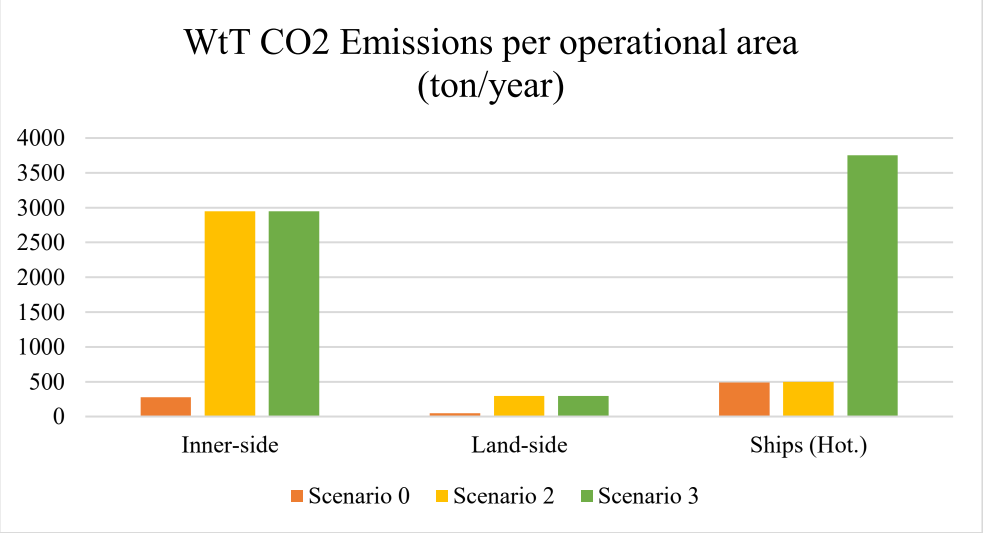

Figure 6.9: *WtT CO_2 emissions per operational area.*

6.3.2 Tank to wheels analysis

Energy Consumption assessment

A variety of sources including data sheets from vehicles manufacturing companies (Liebherr, Gottwald, Sennebogen, Terberg etc.), literature data (Iris and Lam, 2019), and analytical evaluations were referenced to assess energy consumption.

The calculation was carried out by first assessing individual vehicles and then by operational area.

The percentage differences between Scenarios 2 and 3 with respect to Scenario 0 were also assessed.

Table 6.22: Energy consumption assessment

Energy consumption (MWh/year)						
Area	**Means**	**Scenarios**			**Scenarios differences (%)**	
		0	**2**	**3**	**0-2**	**0-3**
Innerside	***Reach Stacker (RS)***	3546	2429	2429	-32%	-32%
	Quay Crane (QC)	4037	3849	3849	-5%	-5%
	Rubber Tyred Gantry (RTG)	2044	675	675	-67%	-67%
	Tug Master (TM)	1117	469	469	-58%	-58%
Landside	***Truck (TR)***	1765	749	749	-58%	-58%
Seaside	***Ships (Hotelling)***	18846	19184	9450	2%	-50%
Seaside	***Ships (Manoeuvring)***	20549	20549	20549	0%	0%
Total	(Manoeuvre excluded)	31356	27354	17620	-13%	-44%

The results show that in general consumption decreases when switching from conventional to electric vehicles. The most evident difference is observed for RTGs (67%), which the consumption in kWh/move is strongly favourable for an electric vehicle compared to a diesel one. The tug masters and trucks present an identical reduction compared to the scenario 0, being the means (after RTGs) that made the biggest difference in terms of reducing energy consumption.

The difference is lower for Quay Cranes that as electric Cranes also have high power outputs compared to conventional ones.

Reach Stackers have smaller differences between Scenario 0 and Scenarios 2 and 3 (32%) than Tug Masters and Trucks (58%) because in the current analysis it refers to RS that are not fully electric, rather hybrid according to what was found in the open literature or data from the producers of these vehicles.

Emissions assessment

Different graphs will be reported for CO2, both for the TtW and the WtT analyses. Regard to the other pollutants, which will instead be adopted only in the Tank-to-Wheels. The results are reported in the Figure 6.10.

It can be observed that the major contribution to emissions is related to Ships, especially for NOx (both for the hotelling phase with 93 tons/year and for the manoeuvring phase with 110 tons/year) and SO2 (for the manoeuvring phase with a maximum value of 111 tons/year constant for the 3 Scenarios). The contribution of inner-side area is also relevant, as it includes 4 categories of vehicles, especially for NOx and CO emissions (28 tons/year for both in Scenario 0). The lowest impact is linked to the landside area.

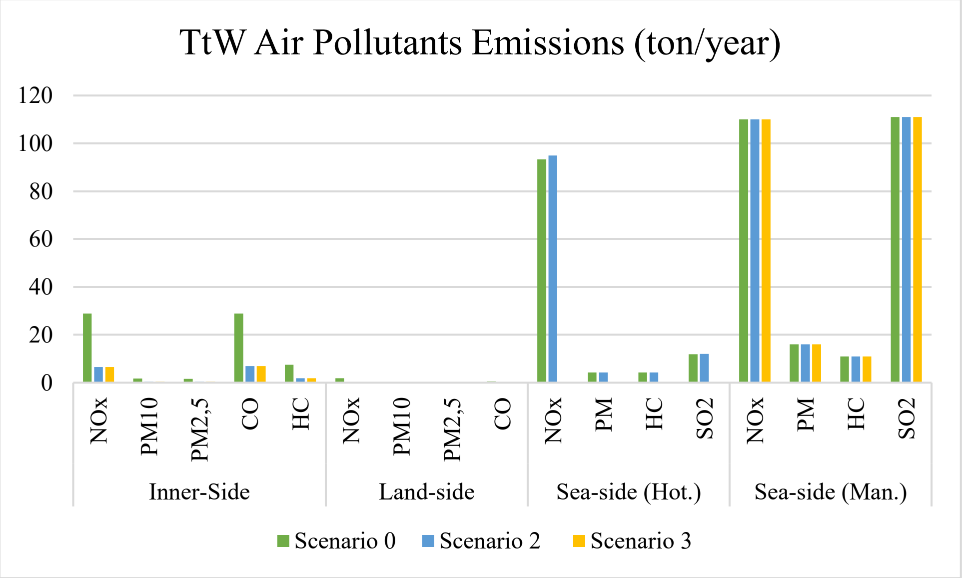

Figure 6.10: TtW Air pollutants emissions per operational area.

The following graphic (Figure 6.11) shows the results of the tonnes of CO2 produced in a year by the single handling mean, in the Tank-to-Wheels (TTW) analysis for the 3 Scenarios considered.

The Figures highlight that for the vehicles of the land side and innerside areas, except for the Reach Stacker (hybrid), the emissions are zero in Scenarios 2 and 3 since the vehicles are electric.

For the seaside area, emissions (about 6000 ton/year) remain the same in the hotelling phase between Scenarios 0 and 2, and go to 0 for Scenario 3, since the use of Cold-Ironing is assumed.

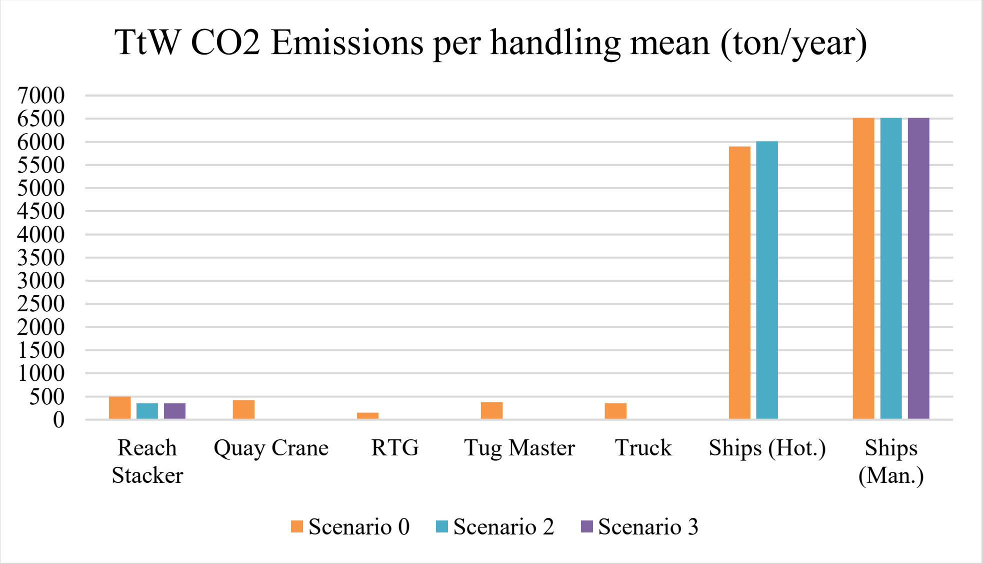

Figure 6.11: TtW CO_2 emissions per handling mean.

The calculation has been also conducted by operational area.
Landside and seaside area coincides with Trucks and Ships from the previous figure, while the inner-side area includes Reach Stacker, Quay Cranes, RTG and Tug Master. The total CO2 reduction for the innerside area is 76%.

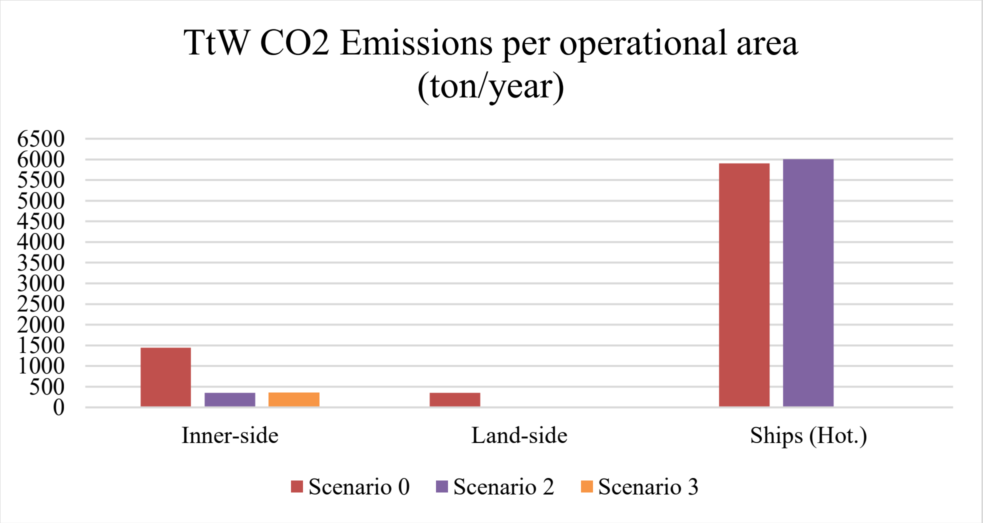

Figure 6.12: - TtW CO_2 emissions per operational area.

6.3.3 Well to wheels analysis

The following figure shows the results of the tonnes of CO2, in the Well-to-Wheels (WTW) analysis emitted in the 3 Scenarios for the single kind of vehicle.
It is evident how for some of the vehicles, i.e. Reach Stacker, Quay Crane and RTG, in the transition from Scenario 0 to Scenarios 2 and 3 there is a reduction in CO2 emissions. For Trucks, Tug Masters and Ships (in this case the variation is evident in the transition from Scenario 0 and 2 to Scenario 3), the opposite occurs.
This difference depends on the characteristics of each vehicle in terms of consumption and technology used.

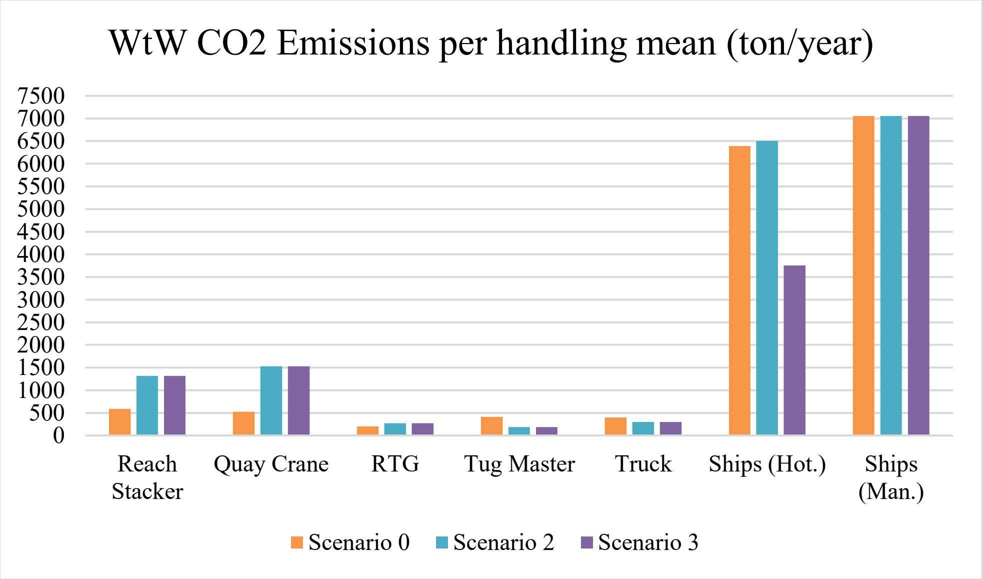

Figure 6.13: WtW CO_2 emissions per handling mean.

The differences of WTW for operational area reported below.

For the innerside area it can be observed that, despite the use of electric/hybrid vehicles, the overall contribution to emissions is greater than that of conventionally powered vehicles.

For the land-side area the emission values are similar in the various scenarios.

Finally, for the sea-side area, it is possible to observe the important reduction of emissions through the use of Cold-Ironing (Scenario 3).

Results summary

The following figure (Figure 6.14) shows the aggregate results, adding the contributions of all the vehicles involved in the analysis.

The trends in the Well-to-Tank and Tank-to-Wheels analyses are opposite in the transition from Scenario 0 to Scenario 3.

This is because the use of electric/hybrid vehicles has a strong impact in reducing emissions at the local level (TtW analysis), but the production, transport, and distribution of electricity (WtT analysis) results in high emissions.

Observing the values given by the sum of the two previous analyses (Well-to-Wheels), it is noted that Scenario 2, despite the use of electric/hybrid vehicles, has an increase in emissions of 18%.

On the other hand, a reduction in overall emissions is seen for Scenario 3, in which, in addition to electric/hybrid vehicles, Cold-Ironing is also used. This reduction is equal to about 14% with respect to Scenario 0.

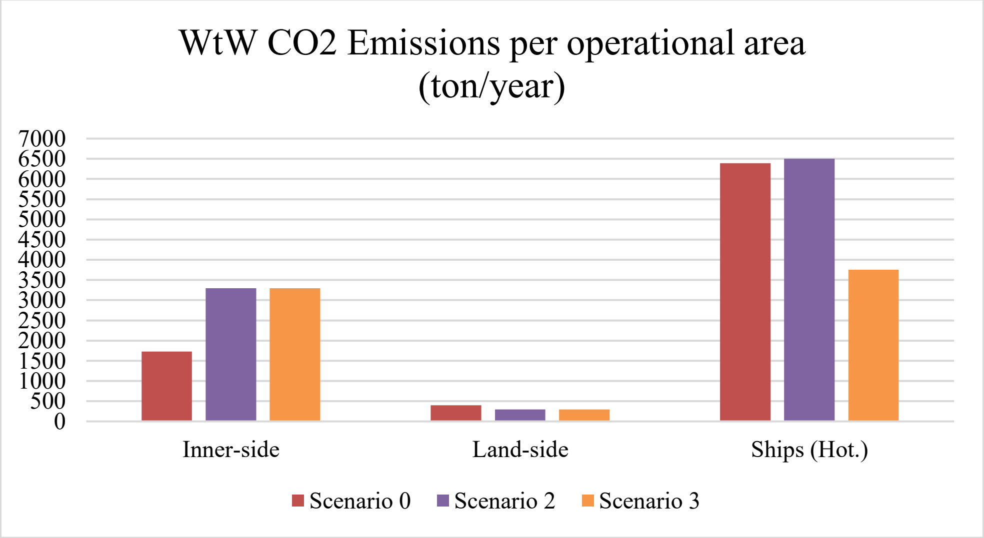

Figure 6.14: WtW CO_2 emissions per operational area.

6.4 Conclusions

Ports are of great importance as strategic hubs and key elements of logistics chains, but at the same time they pose a number of issues in terms of pollutants and greenhouse gases emissions.

The objectives of this chapter can be split into two parts.

The first part deals with the simulation of crane operator fatigue. Several studies on workers fatigue were found in the literature but still is limited the research on crane operators. In this work, the Yerkes-Dodson law was used as reference for the representation of the fatigue behaviour for crane operators. The simulation model of the container terminal adopted in study is implemented using discrete event and multi-agent approaches on the simulation model specified and validated in chapter 5. A specific scenario (Scenario1) was built to simulate operator's fatigue. This scenario was in two parts according the two following approaches: (1a) concerns a variation of the operating time within a work shift con-sidering that the crane operator has his best performance at the beginning of the shift. The second approach (1b) covers a variation of the operating time following the Yerkes-Dockson law, which is represented by a convex polynomial curve, showing the operator's fatigue behaviour in a work shift. In particular, the idea that the polynomial time-varying approach (1b) was a closer reproduction of reality than the deterministic time-varying approach (1a) was rejected, as the results showed that when implementing this curve, only the effect of fatigue was taken into account, but other events influencing the total ships operating time, such as accidents, breakdowns, delays, etc., have not been considered. On the other hand, although the configuration (1a) appears to be too simplified, nevertheless, by considering the time increasing through the standard deviation, the influence of other factors not taken into account by the other approach, is included.

Regard the second part of the chapter, the aims was to assess the energy consumption, and emissions within a discrete-event multi-agent model of the entire fleet of vehicles involved in port activities, and its validation with updated data provided by terminal operators.

Comparisons between consumption and emissions of conventional vehicles (diesel fuelled), with respect to innovative vehicles/technologies (electric or hybrid powered) have been shown to highlight the differences among various Scenarios using a Well-to-Wheels approach. Additionally, also the Cold-Ironing is considered for one of the electrified scenarios.

The case study is related to the port of Salerno and the Scenarios compared are 3 with respect to the Tank-to-Wheels and Well-to-Tank approaches, subsequently added together in the Well-to-Wheels:

- Scenario 0 or Do-Nothing Scenario (DNS)
- Scenario 2 or Electrified Means (No Cold-Ironing) Scenario (EMS)
- Scenario 3 or Electrified Means and Cold-Ironing Scenario (EMCIS)

The aggregate data on CO2 shows that in the transition from conventional means/technologies to innovative means/technologies (and therefore from Scenario 0 progressively to Scenario 2 and Scenario 3) there is a strong reduction in the Tank-to-Wheels phase and therefore at local level. In particular, the reduction goes from 7705 tons/year for Scenario 0, to 6357 tons/year for Scenario 2, and finally to 350 tons/year for Scenario 3.

An opposite trend is observed for the Well-to-Tank, where emission factors are higher for electricity production, transport and distribution than for diesel. The results at this stage are as follows: 813 tons/year for Scenario 0, 3741 tons/year for Scenario 2, and 6995 tons/year for Scenario 3.

It is interesting to observe that from a global point of view (Well-to-Wheels) the results return, despite the use of electric/hybrid vehicles for land-side and inner-side areas, higher emissions for Scenario 2 than for Scenario 0. Scenario 3 results in the lowest CO2 production.

The main contributions consist in the overall analysis of consumption and emissions of the whole fleet of vehicles involved in the activities of the container terminal by means of a discrete event and multi-agent model (developed in chapter 5).

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7 Multi Criteria Decision Making with Analytic Hierarchy Process

7.1 Introduction

Port planning must consider several elements in its development: port development strategy; the relationship between port and city; port financing; the key financial players; economic impacts, both local as national; and environmental impacts. The master plan usually sets out a 10-year port development option, where many different interests come into play, and it requires an agreed course of action. This chapter examines the challenges that a port faces in achieving its primary objectives as outlined in its master plan.

Any maritime port is a small part of the logistic chains, but it may be a giant link for its efficiency.

If its internal efficiency significantly affects its competitiveness and the competitiveness of its catchment area (direct), on the other hand a port may have significant indirect impacts (positive or negative) on the city, and on the resident and economic activities which are located near the port.

A maritime port is an exemplary case study in which several stakeholders, different visions and different goals should be coordinated toward a unique planning framework which should allow achieving the best compromise.

Such an issue relies on a wide literature, but in the recent years the rapid evolution of the maritime sector is creating new challenges for any port, especially in those ports located in urban contexts.

Indeed, together with the internal efficiency, a maritime port/terminal planning should take carefully into account the environmental impacts (atmospheric, acoustic, energy), the social impacts on the workers and the population, the economic impacts on its catchment area and, finally, should pay attention to the impacts on the city (congestion, travel time of resident and freight, etc..).

The objective of the present chapter is to perform a Multiple Criteria Decision Making (MCDM) analysis of the case study treated in this thesis (Salerno Container Terminal) to analyse the functional, environmental and social impact assessment of port operations. This analysis has given rise to general and specific objectives. The General one are: (i) promote the acceptance of specific political choices in terms of port planning (public engagement) and (ii) ranking the different actions to adopt for this aim. The Specific objective is to highlight and quantify the weight for different stakeholders with reference to various macro-objectives. In particular, the functional, environmental, social, and economic impact of ports are analysed.

As reported in the open literature (Mardani et al., 2016, 2015a) the MCDM analysis is considered as a complex decision-making (DM) tool involving both quantitative and qualitative factors. It allows: (i) to guide the decision-maker with regard to evaluating numerous and conflicting choices, (ii) to provide a rational process for choice problems with different objectives and criteria, and (iii) to identify the best compromise solution.

A methodological framework is reported in Figure 7.1:, where the first step in a MDCM technique is to define the objectives, then the performance criteria for each objective are identified. Successively, the competing alternatives are considered. There is after a weighting and scaling phases, that can be performed by several methods such as AHP, FAHP, ANP, etc. In the open literature several studies have been published on these methods, an extensive review and comparison can be found in (Mardani et al., 2016, 2015b, 2015a). In this thesis, the AHP method has been applied being one the most suitable for similar application analysed in this study. Finally, the combination and decision processes are performed as aim of the adoption of the MCDM technique.

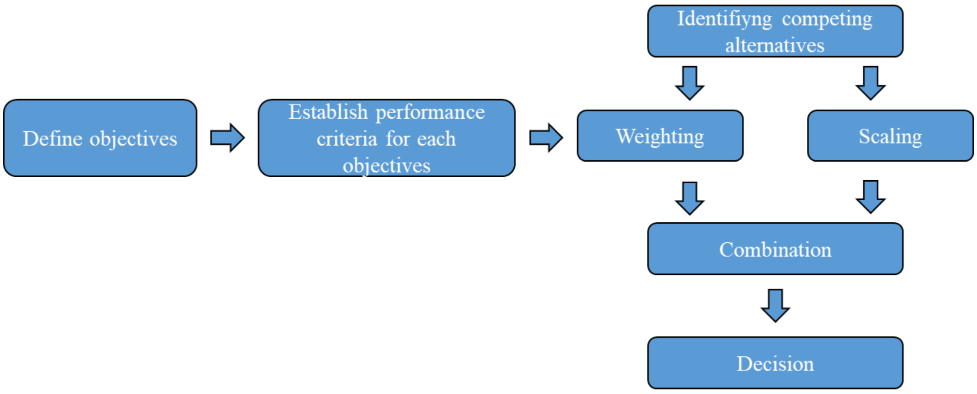

Figure 7.1: Multiple Criteria Decision Making (MDCM) methodological framework.

The rest of the chapter is organised as follows: The section 2 highlights the multi-criteria analysis methods used in a transport system and how could be used in a container terminal. Section 3 presents the survey design, identifying the objectives, the performance criteria and sub-criteria for each of them, the stakeholders are characterised, and the layout of the questionnaire is defined as well as the methodology to be used for the application of the AHP. After in the section 4 the descriptive analyses of the survey results are reported. The section 5 shows the specification of a MCDM through the analytical hierarchy process (AHP) in a case study and finally in the section 6 the conclusions chapter are presented.

7.2 Multi-Criteria Decision Making

Transport systems simulation could be aimed to design physical elements and/or organisational interventions on the transport supply, as well as to assess the effects of such interventions to verify their technical suitability and provide the elements to support choices and implementation decisions. The contexts and types of intervention can be very diverse, as can the perspectives against which the consequences can be assessed. Projects may concern transport infrastructures, regulation and control systems, services and tariffs to be offered; all these interventions may be designed and verified from the point of view of the community served by the transport system under consideration, i.e. the companies producing transport services. A close interdependence between design and decision-making, or system planning, is therefore evident. The decision-making process may concern the evaluation of a project, or the comparison of alternative project solutions. In the first case it is a matter of deciding whether it is economically and financially viable to carry out a project. In the second case, the decision-making process is aimed at choosing the best of several proposed solutions for a project whose cost-effectiveness has been recognised in advance.

The methods for evaluating interventions in the transport system essentially fall into two types: the traditional benefit-cost method, as an example of economic evaluation, and revenue-cost analysis as an example of financial evaluation. On the other hand, the Multi-Criteria analysis methods are those used for the comparison of alternative intervention hypotheses and that will be discussed in more detail in this section.

7.2.1 Multi-Criteria Decision-Making Process

[1] Transport system interventions can have an impact in various areas, e.g. economic, social, administrative, environmental, etc., and can therefore contribute in various ways and degrees to the pursuit of the various, sometimes conflicting, objectives of

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[1] Extract of "Modelli per i sistemi di trasporto. Teoria e applicazioni" (Cascetta 2006)

the decision-makers. Therefore, it is not possible to find projects that maximise the pursuit of all relevant objectives at the same time.

The Multi-Criteria methods, leave the ambition to identify the optimal solution from the point of view of aggregate social welfare and move, on the contrary, in search of the solution of best compromise between the various objectives pursued, i.e. the one in which those investments are identified whose aggregate impacts are as close as possible to their optimal value, and the one in which all those involved in the decision-making process believe they have obtained the maximum possible "gain" and have renounced a quantum that is in any case considered acceptable.

Multi-Criteria Analysis (MCA) establishes preferences between alternatives based on how each of them impacts on the set of explicit objectives that the decision-maker has identified and, for which, he has established measurable criteria.

Multi-criteria methods do not require all the impacts of an investment to be expressed in monetary terms but allow each project effect to be measured using the scale and unit of measurement most appropriate to it. For example, the impact on the accident rate resulting from the construction of a road infrastructure can be measured in terms of number of expected accidents, the impact on air pollution in terms of tons of CO2 emitted by vehicles, the impact on the travel time between the O/D pair affected by the investment, in terms of minutes/passenger etc. In order to make a correct selection of the compared project alternatives, it is necessary to clearly define the objectives to be pursued. These should be specific, measurable, shared, and realistic. It is sometimes useful to classify the objectives according to their status, i.e. they can be divided into final, intermediate and immediate.

Higher level objectives are those of a strategic nature, such as economic growth or sustainable development; lower-level targets, on the other hand, are those that can be directly linked to the results of strategies, programmes or projects.

Once the objectives to be pursued and the related evaluation criteria have been established, an important step is to assign a vector of weights that is able to express the relative importance of each criterion with respect to all the others. The final step is to judge the contribution of each project alternative to each evaluation criterion.

If the projects to be analysed through the Multi-Criteria methods have also been assessed in terms of economic and financial analysis, the impacts associated with each alternative will include the usual economic and financial indicators, including NPV and SRI. In this way, the results of the two different evaluation approaches, mono and multi-criteria, can be mutually integrated.

In general, a multi-criteria method consists of the following main steps (Table 7.1): establishing the decision-making context, identifying the alternatives to be assessed (alternative designs), identifying objectives and criteria, assigning scores, combining weights and scores for each alternative in order to derive a limited number of aggregate values, examining the results, conducting a sensitivity analysis.

Table 7.1: Steps of Multi-Criteria Analysis (Source: handbook by Dodgson, Spackman, Pearman and Phillips (2000)

Steps in Multi-Criteria Analysis
1. Establishing the decision-making context. What are the objectives of the MCA, who are the decision-makers and the main actors?
2. Identify alternatives.
3. Identify objectives and criteria that reflect the value associated with the impacts of each alternative.
4. Describe the expected performance of each alternative in relation to the criteria; score the alternatives, i.e. assign the value to be associated with the effects of each alternative.
5. Assign weights to each criterion to reflect their relative importance to the decision-maker. Combine the weights and scores for each alternative to derive an aggregate value.
6. Review the results.
7. Conduct a sensitivity analysis of the results following changes in the weights and scores.

1) The first step is to identify the context within which the decision is to be taken, the administrative and historical context within which the task is to be carried out, the political, social, and administrative structures in charge of carrying it out, the objectives of the decision-making body, the group of people who may be affected by the decision.

It is essential to have a clear understanding of the objectives to be pursued. What general ambition does the decision want to contribute to? What is the hierarchy of objectives considered as relevant? Who are the decision-makers and those who may be influenced by the decision?

Objectives related to decisions on transport systems usually imply general objectives, such as those to be pursued with the realisation of the plan/project

(external to the transport system) and specific objectives (internal to the transport system) represented by reduction of travel time, costs, increase of accessibility etc.
2) The second step is to define the alternatives, firstly to make a selection of alternatives to identify a final list, using basic data and fast processes. Making decisions on transport systems typically involves alternatives involving infrastructure, control systems, services, and fares.
3) The third step is to "operationally translate" the objectives into evaluation criteria or performance indicators. These represent the measure of performance against which the alternatives will be judged.
The number of criteria should be kept as low as possible to allow a well-founded decision to be made. There is no precise rule to guide this judgement, which will certainly vary from application to application.
4) The objectives may be pursued differently by each of the alternatives under consideration and in order to select the best projects it is necessary to check how well each project alternative performs against the various criteria considered.
5) The assignment of weights represents another fundamental phase of the Multi-Criteria analysis. Each criterion may be given a weight greater than 0 that measures its relative importance, i.e. the importance of the objective of which the criterion is an indicator with respect to the other objectives. Clearly, the definition of weights is an essentially political operation in which the decision-maker, or more frequently the decision-makers, are called upon to express value judgements.
6) The multi-criteria analysis techniques proposed in the literature generate, therefore, a group of non-dominated solutions (projects) and assist the decision maker in the choice to reach a compromise between conflicting objectives. Some techniques generate a continuous set of non-dominated projects defined by continuous decision variables with explicit, preferably linear, relationships between these variables and their effects. In the case of transport system projects, these conditions rarely occur due to the discrete nature of many projects (new infrastructure, for example), the inherent non-linearity of the system (cost functions and demand patterns), and the complexity of the relationships between control variables and effects (e.g. changes in flows and costs resulting from a transport network project).
7) Sensitivity analysis represents the last step of the Multi-Criteria analysis. It tests how sensitive the result obtained, i.e. the ordering of alternatives, is to the assumptions about the parameters used. In other words, it tries to establish whether the solution obtained is stable with respect to variations in the parameters, which are arbitrary. Sensitivity analysis can be conducted by different methods with different levels of sophistication.

7.2.2 Multi-Criteria Analysis in Maritime Port Planning: State of Art

Stakeholder engagement in the Transport sector (and not only) relies on a huge literature that mainly refer to multi-criteria methodologies.

Several studies are available related on multi-criteria methodologies in the literature. Extensive studies on Multiple-Criteria Decision Making (MCDM) can be found in (Mardani et al., 2015a),(Mardani et al., 2015b) and (Mardani et al., 2016). Results of these works highlight that the Analytic Hierarchy Process (AHP) method is ranked as the first method in use.

Additionally, from these analyses resulted that only few studies applied MCDM techniques to port-related fields and the most used technique in this field is the AHP.

In the field literature some criticisms have been expressed towards AHP method in the last decades. Referring to an overview of Toth and Vacik (Toth and Vacik, 2018), issues associated with the usage of the AHP can be allocated into the different steps of MCDM such as: (i) Problem modelling (e.g. general inability of models to represent the problem, uncertainty associated with the development of the model structure); (ii) Weights valuation (e.g. uncertainty associated with the used scale type, the response mode, the vague judgments, etc.); (iii) Weights aggregation (e.g. uncertainty associated with the aggregation mode between the different levels of the problem modelling hierarchy); (iv) Sensitivity analysis (e.g. uncertainty associated with the type of sensitivity analysis); and (v) Group decision making (e.g. uncertainty associated with the combination procedure of several decision makers judgments to derive an appropriate group aggregation).

The major issues that have been pointed out in several articles since AHP became popular concern the use of (1) a linear one-to-nine scale and (2) the problem of rank reversal. This is the reason why many other numerical scales have been proposed to overcome Saaty's scale limits in the pairwise comparisons: (Harker and Vargas, 1987), (Lootsma, 1989), (Salo and Hømøløinen, 1997), (Ishizaka and Labib, 2011). The latter is surely one of the most debated problems. There are two schools of thought on the rank reversal. It is argued that new alternatives that do not introduce additional attributes should not cause rank reversal under any circumstances. The other argues that there are some situations in which a rank reversal can be expected. Rank reversals were allowed in the original formulation. In 1993, Forman introduced the called "ideal synthesis mode", to address choice situations where adding or removing an "irrelevant" alternative should not and will not cause a change in the ranks of existing alternatives (Forman, 1993).

The current version of the AHP can host both schools: its ideal mode preserves rank, while its distribution mode allows ranks to change. Both modes are selected based on the problem in question.

Despite its disadvantages, AHP overall consensus, technical validity and practical utility, still make it one of the most used and reliable MCDM methods.

The most important benefits are presented, in a synthetic way, in the book *Practical Decision Making* (Mu and Pereyra-Rojas, 2017), and are the following:

- The ability of structuring a problem in a way that is easily manageable;
- Making the decision criteria explicit and the decision-making process transparent as a whole;
- Deriving priorities through a rigorous mathematical process using ratio scales;
- Allowing measuring and comparison of tangible and intangible elements;
- Allowing easy sharing of the decision-making process for feedback and buy-in.

Specifically, very few studies, in the open literature, deal with specific applications of MCDM at maritime port level that ranges from port management to port performances evaluation applications. In these available studies the AHP is adopted as for such application is results to be a good compromise between easy implementation and reliability.

In particular, (García-Morales et al., 2015) used the MCDM in a *port management* application which includes the stochastic nature of climate as well as the one of the exploitation agents. This study provides a probabilistic characterization of the performance of different alternatives in terms of a set of indicators that reflect the potential benefits for different interest groups. In the analysis of a hypothetical port in Spain, four alternatives were designed as solutions for port congestion, and the criteria selected were: the service quality provided to vessels, the total freights handled, and the profits accrued by the Port Authority. The criteria measuring the performance of each strategy were statistically analyzed first. Then, assuming the uniform distribution of decision-maker preferences, the alternatives were ranked, and the relative importance of each criterion in the decision-making process was obtained.

(Asgari et al., 2015) instead analyzed the *sustainability performance of five major UK ports*. The UK port system is one of the largest and busiest port systems both in Europe and worldwide. To rank UK ports in terms of sustainability performances (at environmental and economical level) a questionnaire is developed to collect data from port managers and logistics experts. The AHP method is utilized, and a sensitivity analysis is conducted on obtained data to verify the consistency among data and outcomes.

(Junior et al., 2012) present a model for the *port performances evaluation* of container terminals based on a multicriteria methodology. Aim of this work is developing methodologies and results to support port authorities in providing incentives to achieve improvements in efficiency. In particular, factor analysis was used to reduce the number of criteria and ensure independence among them. The model has proved to be satisfactory in the ordering of container terminals considering the available data on major Brazilian ports from 2006 to 2009, according to the decision maker's values. The results and the methodology are useful in supporting. On this topic also (Acer and Yanginlar, 2017) show the evaluation of the performance of 20 container ports operating in Turkey by examining the performance criteria of container ports in the world. Authors adopted the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method, using non-financial data from 2015. The overall performance of the ports was converted into a single score with the help of the TOPSIS method and port performances were evaluated by comparatively examining the results obtained. Mersin port, Ambarl Marport and Kumport derived first with the highest performance.

The lack of studies referring to maritime ports also concerns the sensitivity analysis conducted on the weights of criteria. Between the most relevant references in the open literature there are (Asgari et al., 2015) and (Ren and Lützen, 2017). The first one, as previously mentioned, refers just to environmental and economic aspects; the second to energy and environmental ones.

The Contributions of this study are: *(1)* for the first time in the open literature a MCDM, using AHP method, has been applied to a real case scenario with the aim of evaluate the functional, environmental, social, and economic impact of a port. In the literature only some of those aspect have been considered (e.g. environmental and economical in (Asgari et al., 2015)) or specific analysis on each aspect have been performed on simulation and optimization approaches, an extensive literature review has been developed highlighting this topic that is currently under a peer-reviewed process. In addition, *(2)* an adequate sample of experts conducted the survey (Asgari et al., 2015) allowing this study to be one of the most reliable and complete in the open literature so far (*i.e.* sample of 79 instead of 10), to the best of the authors knowledge.

7.2.3 Multi-Criteria Analysis Methods

Multi-criteria analysis comprises a wide group of techniques able to considers simultaneously a large number of aspects of the issue, both qualitative and quantitative, bringing out the different points of view of the actors involved.

Multi Criteria Decision Analysis (MCDA), is a subject aimed at guiding the decision-maker to make assessments of numerous and conflicting choices, helping to obtain a compromise solution in a clear way. There are many methods of multi-criteria analysis, and this leads to their use in different fields of application; generally, MCDA is used where it is not possible to use an optimisation method directly, due to the numerous decision criteria.

Given their importance, the principles of multi-criteria analysis techniques and their use to support decision-making processes are illustrated below. Multi-criteria analysis is structured to:

- Help the Decision Maker by showing him the best way forward;
- Identify the areas with more or less opportunities;
- Build a priority scale of options;
- Highlight their differences;
- Allow actors to better understand the situation;
- Define the best allocation of resources to achieve the objective;
- Encourage the generation of new and better options;
- Improve communication between parts of the organisation.

These methodologies break down the problem in order to analyse the individual components and finally regroup the partial results of the components to arrive at a solution. The advantages of these methodologies are

- Speeding up the decision-making process;
- Reduction of uncertainty and risk;
- The possibility of modifying the choice of criteria and objectives made by a group of decision-makers, if it is considered inappropriate;
- In the explication of weights and scores in addition to other information;
- Transparency of the decision-making process for internal and external actors;
- Ease of application due to the availability and use of software;
- Improvement of control over the decision-making process;
- Feedback (since choices require evaluation and updating).

Multiple Criteria Decision Analysis problems could be divided into the following categories:

- Choosing Problem, when selecting a group with the smallest number of potentially good alternatives and choosing among them;
- Sorting Problem, when a score is given to each alternative;
- Ranking Problem, when creating a ranking of potential alternatives.

Each Multi Attribute Decision Making method aggregates differently the estimates given to the criteria to obtain the global estimate for each alternative. However, they all offer information on alternatives related to objectives for which attributes have been chosen to evaluate them.

The factors involved in the decision-making process are structured as follows:

- The Goal, i.e. the objective to be achieved;
- The decision-makers who take part in the decision-making process;
- The alternatives, the object of analysis and choice;
- The criteria (and possibly sub-criteria) with which to evaluate the alternatives, which must be carefully established;
- The weights that each decision-maker assigns to the criteria and alternatives.

Multi-attribute decision analysis helps the decision-maker to identify criteria and create a general model. Indeed, with these methods:

- The best alternative is identified;
- An ordering of alternatives is derived;
- Reduce the number of alternatives to be analysed
- Recognise eligible alternatives from non-eligible ones.

An accepted approach in the specialised literature is based on the reciprocal compensatory (rebalancing) or non-compensatory character of the evaluation criteria used. The number of attributes should not be excessive in order not to make the analysis too complex and thus ineffective, but neither should it be limited to avoid carrying out an incomplete study. However, there is no ideal number to refer to: it is usually suggested to use a set of attributes that can include as much as possible of the crucial and relevant aspects of the project, while avoiding unworkable complexity.

Compensatory methods, which consider the eventual trade-offs, include:

- The AHP/ANP method;
- The multi-attribute methods (MAUT);
- The TOPSIS method.

Partially compensatory methods, which only consider the trade-offs generated:

- Promethee;
- Regime

Among the non-compensatory ones, which do not use criteria compensation:

- Dominance methods.

The main application aspects of some of these methods are reviewed below.

7.2.3.1 Analytic Hierarchy Process Method

The analytic hierarchy process (AHP) is a multi-criteria decision support technique developed in the 1970s by Iraqi mathematician Thomas L. Saaty, considered one of the pioneers of Operations Research. Saaty elaborated a draft of the methodology

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already in 1971. From 1974 to 1975, the methodology was further developed in the literature, from a theoretical point of view (Pezze, 2013).
The acronym AHP has the following meaning:

- "analytic", designates that the method, analytical, involves the splitting of an articulated problem into its basic elements;
- "hierarchy", indicates the use of a hierarchical structure, in which the general objective is placed at the top and below it, in successive levels, the criteria, sub-criteria and alternatives;
- "process", defines the pathway comprising a series of actions leading to the goal (making the decision that best satisfies the multitude of key criteria).

The AHP follows a linear hierarchical structure where the relationships between the elements of the different decisional levels are unidirectional along the hierarchy and where there are no dependencies neither between elements of the same cluster (sets of homogeneous elements, also called nodes, comparable among them in which the decisional problem has been decomposed) nor between elements belonging to different clusters(Bottero et al., 2008).

In applying AHP, the reference is made to several possible choices which are studied and compared; it never refers to a single alternative. Where only one hypothesis is available, this must be compared with the zero scenario, i.e. the non-intervention scenario.

The objectives are expressed by means of indicators that allow the different hypotheses to be effectively compared.

Pairwise comparisons allow the decision-maker to make judgements based on a comparison of two elements at a time. Preference should always be understood in a relative sense to the comparison of two possibilities and never in an absolute sense. The preference of one alternative over another is thus expressed and quantified individually for each criterion. There are different scales for quantifying the preference between two alternatives. One of the most widely used rating scales is Saaty's scale.

The compatibility and consistency of judgements is checked by reference to the principle of transitivity.

The AHP is very easy to use and gives excellent results when the problem can be modelled through a hierarchy of independent elements on the same level.

The hierarchical structuring of an evaluation problem implies that the elements (objectives, criteria, sub-criteria, and alternatives) are arranged in an ascending sense according to the level of abstraction: the elements at the top of the hierarchy are therefore abstract and general, while those at the bottom are concrete and particular (Figure 7.2).

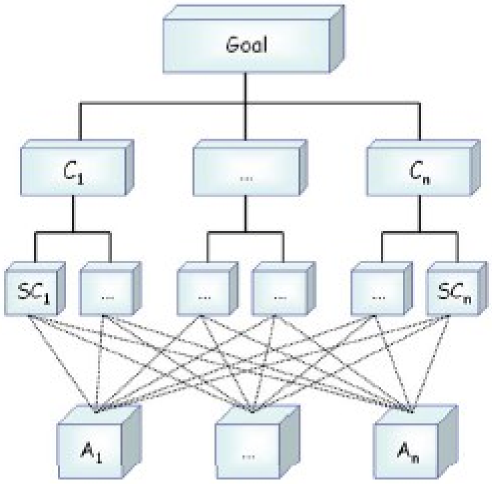


Figure 7.2: Example of hierarchy in the AHP method

The steps of the AHP method are outlined below:

- Creation of the hierarchy from top to bottom via intermediate criteria;
- Comparison of characteristics using a series of pairwise comparison matrices;
- Definition of the priority vector once the weights for all criteria have been defined;
- Consistency analysis of judgements;
- Overall ranking.

Hierarchy construction

The first step is to create a hierarchy, i.e. to break down a complex system into its various constituent elements and to analyse the relative importance of each level. This allows a better understanding of the problem. To structure a hierarchy, it is essential to:

- Identify the overall objective (goal);
- Identify secondary objectives;
- Identify the criteria that may allow the objectives to be achieved;
- Know who is involved in the decision-making process.

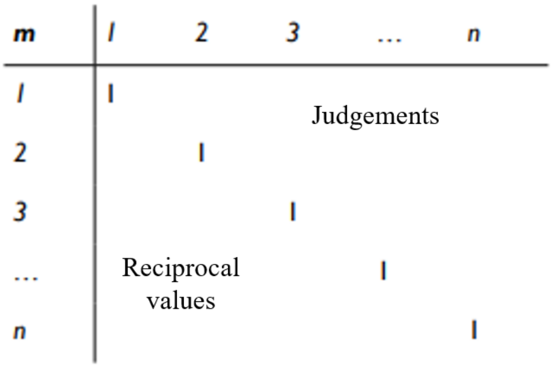
The decision-maker creates a hierarchy characterised by several levels following the analysis of the various aspects of the problem; this leads to great simplification.

The realisation of a hierarchy implies that the elements (objectives, criteria, and alternatives) are arranged according to their level of abstraction: elements at lower levels are concrete and particular, while those higher up in the hierarchy are more abstract and general. Consequently, a possible hierarchy is one in which the objective (goal) is at the highest level of the hierarchical structure, followed at the intermediate level by the criteria for achieving the goal, and by the alternatives at the lowest level. The hierarchical structure presented above constitutes a complete hierarchy. The hierarchical structure is not rigid: it is possible to add criteria or sub-criteria that were not previously considered. If sub-criteria are considered for some criteria and not for others, this is called an incomplete hierarchical structure.

Pairwise comparisons

The second step is the pairwise comparison of sub-criteria belonging to the same criteria, or between criteria of the same level. The elements (criteria or sub-criteria) of each group are compared by establishing which of them is the most important and to what extent; these are relative judgments, i.e. with reference to the higher-order element. Criteria can be compared with each other with respect to the objective, sub-criteria are compared with respect to the criterion on which they depend, and alternatives can be compared with each other with respect to the criteria or sub-criteria to which they refer.

For this purpose, a matrix is created with the list of criteria per row and per column. Based on information examined individually by the decision-maker and his or her subsequent judgement, the matrix is then filled in with numerical values highlighting the importance of one factor over another. Assigning a high value means assigning greater importance to the factor placed in the row than to the one with which it is compared along the column. When a factor is compared with itself the importance ratio is obviously one. Below (Figure 7.3) is presented an example of the structure of the pairwise comparisons matrix.



m	1	2	3	…	n
1	1			Judgements	
2		1			
3			1		
…		Reciprocal values		1	
n					1

Figure 7.3: Pairwise comparison matrix

The matrix A is characterised by several properties:

- It is positive. Therefore, all the minor principals are positive (the minor principal is the determinant of the square submatrix formed by the first m rows and m columns, with $1 \leq m \leq n$)
- It is reciprocal and square.

The values a_{ij} of the matrix A are characterised by the following properties:

- If $a_{ij} = a$, then $aji = 1/ a$, with $a > 0$;
- If ai is judged to be of equal intensity relative to a_j, then $a_{ij} = a_{ji} = 1$.

In particular, the principal diagonal of the matrix A is composed entirely of unit values, i.e. $a_{ii} = 1$.

To obtain the values a_{ij}, the "Saaty's semantic scale" is used. This scale makes it possible to switch from exclusively qualitative to quantitative numerical judgements. The first nine integers are related to as many judgements expressing the importance of one aspect over another.

Table 7.2: Saaty's scale

Numerical Value	Definition
1	a and b are equally important
3	a is weakly more important than b
5	a is fairly more important than b
7	a is strongly more important than b
9	a is absolutely more important than b
1/3	a is weakly less important than b
1/5	a is fairly less important than b
1/7	a is strongly less important than b
1/9	a is absolutely less important than b

The minor element of comparison is unity, which represents equal importance. With respect to this, it is assessed how many times an element is more or less dominant.

Definition of weights

Once the matrix of pairwise comparisons A has been constructed, the weights to be associated with the various elements of the group are estimated. There are several possibilities for doing this. One of these is to calculate the weights by operating on the individual rows of the matrix (of size n x n) of the pairwise comparisons under consideration. For each row (each of which corresponds to an element of the group),

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the weight of the relevant element is obtained by multiplying the values in the row and evaluating the nth root of that product. Alternatively, the individual values per row of the matrix can be averaged and normalised. Clearly, the same procedure is followed for all other rows of the matrix.

For the vector of weights w, which is unique and consists of positive elements, the following relationship applies:

$$\sum_{i=1}^{n} w_i = 1 \tag{7.1}$$

To calculate the vector of the percentage weights to assign to each node of the cluster it is sufficient to determine the maximum eigenvalue λ and the relative eigenvector v_λ of the node itself. Normalizing the eigenvector v_λ such that the sum of its elements is equal to 1, the vector of the percentage weights or priorities relative to the nodes is obtained:

$$P = \frac{v_\lambda}{\sum_{i=1}^{n} v_\lambda(i)} \tag{7.2}$$

In addition to the calculation of the weights, it may be useful to calculate a coefficient which allows the proportionality between the different weights to be identified intuitively. To this end, a coefficient of 1 is assigned to the element with the greatest weight, while the others are assigned proportional values, using the relation w_i/w_{max}. Given the weights, the generic element of the matrix a_{ij} can also be expressed in the following form:

$$a_{ij} = \frac{w_i}{w_j} \qquad \forall i, j \tag{7.3}$$

The matrix A can then be rewritten as follows, where the ith row is obtained from the ratio between the weight associated with criterion i and the weights associated with the other criteria:

$$\mathrm{A} = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{bmatrix}$$

Figure 7.4: Different writing of the pairwise comparison matrix

Determination of overall weights

The sixth and final step is to calculate the overall ordering of the alternatives, by making the product of the weights of the criteria and the weights of the alternatives with respect to the individual criteria, and then mathematically a row-by-column product. The global weights of the elements present at the base of the hierarchy, in the level following that of the terminal objectives, are the result of the procedure.

Assessment of the consistency of judgements

A very important step is the definition of consistency, which takes place after the comparisons between cluster nodes. For the sentences expressed to be considered coherent, it is necessary to verify the respect of the transitivity property, an example of which is given below:

$$if\ A > B, e\ B > C, \qquad therefore\ A \gg C \tag{7.4}$$

The consistency property is expressed in the following relationship:

$$a_{ik}\ a_{kj} = a_{ik} \qquad \forall i, j, k \tag{7.5}$$

Assuming n elements $A_1,\ldots, A_n$ whose relative weights are $w_1,\ldots,w_n$, could be write the following relation:

$$Aw = \begin{array}{c} A_1 \\ \ldots \\ A_n \end{array} \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix} = n \begin{pmatrix} w_1 \\ \vdots \\ w_n \end{pmatrix} = nw \tag{7.6}$$

This equation identifies a system of linear equations. The vector w is the principal eigenvector of A.

In introducing the identity matrix as well, the relationship can also be rewritten as:

$$(A - nI)w = 0 \tag{7.7}$$

In matrix theory, it is demonstrated that a symmetrical, reciprocal, and consistent matrix has a single eigenvalue, called the maximum eigenvalue, λmax, equal to the order n of the matrix.

To obtain the vector w of the weights associated with the criteria, we must solve the system $Aw=\lambda w$, where λ is the associated eigenvalue.

For the matrix A, since its rows are pairwise proportional, the following properties apply:

- Rank (A)=1;
- All eigenvalues are zero except one;
- The sum of the eigenvalues is equal to the trace of A, which is no other than the sum of the values of all the elements on the main diagonal of the square matrix, i.e. Tr (A)=n.

The solution of the previous relation consists of positive values. For w unique, it is necessary to normalise the values of the matrix by dividing them by their sum.

In general, however, the matrix A does not satisfy the consistency property. Again, the principal eigenvector w of the matrix A, normalised so that the sum of its components is equal to one, is taken as the vector of the weights sought, since if a variation of the values a_{ij} is made, the principal eigenvalue λ_{max} of the matrix will take on a value not very different from n.

Usually, the decision-maker does not provide a matrix of ratios between the weights of the criteria, but a matrix of estimates of these ratios (this explains why the relation $a_{ij} = \frac{w_i}{w_j}$ is valid without approximations), which leads to small changes in the eigenvalue. Under this hypothesis, the relation to be solved to determine the weights is still given by:

$$(A - \lambda_{max}\, I)w = 0 \tag{7.8}$$

where, $\lambda_{max} > n$.

In the context of the applications, this eigenvalue was calculated using the MATLAB calculation environment.

We then go on to define the methodology for calculating the inconsistency.

The numerical expression of consistency is defined by the Consistency Index (CI). Its value can be calculated using the following formula:

$$CI = \frac{\lambda_{MAX} - n}{n - 1} \tag{7.9}$$

By λ we mean the maximum eigenvalue of the pairwise comparison matrix and by n the number of criteria, and thus the size of the matrix itself. In the case of perfect consistency CI is equal to zero because when the matrix A is perfectly consistent, the principal eigenvalue λ_{max} is equal to n. As the inconsistency increases, instead, the value of CI increases.

Usually, a matrix is perfectly consistent only if it correlates objective measures (length, weight).

The Random Consistency Index (RI) is then defined based on the size of the matrix:

Table 7.3: Random Consistency Index

RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10

This index has a fixed value for each value n of the size of the matrix of pairwise comparisons. Its possible values, were derived by a group of experts from the Oak Ridge National Laboratory and the Wharton School by averaging the CIs of several randomly created reciprocal matrices of the same order (Parente, 2016).
Finally, the consistency ratio, Consistency Ratio (CR), is determined:

$$CR = \frac{CI}{RI} \tag{7.10}$$

In the literature, one of the most used reference thresholds for considering the pairwise comparison matrix consistent is the following: CR<0.1 (10%).

7.2.3.2 Fuzzy Analytic Hierarchy Process Method

The Fuzzy Analytic Hierarchy Process (FAHP) it is similar AHP method but differs from it by using fuzzy logic. Fuzzy logic, provides that each proposition can be given a degree of truth different from 0 and 1 and between them, introduced by the scholar Lofti Zadeh. Multi-criteria analysis is not always suitable for various reasons:

- Imprecise knowledge of reality;
- Imperfection of the scale used to give value to the criteria;
- Poor availability of information for the decision-maker;
- Loss of information and assessment quality when the mathematical transformation of linguistic judgements is carried out;
- Complexity of the methods.

Fuzzy logic is introduced precisely in such contexts, especially where very complex problems arise. Therefore, all intermediate values between the maximum value at which the choice is justified and the minimum value are considered. The purpose of this logic is to give greater logicality and clarity to the analysis, bringing the decision-making process to a better level of comprehension and interpretability.
Fuzzy numbers are fuzzy sets defined on the set R of real numbers with normal and convex membership function. To define a convex membership function, it is

---

necessary to introduce the α-cut set, i.e. given the fuzzy set A the α-cut set, Aα, is the crisp set for which: with Aα = {x | A (x) ≥ α} with 0 ≤ α ≤ 1.
The set Aα defines a threshold that can be interpreted as a confidence level α in a decision or concept represented by a fuzzy set. A fuzzy set (defined on Rn) is defined as convex if all its α-cuts, 0 ≤ α ≤ 1, are crisp (clear, well-defined) convex sets in the classical sense. Classically used fuzzy numbers are triangular and trapezoidal. Triangular fuzzy numbers are generally expressed as follows: A = (a_1, a_M, a_2)

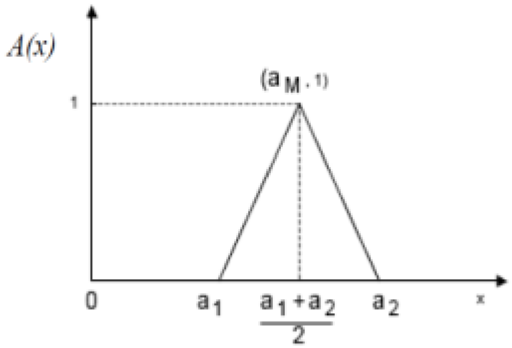
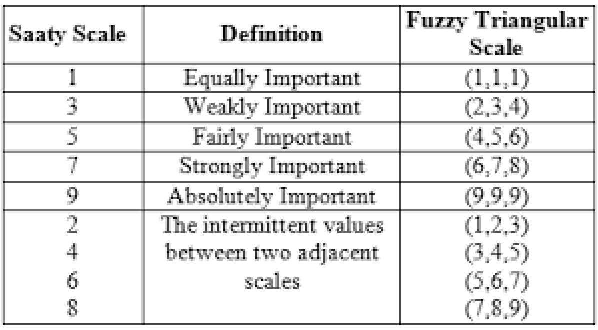


Figure 7.5: Central triangular fuzzy number

The belonging function in this case is of triangular type.
a_1 represents the lower value, a_2 the upper value and a_M the middle value. The latter identifies the most probable value.
When switching to fuzzy logic, the relative importance scale should also be modified:



Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equally Important	(1,1,1)
3	Weakly Important	(2,3,4)
5	Fairly Important	(4,5,6)
7	Strongly Important	(6,7,8)
9	Absolutely Important	(9,9,9)
2 4 6 8	The intermittent values between two adjacent scales	(1,2,3) (3,4,5) (5,6,7) (7,8,9)

Figure 7.6: Saaty's scale with fuzzy logic

7.2.3.3 Analytic Network Process Method

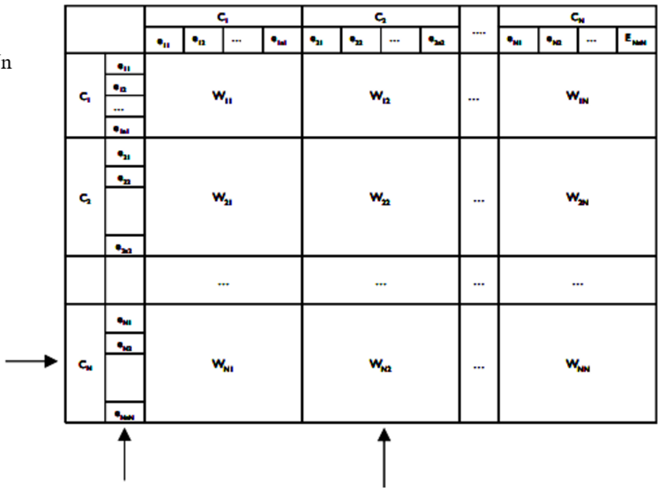
Several problems in the field of decision making cannot be represented by means of a hierarchical structure due to the interaction between elements of both the same level and different levels. It can happen that not only the importance of the criteria determines the importance of the alternatives, as in a hierarchy, but also the importance of the alternatives, in turn, determines the importance of these criteria.
In this context, a very important role is played by the Analytic Network Process (ANP), a method developed by Saaty's since 2005.
The ANP thus consists of a development of the decision-making model, through a network structure, a network that is distributed in various directions, including interactions and cycles.
Through the introduction of a supermatrix, whose generic form is represented in the figure 7.7, it is possible to represent the influence of each element with the others in the network.

$$
W = \begin{array}{cc|cccc|}
 & & C_1 & C_2 & \cdots & C_N \\
 & & e_{11} \cdots e_{1n1} & e_{21} \cdots e_{2n2} & \cdots & e_{N1} \cdots e_{NnN} \\
\hline
C_1 & \begin{matrix} e_{11} \\ \cdots \\ e_{1n1} \end{matrix} & W_{11} & W_{12} & \cdots & W_{1N} \\
C_2 & \begin{matrix} e_{21} \\ \cdots \\ e_{2n2} \end{matrix} & W_{11} & W_{12} & \cdots & W_{1N} \\
\vdots & & \cdots & \cdots & \cdots & \cdots \\
C_N & \begin{matrix} e_{N1} \\ \cdots \\ e_{NnN} \end{matrix} & W_{11} & W_{12} & \cdots & W_{1N} \\
\hline
\end{array}
$$

Figure 7.7: Generic form of a Supermatrix

CN identifies the Nth cluster, Nn symbolises the nth element within the Nth cluster, and W_{ij} is a block of the matrix containing the priority vectors (w).
The "Supermatrix" includes within it the priority vectors extracted from the pairwise comparison matrices compiled during the analysis. It therefore represents the influence relations within the nodes forming part of the decision network. It contains null blocks (i.e. consisting only of 0) where there are no influence relations between the nodes of the clusters. Other blocks are non-zero (i.e. made up of elements other than 0) where there are influence relationships between nodes. The supermatrix makes it possible to observe the existence and type of relationships within the network and the presence of possible loops.

The generic form of the supermatrix used in the ANP is described in the following figure.



Cluster: Cn   n= 1,2,…,N
Nodes: enn enn= en1, en2, …, enNn

CN:N-th cluster

eNn: n-th node within the n-th cluster

Wij: block of the matrix that contains the priority vectors (w) of the influence of the nodes of the i-th cluster with respect to the j-th cluster

Figure 7.8: Structure of the Supermatrix

In this schematic:

- N is the number of clusters;
- n is the number of nodes within the Nth cluster;
- CN represents the nth cluster;
- eNn is the nth node within the Nth cluster,
- Wij represents a block of the Supermatrix that contains the priority vectors (w) of the influence of the nodes of the i-th cluster with respect to the j-th cluster.

In the development of the ANP, three supermatrices are created:

- The "initial supermatrix" (or "unweighted");
- The "weighted supermatrix";
- The "boundary supermatrix".

The "Initial Supermatrix" is derived from pairwise comparisons through which priority vectors are obtained.

The "Weighted Supermatrix" comprises the priorities assigned through the cluster comparison. It is obtained by multiplying the initial supermatrix by the cluster weights.
The "Limit Supermatrix" contains the final priorities of all elements in the decision model and is obtained by multiplying the weighted supermatrix by itself by a number of times tending to infinity.

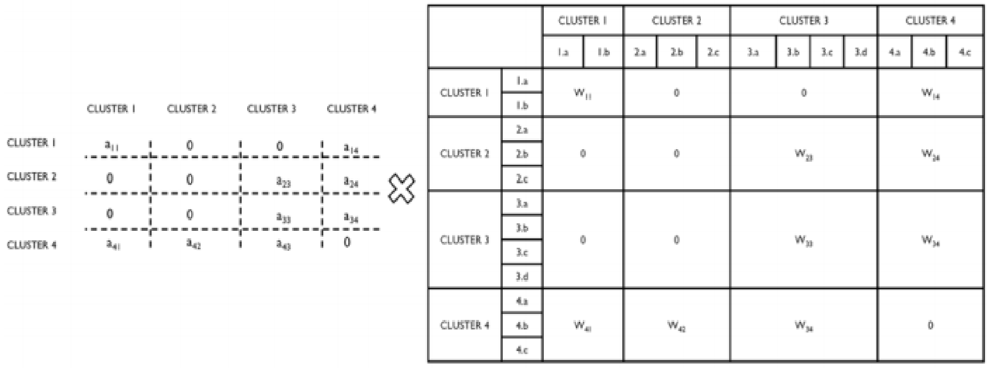


Figure 7.9: Procedure for obtaining the weighted supermatrix

A network model consists of elements or nodes (alternatives and decision criteria) grouped into components, groups, or clusters. The relationship that exists between elements of one and the same component is known as internal reliance or dependence, while interdependence or external dependence refers to the relationship that exists between elements of different components.

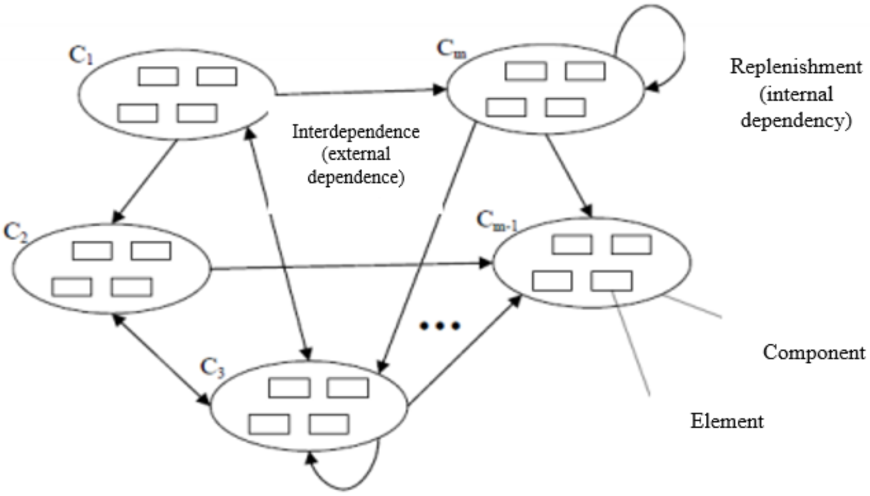


Figure 7.10: Generic ANP network model

The arrow directions by convention are: if an arrow goes from component C_i to component C_j it means that at least one element of component C_j affects at least one element of component C_i.

The main steps of the ANP method are as follows:

- Modelling the decision problem as a network;
- Pairwise comparison;
- Construction of the unweighted supermatrix with the vectors of the relative importance weights of the elements;
- Pairwise comparison between the components;
- Assignment of the block weights of the unweighted supermatrix, using the corresponding component weights, to transform it into the weighted supermatrix;
- Normalisation of the weighted supermatrix by dividing each value by the sum of the columns; this yields a stochastic column matrix, i.e. A matrix whose sum per column is unitary (stochastic weighted supermatrix);
- Raising the stochastic weighted supermatrix to successive powers until its values converge and remain stable (limit supermatrix).

7.2.3.4 Technique for Order of Preference by Similarity to Ideal Solution Method

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria analysis method, which was originally developed by Ching-Lai Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. This method is based on the concept that the chosen alternative should have the shortest geometric distance to the positive ideal solution (PIS) and the longest geometric distance to the negative ideal solution (NIS).

This method (compensatory aggregation) allows the comparison of different alternatives by identifying weights for each criteria. These are then normalised and the geometric distance of the different alternatives from the ideal solution is calculated.

Also in this case, the first step in applying the method requires the construction of the alternatives (m) - criteria (n) matrix.

In order to be able to compare the attributes, a normalisation process must be carried out:

$$R_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} Ra_{kj}^{2}}} \tag{7.11}$$

Where R_{ij} is the value of the ith alternative with respect to jth attribute.

$$\boldsymbol{R}=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

Figure 7.11: Normalised decision matrix

The second step is to construct the weighted normalised decision matrix, in which each column of the normalised decision matrix must be multiplied by its corresponding criteria.

$$\boldsymbol{V}=\begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_m r_{1m} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_m r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ w_1 r_{n1} & w_2 r_{n2} & \cdots & w_m r_{nm} \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1m} \\ v_{21} & v_{22} & \cdots & v_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ v_{n1} & v_{n2} & \cdots & v_{nm} \end{bmatrix}$$

Figure 7.12: Weighted normalised decision matrix

The third step is to determine the ideal solution A+ and the negative-ideal solution A-.

The solutions A+ and A- are virtual solutions constructed from the normalised and weighted evaluations contained in the V-matrix. The ideal solution A+ is determined by considering, for each criterion, the best performance offered by the alternatives in question. The solution A-, on the other hand, is obtained by combining the worst performances of the alternatives with respect to each criterion. The "best" performance means the highest value offered by the alternatives, if it is referred to a direct criterion with respect to the objective, the lowest, if it is referred to an inverse criterion. The analytical definition of the two virtual solutions is as follows:

$$A^{+} = \left\{ \max v_{ij} \; con\, j \, \in J_d ; \min v_{ij} \; con\, j \, \in J_i \right\} per\ i = 1, 2, \dots n \qquad (7.12)$$

$$A^{-} = \left\{ \min v_{ij} \; con\, j \, \in J_d ; \max v_{ij} \; con\, j \, \in J_i \right\} per\ i = 1, 2, \dots n \qquad (7.13)$$

Where J_i is the set of direct criteria, J_d is the set of inverse criteria with respect to the objective.

The fourth step is to calculate the distance of each real alternative from the two virtual alternatives A+ and A-. Each of the n (real) alternatives Ai and two (virtual) alternatives A+ and A- can be understood as a point in an m-dimensional space (with m number of criteria) where the generic jth axis measures the normalized and weighted performance (of the type v_{ij}) of the considered alternative with respect to the criterion C_j. That said, the Euclidean distance Si+ of the alternative A_i (i=1, 2, ..., n) from the ideal one A+ and the distance Si- of Ai from the negative-ideal one A- can be obtained through the following expressions:

$$S_i^+ = [\sum_{j=1}^{m}(V_{ij} - V_j^+)]^{0,5} \quad per\ i = 1, 2, \dots, n \tag{7.14}$$

$$S_i^- = [\sum_{j=1}^{m}(V_{ij} - V_j^-)]^{0,5} \quad per\ i = 1, 2, \dots, n \tag{7.15}$$

The fifth step is to define the relative distance of the alternatives from the ideal solution. Given the distances Si+ and Si- of the alternative A_i (i=1, 2, ..., n) from the virtual solutions A+ and A- respectively, it is possible to determine the relative distance of the alternative itself from the ideal solution by the following relation:

$$C_{i+} = \frac{S_i^-}{S_i^- + S_i^+} \tag{7.16}$$

It is evident that if Ai coincides with the negative-ideal solution A-, the result is $Si^-=0$ and, therefore, $Ci^+ = 0$. Vice versa, if $Ai=A^+$, the result is $Si^+=0$ and, therefore, Ci* = 1:

$$0 \leq C_{i+} \leq 1 \tag{7.17}$$

The sixth and final step is to define the preference ranking of the alternatives. This is done with reference to the value of Ci* for each alternative. In particular, the solutions with the highest Ci* value are preferred.

7.2.3.5 Preference Organisation Ranking Method

The Preference Organisation Ranking Method (PROMETHEE) is a type of Multi-Criteria Analysis belonging to the outranking methods, which are based on the comparison of different alternatives for each criteria by means of preference functions defined by the decision maker. The method is applicable to different fields from environment, to finance, to logistics.

Firstly, the alternatives to be analysed are defined. The decision-maker aims to optimise objectives to solve a problem. This is done by maximising or minimising alternatives using criteria. This phase can be represented as follows:

$$Max: \{f_1(a), f_1(a), \dots, f_h(a)\} \tag{7.18}$$

a represents an alternative. Furthermore, the generic function $f_j(a)$ represents the "evaluation" according to criterion j of alternative a. This is indicative of the performance of the alternative for the criterion considered. If there are both criteria to maximise and to minimise, the following procedure is followed:

$$f_j(s) \geq f_j(a) \ \forall \ a \in \text{ K e} \ \forall \ h \ (maximisation) \tag{7.19}$$

$$f_j(s) \leq f_j(a) \ \forall \ a \in \text{ K e} \ \forall \ h \ (minimisation) \tag{7.20}$$

No single alternative can optimise all criteria. The comparison between two alternatives (a and b) is shown below. Considering h criteria, the related functions are f_1, f_2, ..., f_h. If $f_h(a) > f_h(b)$ a is preferred, and therefore dominates, b. The comparison should be made between all alternatives for each criterion. The following shows how the intensity of preference can be assessed. with respect to alternatives a and b and the following relations are defined:

- P_b if and only if $f(a) > f(b)$
- I_b if and only if $f(a) = f(b)$

where f represents a particular preference function for any criterion. The preference of one alternative over the other occurs when the following difference is mathematically considerable: $f(b) - f(a) > \alpha$ where α is an arbitrary parameter. The importance of each individual criterion will be given by the weight assigned to it in relation to the weights assigned to the other criteria.

Then the so-called preference index is defined:

$$\pi(a,b) = \frac{1}{k}\sum_{h=1}^{k} P_h(a,b) \tag{7.21}$$

This indicates how much alternative a is preferred over b with respect to all h criteria. Then the product for the different weights will be made, in case the criteria have different weights in the final decision:

$$\pi(a,b) = \frac{1}{k}\sum_{h=1}^{k} P_h(a,b)w_h \tag{7.22}$$

Once the preference for alternatives has been established with regard to a specific criteria, the decision-maker will have to operate in the same way for the remaining chosen criteria.

The next step is to calculate the outranking flows, which are fundamental elements of the PROMETHEE methodology. Considering the alternative a for it is fair to assume that some alternatives are dominated by a, but at the same time some dominate it. The measure of how much an alternative is preferred over the others is done through outranking flows.

They are defined as follows:

$$\phi^{+}(a) = \frac{1}{n-1}\sum_{x\in \mathrm{K}} \pi(a,x) \tag{7.23}$$

$$\phi^{-}(a) = \frac{1}{n-1}\sum_{x\in \mathrm{K}} \pi(x,a) \tag{7.24}$$

ϕ+ represents the positive outranking flow and ϕ- the negative one. (n-1) represents the alternatives with which alternative a was compared, K is the space where all alternatives are defined, x represents the deviation of the specific preference function f for a with respect to the same preference function for the other alternatives. The outranking flows then show how much an alternative dominates and is dominated by the others. The higher ϕ+(a) (small ϕ-(a)), the stronger the alternative in question is, and vice versa (Fornea, 2016).

PROMETHEE I and II

The PROMETHEE I method does not allow a comparison of all available alternatives but avoids comparisons which may be wrong because they involve uncomfortable alternatives. This may be the case for some data or criteria.

The PROMETHEE II method allows a faster classification as alternatives are compared by looking at the difference in outranking flows:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{7.25}$$

In this case, when the different alternatives are compared, the classification scheme will be as follows:

- P b if $\phi\ (a) > \phi\ (b)$
- I $_b$ if $\phi\ (a) = \phi\ (b)$

The method thus makes it possible to obtain a complete classification of alternatives, but care must be taken to avoid comparing alternatives that are incomparable to each other.

7.3 Survey Design

7.3.1 Objectives and performance criteria specification

Multi-criteria analysis defines preferences between alternatives according to how they impact on the objectives that the decision-maker has identified and for which he has established measurable criteria. Before of getting into the full scope of survey design, it is necessary to clearly define the objectives to be pursued, which must be specific, measurable, and realistic.

In a commercial port, the main objective is the functional efficiency, but besides other aspects must be considered in terms of impacts inside and outside the port and in terms of sustainability (environmental, economic and social).

These macro-objectives can affect various types of stakeholders in different ways, who have different visions of the macro-objectives. These stakeholders include entities with decision-making responsibilities, such as port authorities, ministries, regions and municipalities, entities in logistics chains such as carriers and terminal operators, experts in maritime economy, environment and logistics such as professors, researchers, self-employed professionals and employees, and finally figures without specific competences but directly affected by political choices such as citizens (Figure 7.13:).

Except for citizens, all the individuals involved have either expertise in maritime transport, logistics or the environment, or are involved in activities related to logistics chains.

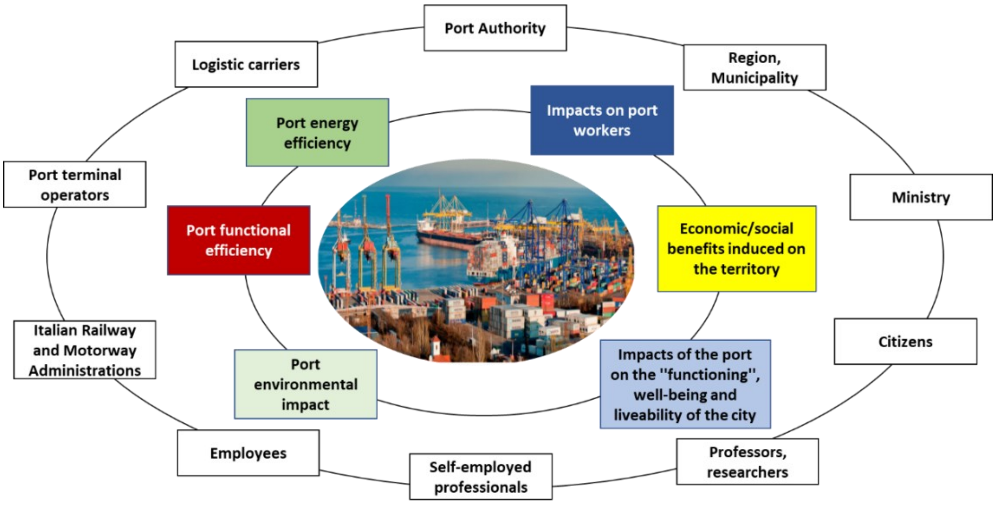


Figure 7.13: Main objectives and entities involved in the survey of the case study.

In order to define the objectives and performance criteria specification, a detailed literature review analysis has been developed, such analysis is the object of a separate work, currently under review.

Each macro-objective was articulated according to indicators suitable for estimating the achievement of the macro-objectives. The scheme of the model specification is reported in Figure 7.14

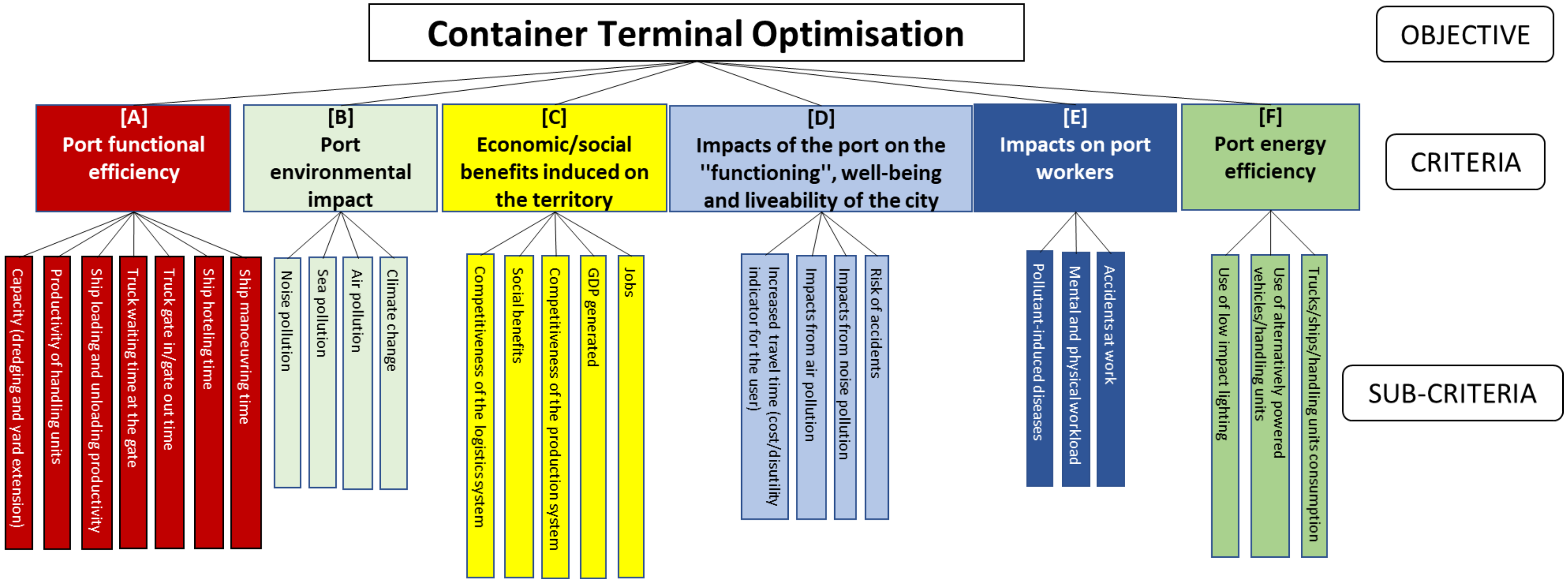


Figure 7.14: Objectives and performance criteria specification.

On the other hand, these objectives with respect to the 17 macro-objectives of sustainable development (UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT, 2020), this study addresses 6 of them (Figure 7.15), GOAL 3: Good Health and Well-being, GOAL 7: Affordable and Clean Energy, GOAL 8: Decent Work and Economic Growth, GOAL 11: Sustainable Cities and Communities, GOAL 13: Climate Action, GOAL 14: Life Below Water, respectively.

Figure 7.15: Sustainable development goals by 2030

Once the complex phase of defining the main macro-objectives to be pursued in the functional design of a port and the related indicators, understood as sub-criteria, allowing for their understanding from a quantitative point of view, the next step was to carry out a survey using a questionnaire. This is aimed at analysing, through the application of the AHP technique, the weights attributed to the above-mentioned macro-objectives by different categories of actors, politicians and technicians, ordinary citizens, and other subjects with various competences in the field of logistics and transport, which are better presented below. The AHP method was chosen over other multi-criteria methods because of its major advantages, namely its flexibility, its intuitive approach for decision-makers (experts) and, finally, its effectiveness in testing inconsistencies in judgements.

7.3.2. Purpose and distribution of the survey

The data on which the results are based were obtained from the processing, by applying the AHP method, of the answers obtained in a survey addressed not only to the subjects directly involved or involved in the decision-making process regarding the activities and intervention policies in a port, but also to the individuals on which these decisions have an impact, i.e. the citizens. Specifically, the survey was proposed in the form of an interview using an online questionnaire. The following actors were involved:

- Port Autorithy (PA)
- Ministry(M)
- Professors, researchers(P&R)
- Citizens(C)
- Employees(E)
- Self-employed professionals (SEP)
- Region, Municipality(R&M)
- Logistic carriers (LC)
- Italian Railway and Motorway Administrations (Ita.R&M Adm.)
- Port terminal operators (PRO)

A sample of 79 persons have been interviewed making this study of particular interest in the field, providing a holistic vision (functional, environmental, social etc.) on the impacts.

The questionnaire was designed in steps, trying to cover in an increasingly precise and complete way all the main aspects (environmental, social, functional, economic) linked to logistics chains and city-port systems and avoiding neglecting elements relevant to the analysis, in order to allow the respondents to have a clear view of the problem.

The questions included in the questionnaire were aimed at defining the main macro-objectives that the different interviewees consider most important for the optimisation of a freight port.

7.3.3. Stakeholder characterisation

Once the purpose of the questionnaire had been defined, and thus the factors and concepts to be surveyed and their indicators made explicit, the contact persons to whom the survey was to be addressed were established. The objectives that can be pursued in transport planning are numerous and different, sometimes consistent with each other, sometimes conflicting. The " Good planning" must consider the different decision-makers, their visions, and corresponding objectives. Each decision-maker has a main objective, secondary objectives, and "negligible" objectives.

Stakeholders were chosen from different categories such as: Port System Authorities; Professors, and researchers with experience in maritime transport, logistics and environmental issues; political personalities at ministerial regional and municipal level with managerial or technical positions; terminal operators; carriers; and finally students considered as the expression of the citizenship that lives the consequences of the choices adopted in the port area.

The Port System Authority is a public entity with legal personality whose institutional aims include the management and organisation of freights and services in the respective port area.

The Port Authority has administrative, budgetary, and financial autonomy within the limits provided for by law. It has been assigned numerous functions:

- Spatial planning of the port area;
- Programming, coordination and control of port operations and other activities carried out in ports, identifying strategies for the development of port activities and interventions to guarantee compliance with the set objectives of reducing the risks of accidents related to activities and guaranteeing hygienic working conditions;
- Ordinary and extraordinary maintenance of common parts in the port area, such as maintenance for the maintenance of the seabed. This function is entrusted in concession to the port authority through a public tender;
- Concession and control of activities aimed at providing services of general interest, not strictly related to port operations;
- Administration of the areas and assets of the maritime domain included in the territorial district.

The Ministry, Region and Municipality were involved in the survey because of their possibility to intervene through political choices and agreements on port systems. The Ministry of Infrastructure and Transport, in agreement with the Region, has direct influence on the Port System Authorities as it appoints their presidents, chosen from a list of experts in the transport and port economy sectors. The Region, but also the Municipality, come into play in the definition of the Port Management Committee, composed, as well as by the President of the A.d.S.P., by a component designated by the Region itself and by a component designated by the mayor of each of the metropolitan cities, also partially part of the port system, as well as by a component designated by the mayor of each of the municipalities already seat of the port authority.

The professors and researchers involved in expressing judgements on the macro-objectives are experts in the various fields referred to in this work. In particular, maritime transport, logistics and the environment. The objective, as for all other stakeholders, is to bring out visions and positions linked to the cultural background and skills of each individual.

Terminal operators, having the task of supervising and directing the activities of a terminal, play a central role in the efficiency of logistics activities. A port operator is a company or port authority which is authorised by a port management authority to handle freights within a port. It may be state-owned or privately owned. Its activity involves the handling of containerised freight between container ships, trucks and trains in order to optimise the passage of freight through Customs and to minimise the waiting time of ships within the port. Efficiency is maintained by managing and updating roads, storage facilities, cranes and handling equipment, berths, communication equipment, IT systems and workers' contracts. In the present case the operators of the Salerno Terminal Container were involved.

Carriers are the category that physically carries out a transport operation. Carriers may be members of cooperatives, members of consortia or part of a network of companies. It is therefore easy to see how important it is to define the vision of this group with regard to the macro-objectives set.

Subjects involved in the analysis were also RFI (Rete Ferroviaria Italiana), ANAS (Azienda Nazionale Autonoma delle Strade) and Società Autostrade. These companies are relevant to the survey because of their participation in initiatives to improve the competitiveness of the port and inter-port system through Integrated Logistic Areas, an instrument to promote sustainable transport systems and eliminate bottlenecks in the main network infrastructures. In region Campania in particular, the PON focuses on the development of connections between the Ports of Naples and Salerno, the Nola and Marcianise freight villages and the TEN-T network, i.e. the set of linear (rail, road and river) and punctual (urban nodes, ports, freight villages and airports) infrastructures considered relevant at EU level. Therefore, the actors belonging to these categories have a relevant role in the organisation of the regional logistics system and it was considered important to know their views on the various macro-objectives.

Interviews were also conducted with employees and professionals (including three experts in the field) who have expertise in transport and logistics.

Finally, the student category was considered as an expression of the position of citizens, who are directly affected by the political choices concerning the port.

7.3.4. Questionnaire layout

Specifically, the questionnaire, created through the Google Forms app, entitled "What macro-objectives should be pursued in the functional design of a freight port?". It is divided into the following different parts:

- Socio-economic background of the interviewees;
- Expression of absolute ratings related to individual macro-objectives;
- Expression of comparative ratings between pairs of macro-objectives.

The homepage consists of a presentation of the topic addressed and the objectives to be pursued. The questionnaire is part of the *PON AIM project - Attraction and International Mobility of Researchers - Line 1 (Mobility of researchers)*.

The interviewees, after having identified which kind of actors are (e.g. port authority employee, logistic carriers, etc.), are asked about their specific position held.

For example, in the case of the "Port System Authority", a further distinction was defined between:

- Governance;
- Manager;
- Technical Officer.

For the "Region/Municipality" and "Ministry" sectors, the roles were divided into:

- Governance (Mayor, Councilor);
- Technical Office/Technical Service.

The following step, for all categories, is the socio-economic classification: gender, age and residence.

For those who belonged to the categories "Expert in the sector" as regards the definition of the role, the employment status (student, unemployed, housewife, retired/pensioner, self-employee, employee) was requested.

In Table 7.4 the macro-objectives are presented with the related indicators (sub-criteria).

Table 7.4: Description of the macro-objectives to be evaluated

A	**Port functional efficiency** IMPROVEMENT of: capacity (dredging and yard extension), ship time, truck waiting time at the gate, truck gate in/gate out time, container handling time, productivity of the cranes, productivity of handling units.
B	**Port environmental impact** REDUCTION of: pollutant emissions and concentrations produced by port activities and which affect atmospheric pollution, sea pollution along the coast, noise pollution, dredging impact, etc.
C	**Economic/social benefits induced on the territory** INCREASE of: benefits generated by the port activity (jobs, GDP generated, competitiveness of the production system, social benefits, competitiveness of the logistics system, etc.)
D	**Impacts of the port on the "functioning", well-being and liveability of the city** REDUCTION of: impacts induced on citizens or businesses by port activities (travel times, traffic, risk of accidents, diseases induced by pollution, etc.)
E	**Impacts on port workers** REDUCTION of: accidents at work, physical stress, mental stress, diseases induced by pollutants and noise pollution
F	**Port energy efficiency** REDUCTION of: energy consumption of port activities through, for example, the use of: alternative powered vehicles/handling units (electric, hybrid, hydrogen), low-impact lighting, renewable sources, etc.

After, interviewees were asked to express an absolute rating on the individual macro-objectives. They rated each of them according to a scale representing five different levels of importance:

- Extremely important (5);
- Very important (4);
- Fairly important (3);
- Unimportant (2);
- Not at all important (1).

Afterwards, to be able to implement the AHP method in the data processing phase, the interviewees were asked to make pairwise comparisons (without repetition) in a total number of 15 across all the six macro-objectives. To simplify the understanding, an example was first included.

Everyone is asked to express the level of preference of each criterion over the other. In this specific case study, rather than using Saaty's nine-value scale (Saaty, 1980), it was decided to use a seven-value scale for improving the simplification and usability of the survey. In particular, the preference levels adopted are as follows:

- Absolutely more important (+7);
- Fairly more important (+5);
- Slightly more important (+3);
- Equally important (+1);
- Slightly less important (-3);
- Fairly less important (-5);
- Absolutely less important (-7).

Certainly, studying the results of the survey, the real Saaty’s scale was used, hence the negative numbers of the previous scale were replaced by fractions (e.g. from -3 to 1/3, from -5 to 1/5, from -7 to 1/7). For a better understanding of the questions, representative images have been added in questionnaire (Figure 7.16). The same was done for the importance scale (Figure 7.17).

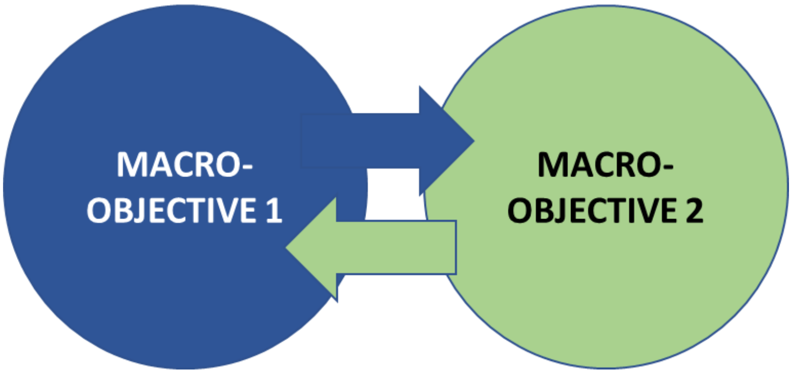


Figure 7.16: Macro-objective comparison images.

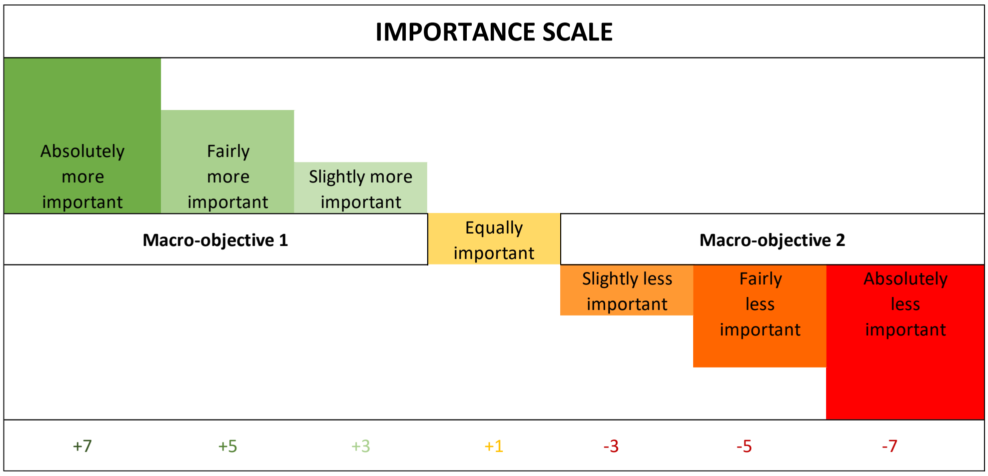


Figure 7.17: Importance scale for comparing macro-objectives.

7.3.5 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is a multi-criteria decision support technique (introduced in the section 7.2.3.1) in which their acronym can be explained as follows, "analytic", highlights that the method, analytical, involves breaking down an articulated problem into its basic elements; "hierarchy" indicates the use of a hierarchical structure, in which the general objective is placed at the top and below it, in successive levels, the criteria, sub-criteria and alternatives; and "process", defines the pathway comprising a series of actions leading to the achievement of the objective (making the decision that best satisfies the multitude of key criteria). An extensive literature is available on this topic, see (Davies, 2001; de FSM Russo and Camanho, 2015; Emrouznejad and Marra, 2017).

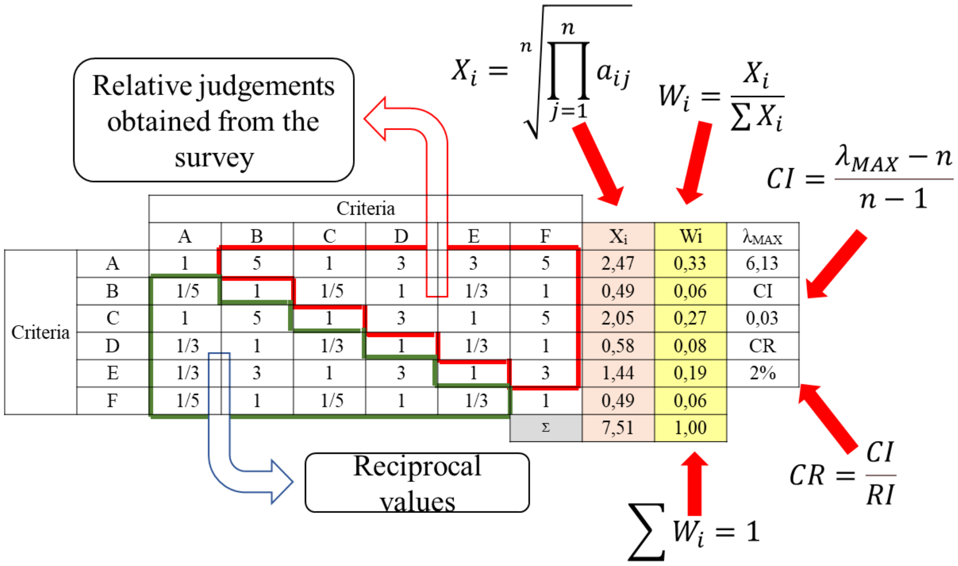
The steps of the AHP method are outlined below and briefly recalled:

1. Creating the hierarchy from top to bottom via intermediate criteria;
2. Comparison of characteristics using a series of pair-wise comparison arrays;
    2.1. criteria arranged along rows and columns
    2.2. comparisons reported according to the Saaty's scale
3. Definition of the priority vector once the weights for all criteria have been defined;
    3.1. calculation of the geometric mean through the n-th root, where n is the number of criteria, of the product of all the ratings in each row (X_i)
    3.2. normalization (W_i)
4. Consistency analysis of ratings;
    4.1. calculation of the maximum eigenvalue of the matrix (λ_{MAX})

   4.2. calculation of the Consistency Index (CI)
   4.3. calculation of the Consistency Ratio (CR)
5. Overall ranking.

An example of how to proceed is presented:

Given the pairwise comparison matrix reported in Figure 7.18, where a_{ij} are the relative judgements obtained from the survey and $1/a_{ij}$ are the mutual values, it is possible to proceed with point 3, 4 and 5 reported in the above list.



		Criteria								
		A	B	C	D	E	F	X_i	Wi	λ_{MAX}
Criteria	A	1	5	1	3	3	5	2,47	0,33	6,13
	B	1/5	1	1/5	1	1/3	1	0,49	0,06	CI
	C	1	5	1	3	1	5	2,05	0,27	0,03
	D	1/3	1	1/3	1	1/3	1	0,58	0,08	CR
	E	1/3	3	1	3	1	3	1,44	0,19	2%
	F	1/5	1	1/5	1	1/3	1	0,49	0,06	
							Σ	7,51	1,00	

Figure 7.18: Pairwise comparison matrix.

The calculation of the geometric mean through the n-th root, where n is the number of criteria, of the product of all the ratings in each row (X_i) is represented by the following formula:

$$X_i = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \tag{7.26}$$

Where n is the number of criteria.

For the vector of weights Wi, which is unique and consists of positive elements, the following relationship applies:

$$\sum W_i = 1 \tag{7.27}$$

Where W_i is defined as follows:

$$W_i = \frac{X_i}{\sum X_i} \tag{7.28}$$

Subsequently is possible to identify the Consistency Index (CI) using the following formula:

$$CI = \frac{\lambda_{MAX} - n}{n - 1} \tag{7.29}$$

Where λ is the maximum eigenvalue of the pairwise comparison matrix and n is the number of criteria, and thus the size of the matrix itself. In the case of perfect consistency CI is equal to zero because when the matrix is perfectly consistent, the principal eigenvalue λmax is λmax=n. As the inconsistency increases, instead, the value of CI increases.

Usually, a matrix is perfectly consistent only if it correlates objective measures (length, weight).

The Random Consistency Index (RI) is then defined based on the size of the matrix (Table 7.5):

Table 7.5: Random Consistency Index.

RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49
n	1	2	3	4	5	6	7	8	9	10

The RI has a fixed value for each value n of the size of the matrix of pairwise comparisons, the specific values reported in Table 7. are available in the open literature (Golden et al., 1989).

Finally, the Consistency Ratio (CR), is determined:

$$CR = \frac{CI}{RI} \tag{7.30}$$

In the literature, one of the most widely used thresholds for considering the pairwise comparison matrix consistent is the following: CR<0.1 (10%).

7.3.6. Sensitivity Analysis

The solution of a problem is not complete with the exclusive determination of a rank order of decision alternatives. In order to develop an overall strategy to meet the various conditions, is necessary to conduct a sensitivity analysis (SA) for the hierarchical decision model (HDM) results (Chen and Kocaoglu, 2008).

The sensitivity analysis has several purposes:

- Help visualize the impact of changes at the policy and strategy levels on decisions at the operational level;
- Test the robustness of the recommended decision;
- Identify the critical elements or the decision (armacost and hosseini, 1994) (triantaphyllou, 2000);
- Generate scenarios of possible rankings of decision alternatives under different conditions (winebrake and creswick, 2003);
- Help judgment providers reach consensus (yeh et al., 2001);
- Offer answers to "what if" questions.

In a sensitivity analysis it is possible to analyse how the priorities of the alternatives change with the weight's variation of a criterion or sub-criterion. Sensitivity can be studied for a single criterion or sub-criterion. It's used to find what are the important factors that influence a decision.

A standard method to conduct a SA is to change one variable at a time. For this reason, the method is also known as One-at-a-time (OAT) (Chen et al., 2010).

The sensitivity analysis in AHP is helpful in identifying the rank reverse, points where it's possible to observe how the rank changes after the change of criteria's weights.

Generally, the solution is presented graphically, and there are two possible ways to show the results: tornado diagram or spider plot.

The software used to check the evaluation of the criteria's weights, the consistency of the judgments and for the implementation of the sensitivity analysis is SuperDecisions.

SuperDecisions is a software that implements the AHP and ANP (section 7.2.3) methods and was developed by the team of the creator of these methods, Thomas Saaty. An important reference which investigates the different multi-criteria analysis software is (Buchholz et al., 2009). Among the most used tools, this is the only that allows for inclusion of stakeholders in the criteria weighting process. In particular, its weighting method is based on the eigenvector method (Shirali and Nematpour, 2019). A synthetic description of the procedure steps to be implemented for the construction of the model is presented below. For a more detailed one, see (Mengistu et al., 2020)

The first step consists in identifying the various hierarchical levels, clusters. The second one is related to the creation of the nodes for each cl~~uster (criteria, sub-~~

criteria, alternatives, etc.). The third step consists in creating the connections of each element (node) of a single cluster, with the nodes of the cluster at a lower hierarchical level.

The pairwise comparisons, in the "Judgments" screen, is based on the 1-9 Saaty’s scale. In particular, there are five ways to perform pairwise comparisons. “Questionnaire” is the default one. Filled in all the comparisons, the final weights attributed to each element of the cluster are returned by the programme. In the same section it is possible to read the value of the inconsistency.

In the “Computations” screen it is possible to observe the final ranking.

The software allows also to conduct a sensitivity analysis based on criteria’s weights. Selecting the node with respect to the one the variation of the results is to be observed, the programme gives as output the spider plots.

7.4. Descriptive Analyses

The main results of the questionnaire are set out below. The evaluations expressed have made it possible to highlight the macro-objectives to which the various figures give major or minor importance, both in relation to the expression of absolute and relative judgements. These latter, by applying the AHP method has been possible to estimate the weights of these macro-objectives.

7.4.1. Data analysis of the total sample

The questionnaire received a total of 79 responses. These responses are distributed among the different categories as follows:

- Port System Authority: 13;
- Region/Municipality: 12;
- Ministry/Ministry corporations: 4;
- Professors/researchers: 18;
- Port terminal operators: 2;
- Logistic carrier: 2;
- RFI/ANAS/Motorway Company: 3;
- Self-employed professionals: 8;
- Employees: 6;
- Students: 11.

Of these 79 questionnaires, through the application of the AHP method, the consistency of the answers was evaluated by calculating the consistency ratio (CR), based on the property of transitivity. The acceptability threshold of CR<15% was established. Usually, this threshold is set at 10% in the Saaty approach but considering the impossibility of resubmitting the questionnaire to the respondents allowing them to correct inconsistencies and in order to work on a more significant sample with values that are not excessive in CR, it was decided to raise the range of acceptability.

In addition, a limit of the consistency ratio was set at 25% to define the questionnaires considered un-processable for the analysis, as they were too inconsistent. This led to the elimination of 11 questionnaires, and thus to a total number of 68 were analysed. Of these, 22 fell within the CR range between 15% and 25%. Taking into account the possible loss of attention of the stakeholder during the response, especially with reference to the pairwise comparisons at the end of the questionnaire, it was decided to intervene on some of them to make corrections according to a pre-established procedure. The Superdecisions software was used, which, once the hierarchy has been constructed and the relative judgements have been reported in the matrix, provides not only the values of the weights associated with the various elements of the cluster, but also the value of inconsistency and makes it possible to identify the comparisons that contribute to increasing it and on which it is therefore convenient to intervene to reduce the value of the CR.

The following constraints were defined in order to not alter the respondent's evaluations:

- Jumps from indifference ratings to liking ratings and vice versa were not allowed (e.g. from 1 to 3 or from 1 to -3 and vice versa);
- Jumps of more than one step in the preference scale were not allowed (e.g. from 7 to 3 and vice versa, or from -7 to -3 and vice versa).
- Maximum number of changes is 3.

Finally, a total of 79 interviewees, 46 have a CR<10%, 22 have a 10%<CR<15% and 11 have a CR>15%, these latter have been excluded from the analysis and considered as outliers.

The questionnaires actually considered for the purposes of the analysis were therefore 68. The data differentiated between the CR threshold below 10% and between 10% and 15% are presented below.

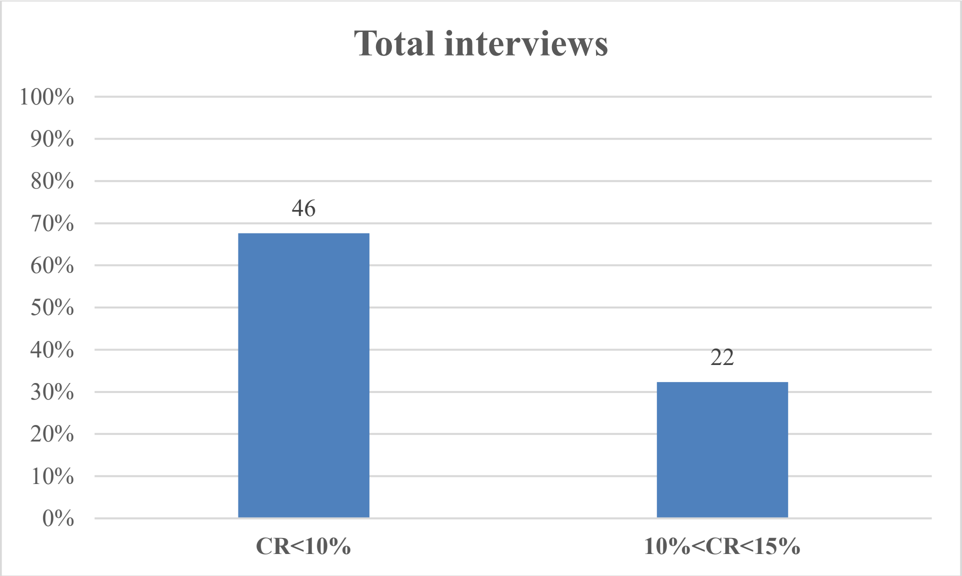


Figure 7.19: Total interviews considered

Of the initial total, 86.1% of the questionnaires were considered acceptable. Of these, 67.65%, corresponding to 46 questionnaires, had a higher consistency, with a CR<10%, while the remaining 32.35%, corresponding to 22 questionnaires, had a CR between 10 and 15%.

Table 7.6: Total interviews

Total Interviews	
Port Authority (PA)	11
Ministry(M)	4
Professors, researchers(P&R)	17
Citizens(C)	9
Employees(E)	6
Self-employed professionals (SEP)	6
Region, Municipality(R&M)	8
Logistic carriers (LC)	2
Italian Railway and Motorway Administrations (Ita.R&M Adm.)	3
Port terminal operators (PRO)	2
Total	**68**

The sample characteristics are shown (Figure7.20). The figures highlights that the cluster of Port authority and Professors/Researchers are the ones with higher interviewees

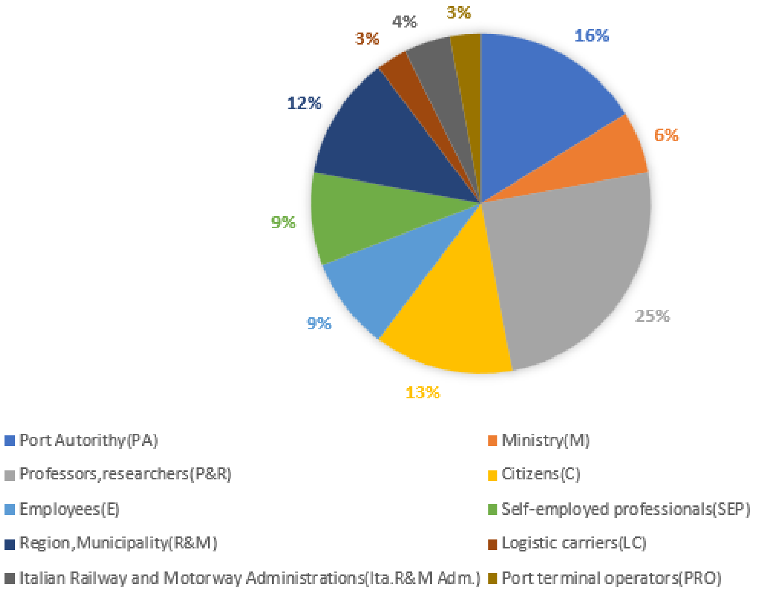


Figure 7.20: Sample characteristics

The categories with lowest numbers of participants are Logistic carriers, Port terminal operators and Italian railway and Motorway administration.

The descriptive analysis was carried out considering each of the interviewees representing the 10 stakeholders described above, analysing both the absolute judgements and the pairwise comparison of each one of them (relative judgements), in order to simplify the reading of the chapter, only some of them are presented, because at the end of this section, the result of all analyses will be presented in two graphs.

The Figure 7.21 shows an example of the descriptive analysis of different stakeholders in each macro-objective. In particular, 4 out of 10 categories are reported in the Figure 7.21. Assigning a score from 5 to 1, according to the Likert scale (Albaum, 1997), in the transition from extremely important to not at all important, an overall ranking is obtained and shown on the right of the various graphs. It can be observed that for port authorities and terminal operators the most important macro-objective is functional efficiency. For terminal operators the impacts on port workers are also of great importance. At the same time, for both categories, the least important aspect is the impacts on the "functioning", well-being and liveability of the city.

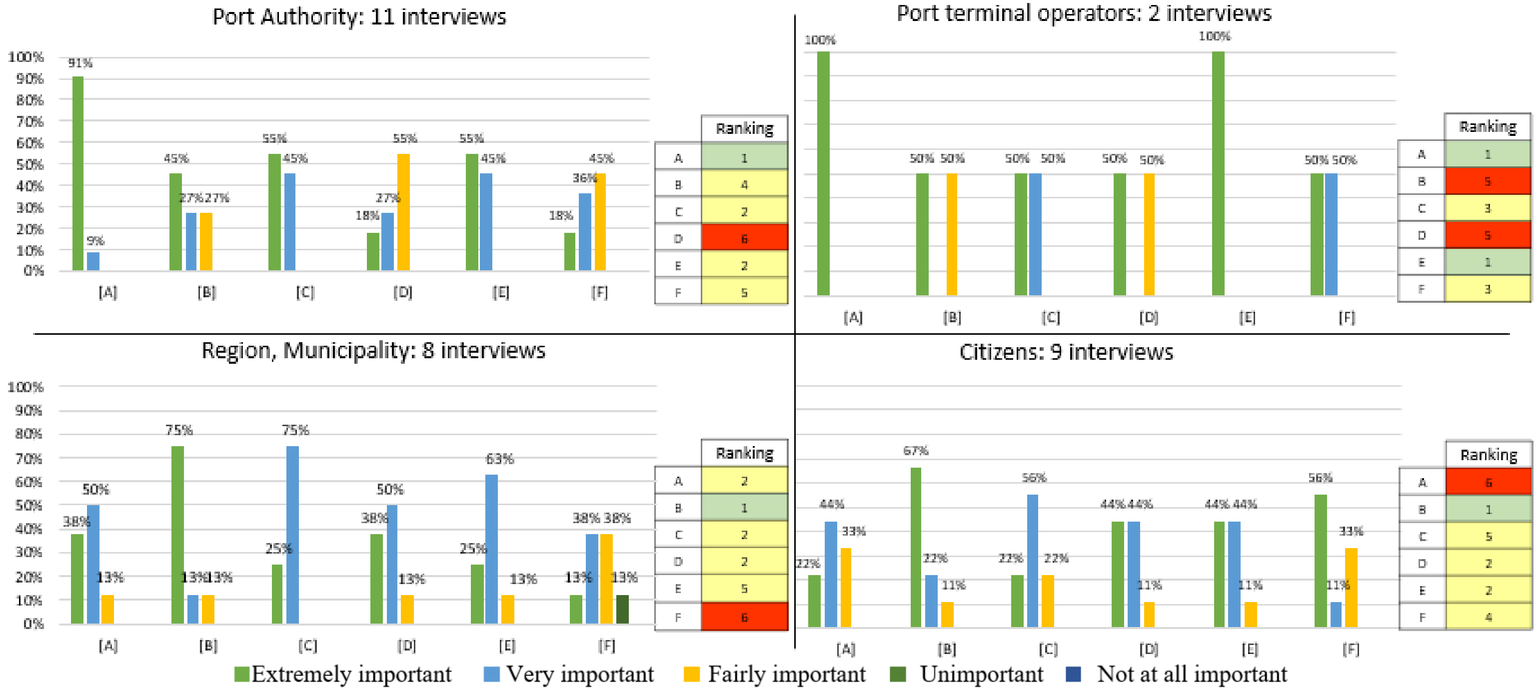
Regions and municipalities consider the environmental impact of the port more important, while the last macro-objective in importance is the energy efficiency of the port.

In contrast with the largest part of the results of all the 10 clusters, citizens globally associate less importance to the functional efficiency of the port, putting the environmental impact of the port first.

The variability of the results confirms the need for a multi-stakeholder analysis as if the positions of only one of the categories were considered, the hierarchy of policy interventions would vary.

In order to make the graphs comparisons between macro-objectives easier to read, they will be indicated by a letter:

- A: port functional efficiency;
- B: environmental impact;
- C: economic/social benefits induced on the territory;
- D: impacts of the port on "functioning", well-being and liveability of the city;
- E: impacts on port workers;
- F: port energy efficiency.



Port Authority: 11 interviews

	Ranking
A	1
B	4
C	2
D	6
E	2
F	5

Port terminal operators: 2 interviews

	Ranking
A	1
B	5
C	3
D	5
E	1
F	3

Region, Municipality: 8 interviews

	Ranking
A	2
B	1
C	2
D	2
E	5
F	6

Citizens: 9 interviews

	Ranking
A	6
B	1
C	5
D	2
E	2
F	4

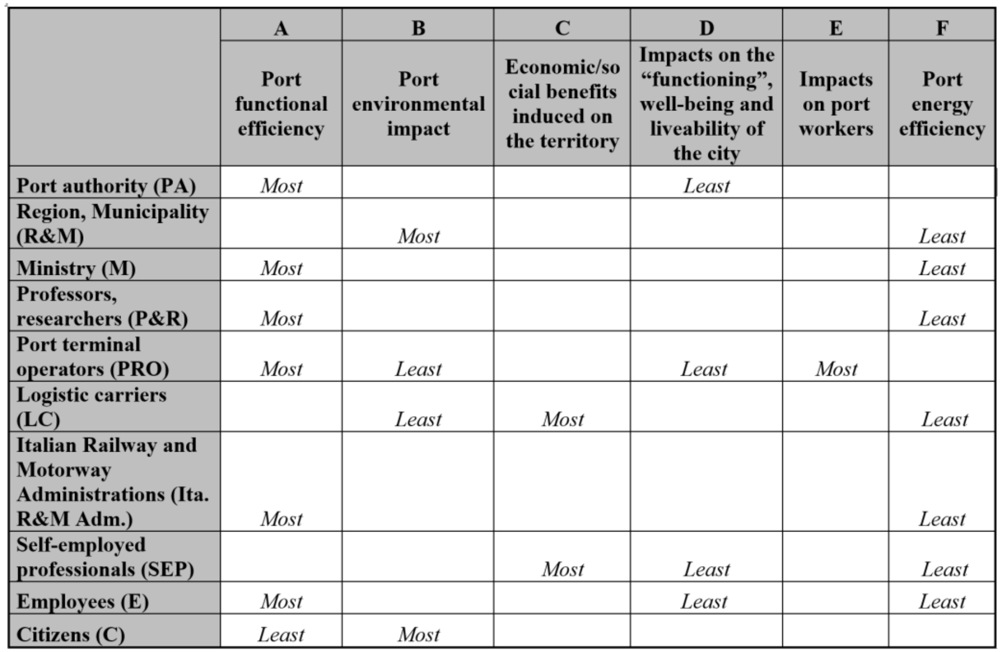
Figure 7.21: Example of descriptive analysis for stakeholder rating of different macro-objectives.

Figure 7.22 highlights the most and least important macro-objectives for the different categories of stakeholders in terms of **absolute judgement**.

Many stakeholders associate a higher importance to functional efficiency and a very low importance to the energy efficiency of the port, which in most cases comes last in the rankings of the various stakeholders. Functional efficiency is only considered less important than all macro-objectives by citizens who place the environmental effects of the port first.

Among the different macro-objectives, beyond energy efficiency, impacts on "functioning", well-being and liveability of the city are not ranked first by any category.

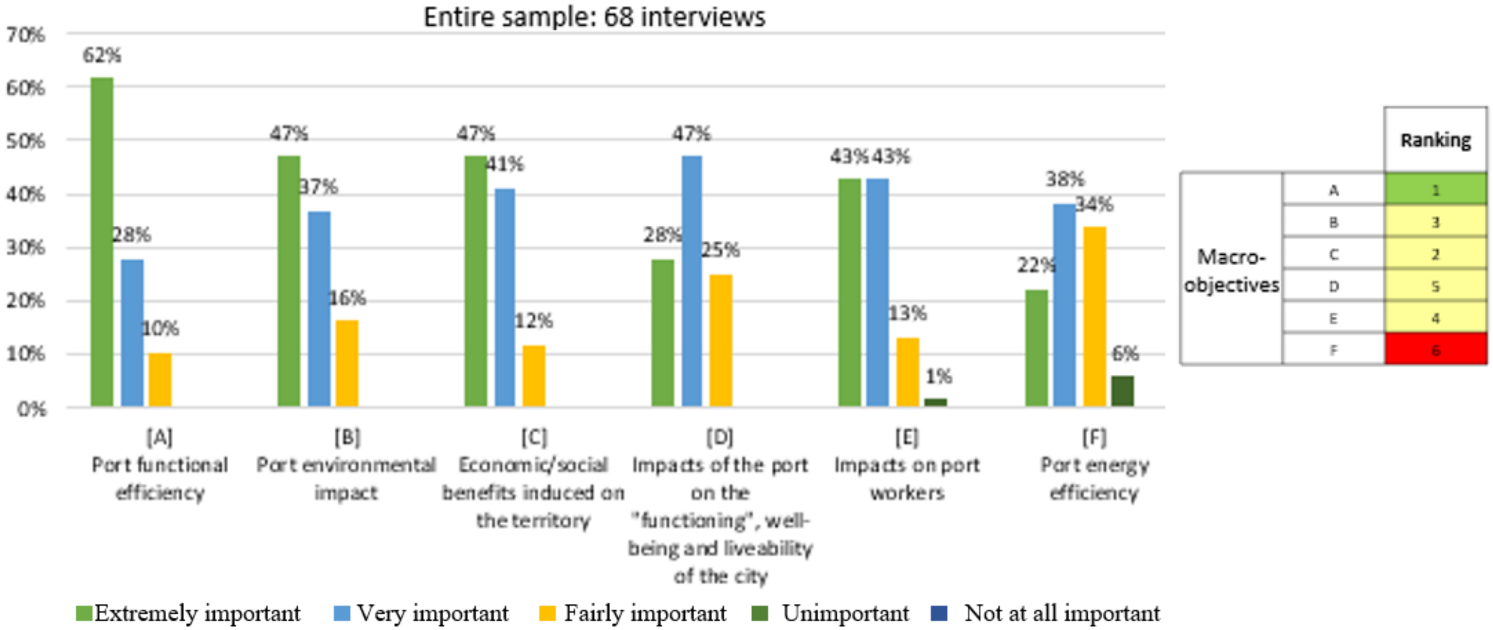
At the same time, the economic/social benefits induced on the territory and the impacts on port workers are not placed in last place by any category.



	A	B	C	D	E	F
	Port functional efficiency	**Port environmental impact**	**Economic/social benefits induced on the territory**	**Impacts on the "functioning", well-being and liveability of the city**	**Impacts on port workers**	**Port energy efficiency**
Port authority (PA)	*Most*			*Least*		
Region, Municipality (R&M)		*Most*				*Least*
Ministry (M)	*Most*					*Least*
Professors, researchers (P&R)	*Most*					*Least*
Port terminal operators (PRO)	*Most*	*Least*		*Least*	*Most*	
Logistic carriers (LC)		*Least*	*Most*			*Least*
Italian Railway and Motorway Administrations (Ita. R&M Adm.)	*Most*					*Least*
Self-employed professionals (SEP)			*Most*	*Least*		*Least*
Employees (E)	*Most*			*Least*		*Least*
Citizens (C)	*Least*	*Most*				

Figure 7.22: Most and least important macro-objectives for the different categories of stakeholders in terms of absolute ratings (descriptive analysis).

In Figure 7.23 the macro-objectives distribution in terms of **absolute judgement** are reported. Overall, the first four macro-objectives have no responses associating low importance ratings. This is the case for the macro-objectives of impacts on port workers and energy efficiency of a port, where the low importance rating reaches 6%.



		Ranking
Macro-objectives	A	1
	B	3
	C	2
	D	5
	E	4
	F	6

Figure 7.23: Macro-objectives distribution in terms of absolute ratings

Additionally, the macro-objective of functional efficiency is the one considered most important. In the last position is the macro-objective of energy efficiency of a port.

It can be seen that almost the entire sample gives at least a 'fairly important' evaluation for each category. In particular, the functional efficiency of the port is considered extremely important by most respondents, with 62%, followed by very important at 28%. For the environmental impact of the port, the economic/social benefits on the territory and the impacts on port workers there is an almost equal distribution of "extremely important" and "very important" ratings, with a slight advantage in all three cases for extreme importance.

For impacts on the efficiency, well-being and liveability of the city, there is a majority of 'very important' ratings, with 47%. With lower percentages, around 25%, there is some equality between "extremely important" and "fairly important".

Energy efficiency is considered very important by 38% of the total number of respondents, but has the lowest percentage of "extremely important" evaluations compared to the other macro-objectives, and the highest percentage of "not very important" evaluations, with 6%.

As in the previous case, to make the graphs of the pairwise comparisons between macro-objectives easier to read, they will be indicated by a letter:

- A: port functional efficiency;
- B: environmental impact;
- C: economic/social benefits induced on the territory;
- D: impacts of the port on” functioning”, well-being and liveability of the city;
- E: impacts on port workers;
- F: port energy efficiency.

The following histogram (Figure 7.24) shows the percentage distribution of **relative judgements** for the individual pairwise comparisons, according to the rating scale chosen.

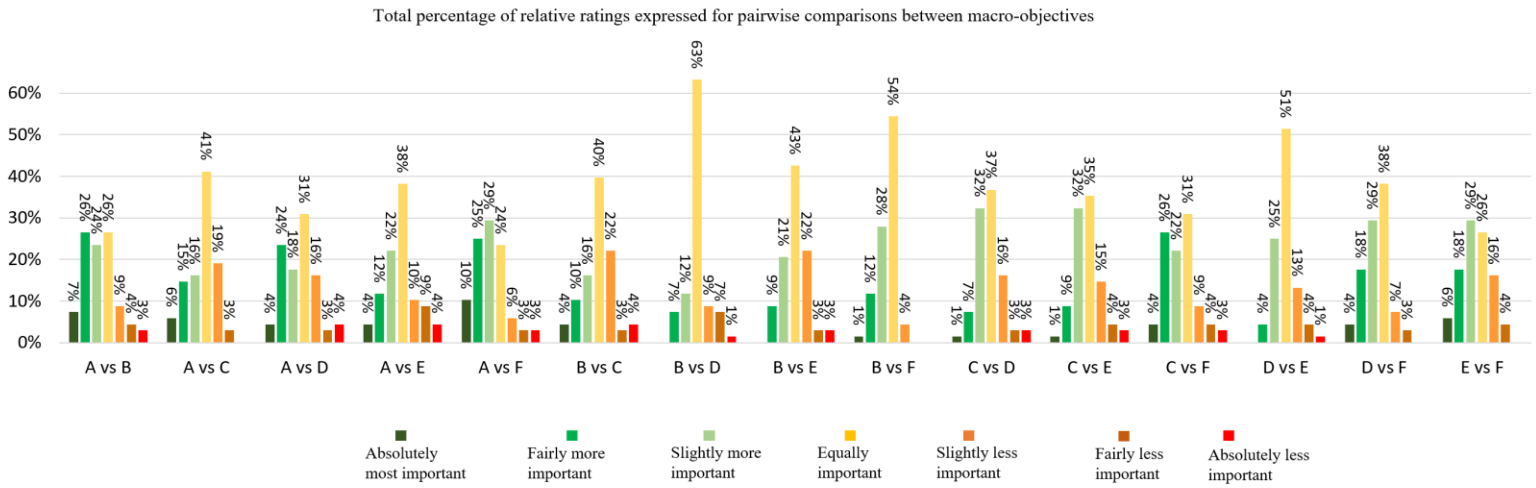


Figure 7.24: Macro-objectives distribution in terms of relative ratings

What is immediately clear from the histograms is that in many evaluations the respondents opted for equal importance of the two macro-objectives compared.
This is the case for the following pairwise comparisons:

- A, functional efficiency of the port, with C, economic/social benefits on the territory;
- A, functional efficiency of the port, with E, impacts on port workers;
- B, environmental impact of the port, with C, economic/social benefits on the territory;
- B, environmental impact of the port, with D, impacts on the efficiency, well-being and liveability of the city, where the highest percentage is observed with 63%;
- B, environmental impact of the port, with E, impacts on port workers;
- B, environmental impact of the port, with F, energy efficiency of a port, with the remaining assessments mainly in favour of criterion B;
- C, economic/social benefits on the territory, with D, impacts on the efficiency, well-being and liveability of the city, with a high percentage of 'slightly more important' assessments (32%);
- C, economic/social benefits on the territory, with E, impacts on port workers, again with a high percentage rating of ' slightly more important' (32%);
- D, impacts on efficiency, well-being and liveability of the city, with E, impacts on port workers;
- D, impacts on the efficiency, well-being and liveability of the city, with F, energy efficiency of a port, where the remaining ratings are mainly in favour of D;

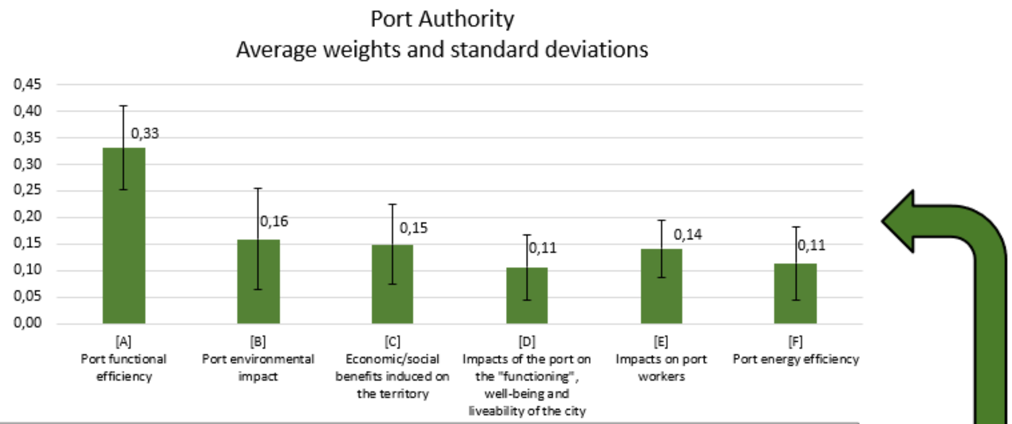
Regard to macro-objective A, functional efficiency of the port, there is a greater preference for this criterion in comparison with B, environmental impact of the port, D, impacts on the efficiency, well-being and liveability of the city, and F, energy efficiency of a port.
Likewise, in the comparison between C and F, energy efficiency of a port, the former is preferred over the latter.
Finally, in the comparison among E, impacts on port workers, and F, energy efficiency of a port, a slight tendency towards macro-objective E is observed, with 29% answering "slightly more important" and 18% "fairly more important".

7.5. Specification, calibration of the MCDM Problem Through AHP

7.5.1 AHP analysis

After the descriptive analysis, the application of the AHP method is necessary to give weight to the macro-objectives by the different stakeholders. This was first applied to the individual subjects of the different clusters. The weights obtained for these subjects were then aggregated through an arithmetic average over the same cluster, and finally over the entire sample.

In particular, : shows the weights assigned by the individual actors in the category (i.e. Port Authority), then aggregated into group average weights. As also evident from the histograms regarding absolute and relative ratings, the highest weight is associated with the macro-objective of functional efficiency, followed by the environmental impact of the port. These analyses have been conducted for all categories.



		Weights associated to the single actors of the cluster														
		1	2	3	4	5	6	7	8	9	10	11		Avg weights	Dev. St.	Ranking
Macro-objectives	A	0,27	0,34	0,34	0,46	0,30	0,33	0,23	0,48	0,23	0,37	0,29	A	0,33	0,08	1
	B	0,29	0,18	0,18	0,06	0,34	0,06	0,25	0,07	0,06	0,12	0,15	B	0,16	0,09	2
	C	0,05	0,12	0,12	0,20	0,06	0,27	0,13	0,14	0,26	0,05	0,22	C	0,15	0,08	3
	D	0,05	0,08	0,08	0,16	0,08	0,08	0,08	0,09	0,28	0,07	0,11	D	0,11	0,06	6
	E	0,05	0,13	0,13	0,10	0,17	0,19	0,13	0,14	0,09	0,27	0,15	E	0,14	0,06	4
	F	0,27	0,15	0,15	0,03	0,05	0,06	0,19	0,08	0,08	0,11	0,08	F	0,11	0,07	5
	CR	0%	15%	15%	13%	6%	2%	14%	10%	12%	4%	9%				

Figure 7.25: Average weights associated to the macro-objectives for Port Authority

Figure 7.26 shows the average weights associated with the macro-objectives through the application of the AHP method. The figure highlights that, in 2 (i.e. Port Authority and the Terminal Operator) of the 4 categories, resulted that greater weight to the macro-objective of functional efficiency. The lowest weight is associated with the macro-objective of impacts on the “functioning”, well-being and liveability of the city. For the Region and the Municipality, the criterion of least importance is the energy efficiency of a port and the one of greatest importance is the port environmental impact from the analysis of relative rating. Likewise for the Citizens, in terms of relative ratings, the greater importance is associated to the environmental impact of the port. In contrast to the other groups, the lowest weight is associated with the macro-objective considered most important by the other categories, i.e. functional efficiency.

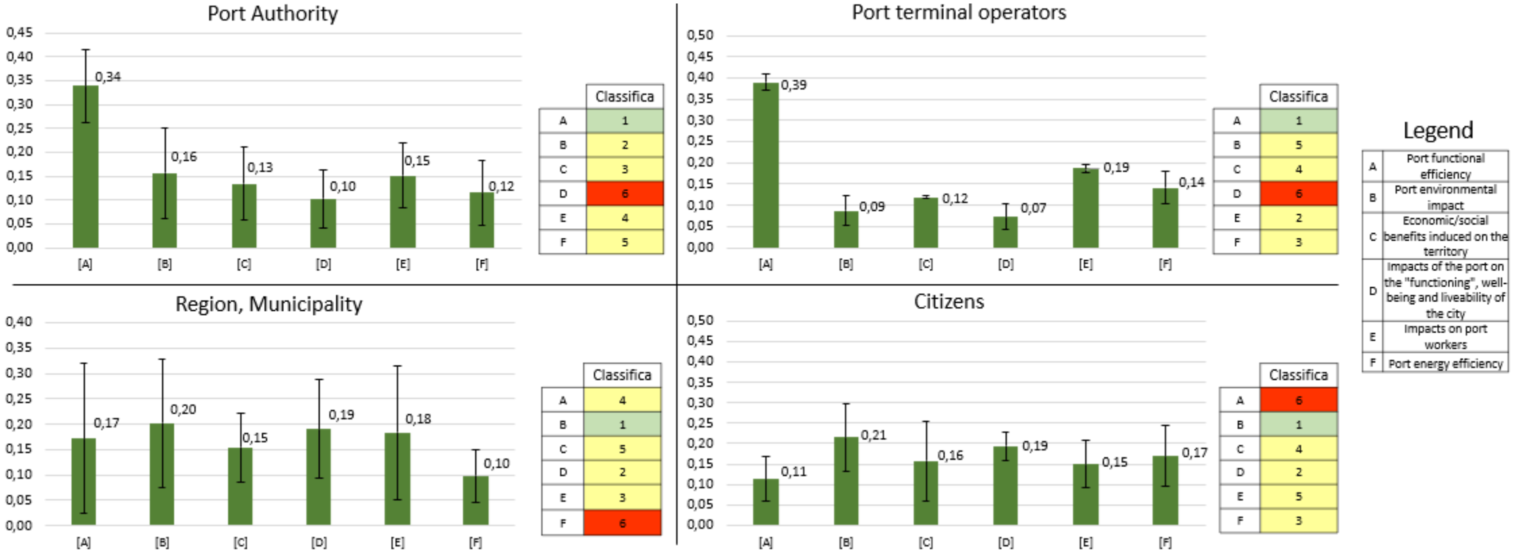


Figure 7.26: Average weights associated to the macro-objectives for 4 categories (AHP).

In Figure 7.27 it is possible to observe the macro-objectives with higher and lower weight, respectively, for the different categories. The extreme importance of functional efficiency is reconfirmed, with 6 out of the 10 categories ranking first. At the same time, it is again energy efficiency that has the lowest overall weight for most of the categories. Among the macro-objectives that never come in last place are the economic and social benefits for the territory and the impact on port workers. Among the macro-objectives that never come first for any group are impacts on efficiency, well-being, liveability of the city, the impact on port workers and the energy efficiency of the port.

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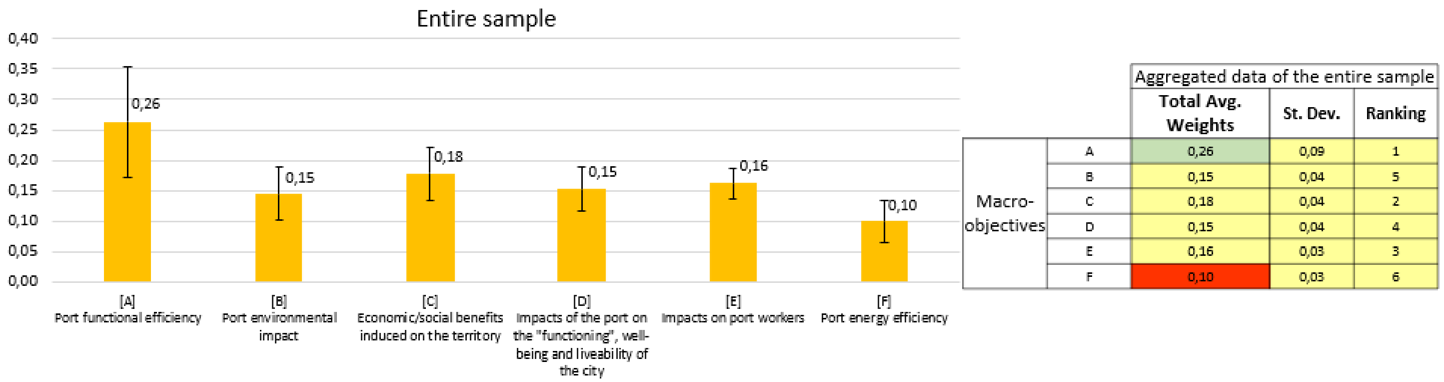
	A	**B**	**C**	**D**	**E**	**F**
	Port functional efficiency	**Port environmental impact**	**Economic/social benefits induced on the territory**	**Impacts on the “functioning”, well-being and liveability of the city**	**Impacts on port workers**	**Port energy efficiency**
Port authority (PA)	*Most*			*Least*		
Region, Municipality (R&M)		*Most*				*Least*
Ministry (M)	*Most*					*Least*
Professors, researchers (P&R)	*Most*					*Least*
Port terminal operators (PRO)	*Most*			*Least*		
Logistic carriers (LC)	*Most*	*Least*				
Italian Railway and Motorway Administrations (Ita. R&M Adm.)			*Most*			*Least*
Self-employed professionals (SEP)			*Most*			*Least*
Employees (E)	*Most*					*Least*
Citizens (C)	*Least*	*Most*				

Figure 7.27: Most and least important macro-objectives for the different categories of stakeholders in terms of absolute ratings (AHP)

Once the comparative evaluations of all the questionnaires were obtained, through the application of the AHP method for each individual respondent, it was possible to obtain the weights attributed to all the macro-objectives by each participant in the survey. The weights of each person involved in the survey were aggregated into a single indicator of the weight associated by the entire sample to all the macro-objectives.

From the aggregate analysis on the entire sample (Figure 7.28) it emerges, also as a consequence of the previous figure, that the most important macro-objective is functional efficiency, followed by economic/social benefits on the territory. The last two positions are occupied, respectively, by the port environmental impact and the port energy efficiency.



		Aggregated data of the entire sample		
		Total Avg. Weights	**St. Dev.**	**Ranking**
Macro-objectives	A	0,26	0,09	1
	B	0,15	0,04	5
	C	0,18	0,04	2
	D	0,15	0,04	4
	E	0,16	0,03	3
	F	0,10	0,03	6

Figure 7.28: Average weights associated to the macro-objectives (AHP)

The total number of respondents attaches greater importance to the functional efficiency of the port with a weight of 0.26, although this macro objective is characterised by the highest value of the standard deviation (0.09), highlighting the different positions of the various interview participants. In second position are the economic/social benefits induced on the territory with a weight of 0.18, followed by the impacts on port workers at 0.16, the environmental impact of the port at 0.15, the impacts on the efficiency, well-being and liveability of the city with 0.15 and finally the energy efficiency of the port with 0.10. These results derive from the weights associated to the different macro-objectives by the individual questionnaire respondents. Below is a summary graph.

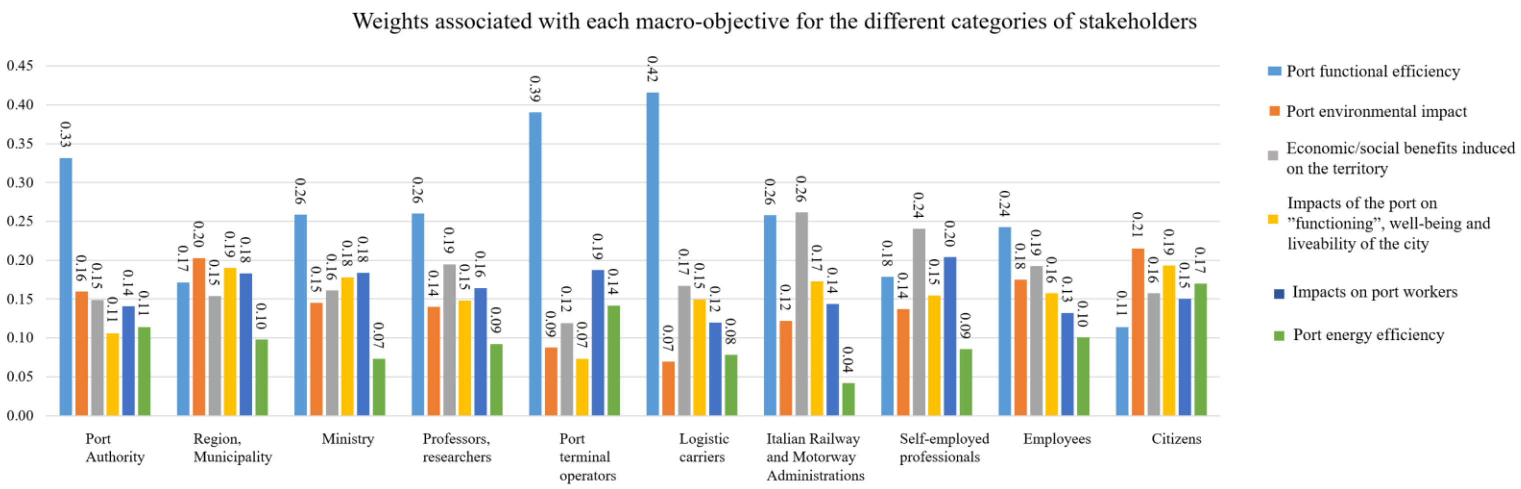


Figure 7.29: Weights for each macro-objective by all stakeholders’ categories

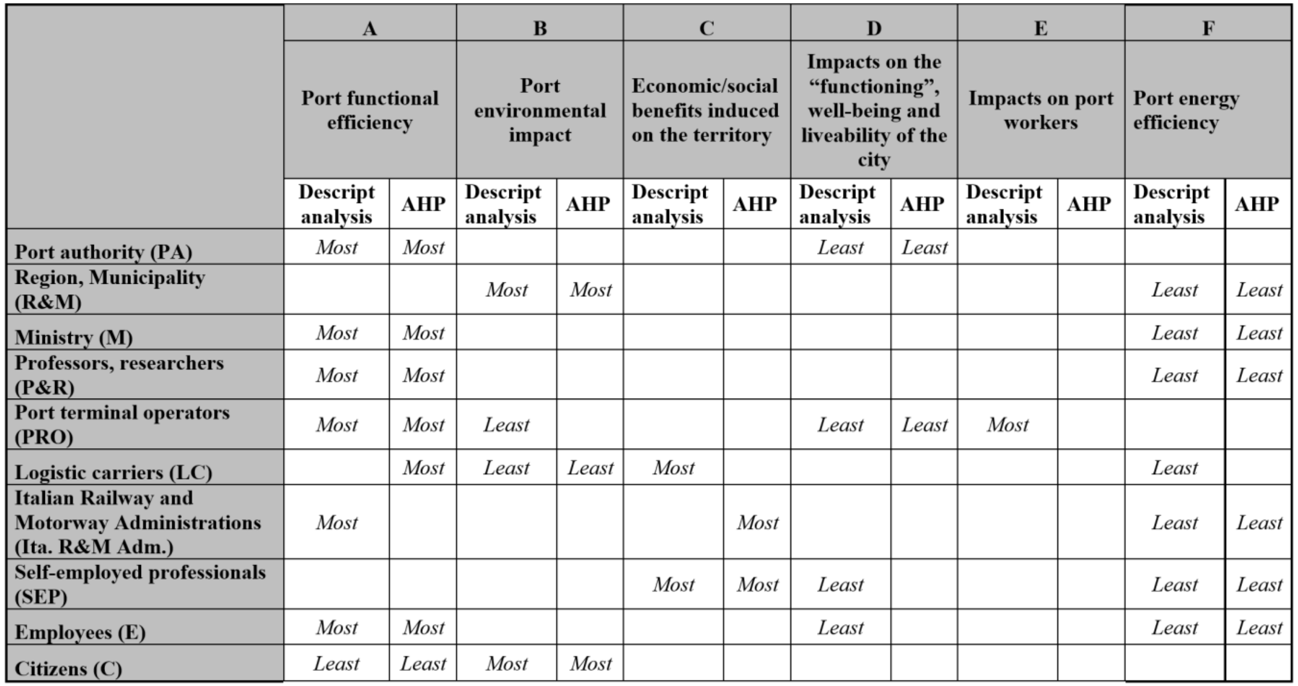
It can be observed that most categories of respondents associate a higher importance to the macro-objective of port functional efficiency. The latter is predominant for the categories Port System Authorities, Terminal Operators and Carriers. The Ministry, Professors, Researchers and Employees categories also put this criterion in first place but with lower weights. The last two categories just mentioned then consider in second place the economic/social benefits on the territory, while the Ministry is more interested in the impacts on port workers. The persons belonging to the Region and the Municipality consider the macro-objective impacts on port workers as the most important.

The groups RFI/ANAS/Motorway Company and Freelancers put the economic/social benefits on the territory first.

As for the students, who are the expression of the citizens' vision, they give prominence above all to the environmental impact of the port and the impacts on the efficiency, well-being and liveability of the city.

Overall, the criterion considered least important is that of the port's energy efficiency, which has the least weight for almost all categories and is considered most relevant by Students and Terminal Operators.

Summarizing, Figura 7.30 shows a synthetic comparison between the descriptive analysis and the application of the AHP method. This comparison refers to the first and last criteria of the ranking. It can be observed that in many cases there is a perfect overlapping of the evaluations, e.g. for Port Authority, Ministry, Researchers and citizens. Small variations can be observed for employees and self-employed professionals, who, in the case of the descriptive analysis, are associated with the corresponding macro-objective placed in last position in the AHP method. Different evaluations are observed in a more marked way for Italian railway and motorway administration, logistic carriers in which either the most relevant macro-objective or the least relevant one does not coincide between the two different approaches.



	A		B		C		D		E		F	
	Port functional efficiency		Port environmental impact		Economic/social benefits induced on the territory		Impacts on the “functioning”, well-being and liveability of the city		Impacts on port workers		Port energy efficiency	
	Descript analysis	AHP	Descript analysis	AHP	Descript analysis	AHP	Descript analysis	AHP	Descript analysis	AHP	Descript analysis	AHP
Port authority (PA)	*Most*	*Most*					*Least*	*Least*				
Region, Municipality (R&M)			*Most*	*Most*							*Least*	*Least*
Ministry (M)	*Most*	*Most*									*Least*	*Least*
Professors, researchers (P&R)	*Most*	*Most*									*Least*	*Least*
Port terminal operators (PRO)	*Most*	*Most*	*Least*				*Least*	*Least*	*Most*			
Logistic carriers (LC)		*Most*	*Least*	*Least*	*Most*						*Least*	
Italian Railway and Motorway Administrations (Ita. R&M Adm.)	*Most*					*Most*					*Least*	*Least*
Self-employed professionals (SEP)					*Most*	*Most*	*Least*				*Least*	*Least*
Employees (E)	*Most*	*Most*					*Least*				*Least*	*Least*
Citizens (C)	*Least*	*Least*	*Most*	*Most*								

Figure 7.30: Most and least important macro-objectives for the different categories of stakeholders in terms of absolute ratings: descriptive statistics and AHP results comparison

7.5.2 Scenarios Application

Three Scenarios have been developed for the analysis and implementation of the complete AHP procedure:

1) Scenario 0
2) Scenario 1 or Workload Scenario
3) Scenario III or Cold Ironing Scenario

All Scenarios have been developed using the model described in chapter 5. In particular, the Scenario 0 and Scenario 1 correspond to those described in Scenario 0 and 1a in section 6.2. Finally, Scenario III deals with the "cold ironing" (Ballini and Bozzo, 2015; Entec, 2005), that is the possibility of directly provide the electric energy to the ships, at the dock, allowing the switching off of the ship's auxiliary engines, in contrast to scenario 3 of section 6.2, only the use of cold ironing is considered in the Scenario III without consider the electrification of the handling means, in this way, local air pollution and the impact of noise and vibration from ships is greatly reduced.

It is important to highlight that the Scenarios are simplified and used with the aim of strengthen the importance and the impact that the MCDM approach has in port applications.

Among the performance indicator described in Section 3.4., the four that change in the various scenarios are the following:

- Ships manoeuvring time;
- Ships hotelling time;
- Ship/Reach Stacker (RS)/Tug Master (TG)/ Rubber Tired Gantry (RTG)/Quay Crane (QC) energy consumption;
- Ship/Reach Stacker (RS)/Tug Master (TG)/ Rubber Tired Gantry (RTG)/Quay Crane (QC) Air pollutants and climate change emissions.

Referring to Scenario 1, as reported it differs from the non-intervention scenario due to the different performance curve of the crane operators regarding loading/unloading operations. It is used the scenario 1a in order to consider not only the mental fatigue of operators also other possible events that have an influence on the total time of the ships, such as contingencies, failures, delays, etc.

The performance indicators that are impacted by this change are the ones related to Ship and Reach Stacker, Tug Master, Rubber Tired Gantry, and Quay Crane. The performance of Trucks and Tug Masters are the same as in Scenario 0.

For Scenario III, the Cold Ironing solution is adopted. This measure is one of the suggested by the European Commission to comply with environmental issues ("Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure (Text with EEA relevance)," 2021) on the deployment of alternative fuels infrastructure . As previously mentioned, it allows to switch off ships' engine, thus the reduction of air pollutant and CO2 emissions and noise improves the environmental quality of ports and surrounding areas.

The on-board electrical system is powered by the land-based network, thus, the auxiliary generators can be switched off gradually. Additionally, these systems can be coupled with renewable energy systems for the energy production (e.g. photovoltaic and wind systems) to reduce transportation and distribution energy losses and improve the efficiency of the entire power generation system.

To date, it has not yet been widely deployed due to the high cost of implementation; in fact, a single power supply point costs around 2.5 million euros.

In the scenario implemented in the simulation model, a total connection/disconnection time of 20 minutes (10 minutes per phase) was considered (Zis et al., 2014). This was included within the ship hotelling time.

The information on handling means, Reach Stacker/Tug Master/ Rubber Tired Gantry/Quay Crane and Trucks energy are the same as in Scenario 0.

In the following the application characteristics and details of the analysis are reported:

the weights of the macro-objectives are those referring to the entire sample

equal weights have been adopted for the functional efficiency indicators (0.5)

ship maneuvering and parking times referred to an average number of 3 berths per day

the calculation of emissions and energy consumption include the contributions from land-side, sea-side and inner-side areas

negative signs for normalized indicators have been used as they all have a negative polarity compared to the global target

In particular, the overall ranking of the alternatives is obtained by calculating the product of the weight of the criteria, the weight of the indicators and the weight of the alternatives assessed against the quantitative values of the indicators, which are

then normalized and thus become indices. The overall weights thus obtained are the result of the procedure.
Additional details on the application weights are reported in Table 7.7.

Table 7.7: Application weights details

Macro-objectives	Macro-objectives weights	Quantitative indicators	Scenarios			Indicator weights	Normalised indicator weights in the three different scenarios		
			A	B	C		0	1	2
A-Port functional efficiency	0,26	Ships Manoeuvring time (h/anno)	2170,0	2170,0	2170,0	0,5	0,33	0,33	0,33
		Ships hotelling time (h/anno)	5652,0	5765,0	5668,0	0,5	0,33	0,33	0,33
B-Port environmental impact	0,15	CO_2 Emissions(t/anno)	14223	14506,54	8333	1	0,31	0,30	0,39
F-Port energy efficiency	0,10	Means energy consumption (MWh/anno)	51904	52281	40767	1	0,32	0,32	0,36

Figure 7. shows the entire AHP framework detailed for the 3 Scenarios. In particular, the product of the local weights of each element with those of the corresponding higher-level elements is reported. Moreover, the sum of the products obtained with respect to the different alternatives (scenarios) is highlighted and, finally, the overall ranking is included. Results highlights that the Scenario III (Cold Ironing) is the best alternative among the ones considered, followed by Scenarios 0 and 1

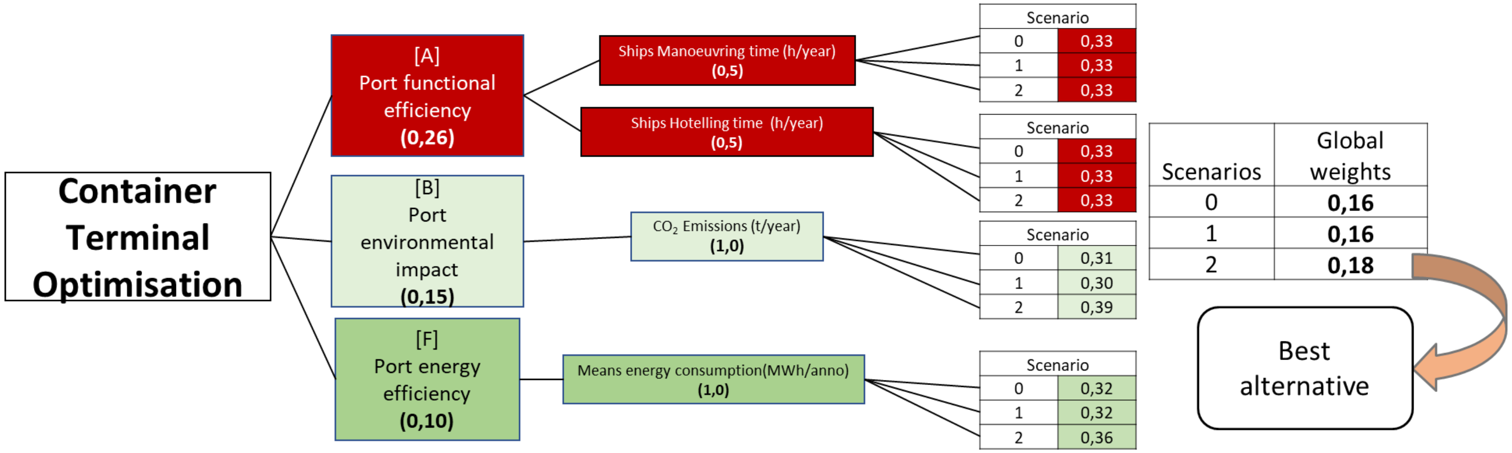


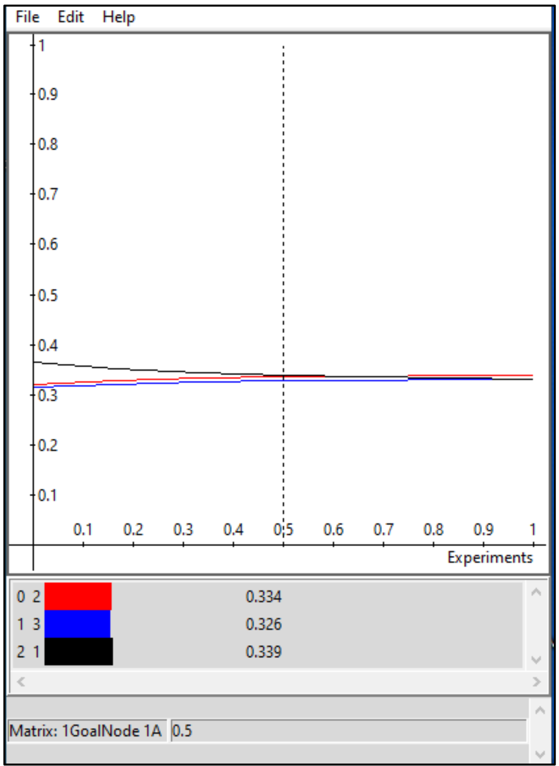
Figure 7.31: Overall ranking

7.5.3 AHP Sensitivity Analysis

The results of the Sensitivity Analysis, implemented in the software Superdecisions, are shown and commented in this section.

The analysis has been conducted with the One-at-a-time method (OAT). The software allows to enter the data about the relative weights of the previously built hierarchy. Then, it is possible to show the variation in the general ranking of the alternatives due to the variation of a single macro-objective's weight. The graphic output consists in spider plots.

About macro-objective A (port functional efficiency), the diagram is shown below.



0 2 🟥 0.334
1 3 🟦 0.326
2 1 ⬛ 0.339

Matrix: 1GoalNode 1A 0.5

Scenario		
0	1	2
🟥	🟦	⬛

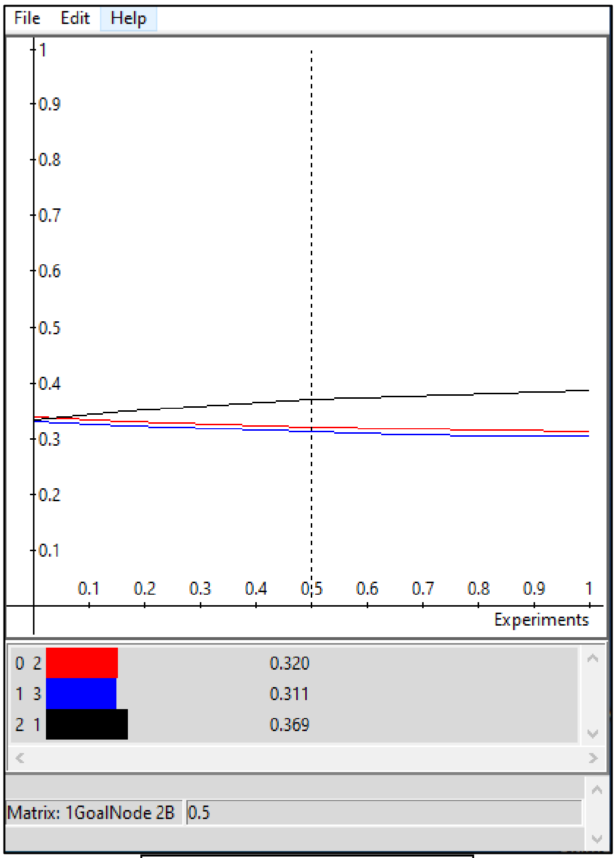
Figure 7.32. Spider plot of the macro-objective A (port functional efficiency).

It is possible to see that the ranking changes for the Scenario 1 (red line) and Scenario III (black line), around the weight value 0.65. This means that if macro-objective A had a higher weight there would have been a reversal in the ranking, with the

Scenario 0 overcoming the Scenario III. The Scenario 1(blue line) is always the worst one.

Incrementing macro-objective A’s weight, the alternatives tend to converge to a similar value.

The next comment is about macro-objective’s B (port environmental impact) diagram.



```
0 2   0.320
1 3   0.311
2 1   0.369
```

```
Matrix: 1GoalNode 2B  0.5
```

Scenario		
0	1	2
🟥	🟦	⬛

Figure 7.33. Spider plot of the macro-objective B (port environmental impact).

As in the previous case, there is a variation ranking for Scenario 0 (red line) and Scenario III (black line), around the weight value 0.05. In the same way Scenario 1 (blue line) is always the worst. Differently from macro-objective A’s sensitivity analysis, incrementing macro-objective B’s weight, the alternatives tend to diverge.

Since the macro-objectives C, D, E do not play a role in the ranking definition, because there are no indicators considered in the scenarios linked to those criteria, the spider plots show 3 straight lines.

Differently from the cases of macro-objectives A and B, there are no ranking reverse for the macro-objective F (port energy efficiency) and the trend of the graph is similar to the one of macro-objective A.

7.6 Conclusions

Ports have a great importance as strategic hubs and are drivers for development. The aim of this work was to deduce the visions and positions regarding various macro-objectives of a functional, environmental, economic and social nature by stakeholders involved, directly or indirectly, in the activities of logistics chains and port systems. This section of the thesis has methodological and operative contributions. From the methodological point of view (i) a multi-criteria analysis method applicable to each port was specified and calibrated, and (ii) the method implemented allows the interpretation of the visions of different stakeholders, as well as the application to real intervention scenarios. From the operative side: (a) the functional efficiency of the port (weight of 0.26) and the economic/social benefits (weight of 0.18) induced on the territory by the port were considered of great importance by the different stakeholders; (b) the environmental impact (weight of 0.15) and the energy efficiency (weight of 0.10) of the port were considered as less important macro-objectives by almost all categories, with the exception of citizens who considered these issues extremely relevant (weight of 0.21 and of 0.17 for the reduction of environmental impacts and of energy efficiency, respectively) compared with the functional efficiency (weight of 0.11).

Moreover, (c) in the simplified application case of the Salerno Port, developed using a multi-agent discrete event model, it was shown that the best alternative is Cold-Ironing.

The sensitivity analysis (d) showed the low presence of rank reversals, which concern specifically Scenario 0 and Scenario 2 regarding the one-at-a-time analysis conducted with respect to macro-objectives A and B.

Finally, future developments include defining the weights of the sub-criteria (indicators) and studying more complex scenarios where a higher number of indicators come into play.

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8. Conclusions and future works

Recognising the importance of ports as strategic hubs and keys to development, there is a clear need for a more in-depth study of these hubs from both an efficiency and sustainability perspective.

The objective of this thesis was the development of a decision support system (DSS) through the specification of an integrated model for the simulation and multi-criteria assessment of the logistics activities, personnel management and environmental impacts of a maritime transport terminal.

This objective was pursued by breaking down the research into two parts:

On the one hand, it concerns the development of a functional tool for the dynamic simulation of a container terminal in order to support decision-making. In this respect, it can be pointed out that, given the main problems within the terminals, be they functional, environmental, energetic, social, etc., the literature highlights two approaches that can be pursued in order to study and therefore resolve these critical issues: on the one hand, it highlights the descriptive or simulation approach and, on the other, the prescriptive or optimisation approach. In the first case, starting from the simulation of the current state of the system under examination, it is possible to identify the most critical points that cause less efficiency in the performance of the terminal and it is therefore possible to propose and test the improvement scenarios; in the case of the approach based on optimisation, knowing the objective functions, the procedure is functional to determine the value of the decision variables that optimise this performance indicator. Since it is intuitively expected that the approach based on optimisation is more efficient from the point of view of computation time, in order to guarantee its actual efficiency it is however necessary to have a clear vision of all the elements (physical and information flows) involved in the simulation process and therefore of their interactions. Therefore, this thesis is intended as a preliminary work for the development of a simulation tool that is able to optimise the performance of a terminal in closed form. In particular, it is based on the first phase of the simulation and therefore of the descriptive approach with the aim of acquiring all the characteristics of the model and guaranteeing a complete and exhaustive abstraction. In particular, the proposed model can be adopted both for the advanced simulation of intervention scenarios and for the real-time management of non-recurring events.

In addition, the literature shows that the functional simulation approach to cope with the different requirements found in the development of activities in a container terminal is a hybrid simulation approach, which combines on the one hand discrete event modelling and on the other hand an agent-based approach, thus obtaining the advantages of each of these, Specifically, the discrete event approach provides a real representation of the system as in a container terminal, the entities represent the handling equipment, containers and all those physical locations relevant to the container terminal operations (dock, yard, gates, etc.).). The handling equipment is a resident and active entity that can be characterised by parameters, variables and activities. Parameters define the main characteristics of each piece of equipment; variables define the state of the entity, such as occupancy status, location; activity defines the duration of the task that the entity performs. The duration of time can be deterministic or stochastic and, in both cases, must be estimated on real data. Containers are passive entities. The focus of the simulation is on how they are moved through the terminal by the handling equipment; therefore, this type of approach allows a good abstraction of the phenomenon, modelling the modularity and representation of the results.

Regarding the agent-based approach it seeks to model the specific behaviours of specific entities. Agents are characterised as modular, decentralised, changeable, unstructured and complex, characteristics well identified in the management of a container terminal:

- Modular: Each decision maker and the resources employed in the terminal have their own set of different state variables;
- Decentralised: A set of actors in a container terminal can be decomposed into autonomous processes, each of which is able to act without interference from the other actors/processes;
- Mutable: A container terminal is subject to change, due to the permanent arrival of ships with different requirements and configurations.
- Unstructured: It is not possible to obtain complete information on all processes of container terminal management due to the use of different systems at the same time, which are not linked together.
- Complex: A container terminal is seen as a complex system with many interacting entities and uncertainties.

It is therefore an effective approach to simulate a container terminal, where several resources are involved with well-defined characteristics between each of them.

In view of this, the simulation model was developed through the hybrid multi-agent event approach using the AnyLogic simulation tool as modelling support. It has allowed the reproduction of a particularly advanced model and therefore coherent with reality; in particular, each agent represents a handling and transport unit, and the interaction between each of them and between load units and handling and transport units is based on the concept of artificial intelligence. Which, each agent will carry out a series of operations not only in a manner consistent with its functionalities but above all adapting to the actual state of the simulation scenario at that given moment.

The specification and validation of the model was centred on the Port of Salerno layout, in order to reproduce the performance of the terminal and test the flexibility of the tool. However, the logical-functional architecture was designed to simulate a generic container terminal, thus the specification can be modified to simulate any container terminal.

From the input data it was therefore possible to calibrate the various curves on the handling times of the various vehicles, in particular specific functions were created for the quay crane operators, which allowed the workload of these to be taken into account when carrying out the loading/unloading operations. Then the model validation phase on the base scenario was initiated. The validation was carried out from a functional and environmental point of view, in comparison with Smart Green Ports and other studies in the literature, showing that the model demonstrates its effective robustness in calculating functional and environmental indicators.

After this first thesis part, the conclusion is that the model obtained is able to correctly simulate 1 week of activity in about 70/80 seconds, thus becoming a possible real-time management system for port activities. It also manages to be a powerful optimisation tool which, thanks to the mono-criteria implementation of various intervention scenarios (electrification of vehicles, workload, cold ironing) and the study of the results obtained, makes it possible to assess the convenience of a modification to the system, whether of a large entity (such as the purchase of new vehicles with electric propulsion, electrification of the docks), as well as small changes (such as changing the direction of travel, changing the arrangement of containers in the dock, better management of workers' workshift, etc.) with almost no economic effort that will serve to make the activities in a container terminal more sustainable.

At the moment the simulation model is able to provide:

- Assisting in the design of a Container Terminal
- Evaluate the performance of a Container Terminal
- Being a real-time control tool
- Assisting in the Terminal optimization
- Consider human factors in the loading and unloading operation ships

In the second part of this thesis, it concerns multi-criteria assessment, in which, the aim was to deduce the visions and positions regarding different macro-objectives of a functional, environmental, economic and social by the stakeholders involved, directly or indirectly, in the activities of logistics chains and port systems. Initially, a survey phase was carried out to identify existing approaches in the literature for the implementation of this type of analysis, highlighting that several studies are currently available on multi-criteria methodologies, and noting that the Analytic Hierarchy Process (AHP) method is the one that ranks as the first method in use. Presenting some advantages:

- Structures a problem in such a way that it is easily manageable;
- Makes explicit the decision criteria, and transparent the decision-making process as a whole;
- Determines priorities through a rigorous mathematical process using ratio scales;
- Enables the measurement and comparison of tangible and intangible elements.

Therefore, based on the above considerations, the AHP is adopted because it is a good compromise between easiness of implementation and reliability.

In this context, the AHP multi-criteria analysis methodology was applied to transform into weight terms the relative judgements expressed on pairwise comparisons between the criteria presented in a hierarchy constructed to assess the impacts on sustainability deriving from port activity. These relative judgements were obtained through a purpose-built questionnaire with a sample of 79 responses from different stakeholders belonging to the public and private sectors. After a consistency analysis of the answers, it was decided to analyse 68 answers, because 11 exceeded the consistency threshold and therefore are considered incongruent.

Overall, it emerged that, of the aggregate sample involved in the survey, the main focus is on the functional efficiency of ports and the economic/social benefits they can produce in the territory. On the other hand, less importance is given to macro-objectives referring to very relevant issues such as environmental impact and energy efficiency. Among the different groups of stakeholders interviewed, only citizens considered these issues (environmental impacts, energy efficiency) extremely relevant, to the detriment of functional efficiency.

Subsequently, different intervention scenarios developed through the simulation model built in the first phase of this thesis work, referring to the case study of the Port of Salerno, were compared. The three scenarios studied include a baseline scenario, a scenario in which the fatigue curve of the crane operators was represented more precisely, and finally the scenario of electrical infrastructure of the docks (cold ironing). By calculating the quantitative indicators that the model makes it possible to measure, simplified applications of the complete multi-criteria procedure were then carried out, which in this specific case showed that the best scenario was the one referring to cold ironing, followed by the baseline scenario and the workload scenario. These scenarios were reported to give an idea of the possible applications of the model, but it was already a dominated solution (cold ironing), in which all indicators assumed a worse value than in the other scenarios.

More interesting is the comparison between the cold ironing scenarios and the baseline scenario. In this case it can be observed that, besides the manoeuvring time of the ships, which is considered the same for the 3 scenarios, in the case of the baseline scenario there is less time stationary, but more emissions and energy consumption (referred to the ships). However, the functional indicator shows only a very slight advantage of the baseline scenario, while the difference in emissions and energy consumption, which is then reflected in the weights, is much more marked in favour of the cold ironing scenario.

Appendix

A. Optimisation problems

In the real world many important applied problems involve finding the best way to accomplish some task. Often this comprises the maximum or minimum value of some function, for instance: the minimum time to make a certain journey, the minimum cost for doing a task, the maximum power that can be generated by a device, and so on. In mathematical terms, an optimization problem is the problem of finding the best solution from among the set of all feasible solutions. Many of these problems can be solved by finding the appropriate function and then using techniques of calculus to find the maximum or the minimum value required.

The first step in the optimization process is constructing an appropriate model; identifying and expressing in mathematical terms the objective, the variables, and the constraints of the problem.

An **objective** is a quantitative measure of the performance of the system that we want to minimize or maximize; the **variables** are the components of the system for which we want to find values and the **constraints** are the functions that describe the relationships among the variables and that define the allowable values for the variables.

Generally, such a problem will have the following mathematical form: Find the largest (or smallest) value of $f(x)$ when $a \leq x \leq b$. Sometimes a or b are infinite, but frequently the real world imposes some constraint on the values that x may have.

Such a problem differs in two ways from the relative maximum and minimum problems we encountered: When we are interested only in the function between a and b, and we want to know the largest or smallest value that $f(x)$ takes on, the second way is when not merely values that are the largest or smallest in a small interval, that is, we seek not a relative maximum or minimum but a global (or absolute) maximum or minimum.

Determining the Problem Type

The second step in the optimization process is determining the category of optimization the model belongs. There are different types of optimisations:

Continuous Optimization vs Discrete Optimization

Some models only make sense if the variables take on values from a discrete set, often a subset of integers, whereas other models contain variables that can take on any real value. Models with discrete variables are discrete optimization problems; models with continuous variables are continuous optimization problems. Continuous optimization problems tend to be easier to solve than discrete optimization problems; the smoothness of the functions means that the objective function and constraint function values at a point x can be used to deduce information about points in a neighbourhood of x. However, improvements in algorithms coupled with advancements in computing technology have dramatically increased the size and complexity of discrete optimization problems that can be solved efficiently. Continuous optimization algorithms are important in discrete optimization because many discrete optimization algorithms generate a sequence of continuous subproblems.

Unconstrained Optimization versus Constrained Optimization

Exists problems in which there are no constraints on the variables but too exist problems in which there are constraints on the variables. Unconstrained optimization problems arise directly in many practical applications; they also arise in the reformulation of constrained optimization problems in which the constraints are replaced by a penalty term in the objective function. Constrained optimization problems arise from applications in which there are explicit constraints on the variables. The constraints on the variables can vary widely from simple bounds to systems of equalities and inequalities that model complex relationships among the variables. Constrained optimization problems can be furthered classified according to the nature of the constraints (e.g., linear, nonlinear, convex) and the smoothness of the functions (e.g., differentiable or no differentiable).

Quantity of Objectives

Most optimization problems have a single objective function, however, there are interesting cases when optimization problems have no objective function or multiple objective functions. Feasibility problems are problems in which the goal is to find values for the variables that satisfy the constraints of a model with no particular objective to optimize. Complementarity problems are pervasive in engineering and economics. The goal is to find a solution that satisfies the complementarity conditions. Multi-objective optimization problems arise in many fields, such as engineering, economics, and logistics, when optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. For example, developing a new component might involve minimizing weight while maximizing strength or choosing a portfolio might involve maximizing the expected return while minimizing the risk. In practice, problems with multiple objectives often are reformulated as single objective problems by either forming a weighted combination of the different objectives or by replacing some of the objectives by constraints.

Deterministic Optimization versus Stochastic Optimization

In deterministic optimization, it is assumed that the data for the given problem are known accurately. However, for many problems, the data cannot be known accurately for a variety of reasons. The first reason is due to simple measurement error. The second and more fundamental reason is that some data represent information about the future and simply cannot be known with certainty. In optimization under uncertainty, or stochastic optimization, the uncertainty is incorporated into the model. Robust optimization techniques can be used when the parameters are known only within certain bounds; the goal is to find a solution that is feasible for all data and optimal in some sense. Stochastic programming models take advantage of the fact that probability distributions governing the data are known or can be estimated; the goal is to find some policy that is feasible for all (or almost all) the possible data instances and optimizes the expected performance of the model.

Guideline for Solving Optimization Problems:

1. Identify what is to be maximized or minimized and what the constraints are.
2. Draw a diagram (if appropriate) and label it.
3. Decide what the variables are and in what units their values are being measured in.
4. Write the formula for the function that is to be maximized or minimized.
5. Use the given constraint to express the formula from Step 4 in terms of a single variable, namely something like $f(x)$ Then identify the domain of this function.
6. Find the critical points of f. Compare all critical values and endpoints to determine the absolute extrema of f.
7. Provide the solution

B. Literature Review: Formulations

B.1. Seaside

Index:

t= time

i=ships

n=trucks

q=quay crane

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j=task group

b=yard block

b'=yard bay

m= berth

k=truckers

s=time slot (on opening gate)

w= commodity

a=arc

p= service positions

<u>*Derived variables/Parameters:*</u>

bnv=Virtual berth-flow network

BN= Berth flow network, including the virtual berth-flow network

BN\bnv= Berth flow network, excluding the virtual berth-flow network

SA^{BN}= The set of stochastic ship berthing arcs in the berth-flow network

SA^{bnv}= The set of stochastic ship berthing arcs in the virtual berth-flow network

P_{az} =Penalty for assigning a ship to a berth of different types on the stochastic ship arc (a,z)

$P_{d,i}$=The penalty cost incurred if the departure of vessel *i* is later than its expected departure time

π_{az}= Penalty for being unable to service the ship corresponding to ship berthing arc (a,z) in the virtual berth-flow network

$\beta_{a,z}$= The sum of the expected values of unanticipated schedule delay costs over all ships

$x_{a,z}^{BN}$= The flow on arc (a, z) in the berth-flow network.

ZE_{isi}= Containers to be exported in the section si of the ship i

ZI_{isi}= Containers to be imported in the section si of the ship i

d_{mb}=Distance between the container block b and the berth segment m

t_{si}= Slack time for ship i

t_{sm}= Slack time of the berth m

t_{ei}=expected berthing time of ship i

t_{fi}=ending berthing time of ship i

$t_{i,m}$=Berthing time of ship i at berth m

$t_{h,i}$=Handling time of ship i

T= Horizon time

c_d=Cost rate of ship i with respect to the deviation of its assigned berthing time from its expected one

$A_{i=}$Arrival time of ship i

ETA_i= Expected time of arrival of ship i

EFT_i= Expected finishing time of ship i

c_{jq}= Cost of task j assigned to Qc_q

Γ_{jq}= Resource needed if task i is assigned to QC q

Qc_c= QC capacity

D_{pi}=The planned departure of ship

D_{ri}= The real departure of ship

$Tc_{l'}^{u}$= completion time of unloading all containers from stack *l'*

$Tc_{l'}^{l}$= completion time of loading all containers into stack *l'*

Tc_h^{-l}= completion time of loading all containers into the hold of hatch *h*

Tc_h^{-u}= completion time of unloading all containers from the hold of hatch *h*

$Tc_{\_h}^{u}$= completion time of unloading all containers from the deck of hatch *h*

$Tc_{\_h}^{l}$= completion time of loading all containers onto the deck of hatch *h*

r^q= ready time of the quay crane q

d^q=due date of the quay crane q

Em_Q= the CO2 emission per QC per hour

ec_Q= the electricity consumption per QC per hour

$c_{ec,i}$=The energy consumption cost of vessel *i* per hour in idle mode

ef= the CO2 emission coefficient

r_q= Quay crane handling rate (in container units per crane-hour)

Tc=Maximum completion time

Variables	Berth Allocation: Objective functions	Strategy	Paper
bnv BN BN\bnv SA^{BN} SA^{bnv} P_{az} π_{az} $\beta_{a,z}$ Decisional $x_{a,z}^{BN}$	$Min f_{1} = \sum_{\mathrm{BN\backslash bnv}} \sum_{a,z \epsilon SA^{BN}} ({P_{a,z}}^{BN} + \beta_{a,z}^{BN}) * x_{a,z}^{BN} + \sum_{a,z \epsilon SA^{bnv}} * \pi_{az} * {x_{az}}^{bnv}$	• This study proposes a berth-flow network modelling approach to deal with the **dynamic berth allocation problem** with stochastic vessel arrival times. In this approach, uncertain vessel arrival times are represented using discrete probability distributions and a flexible berth allocation scheme. • The objective function minimizes the sum of the expected values of unanticipated schedule delay costs and the penalties for unable to serve all ships within the planning horizon. The no served ships are placed in a virtual berth-flow network. The model is formulated as an integer multi-commodity network flow problem.	(Shangyao Yan et al., 2019)
ZE_{isi} ZI_{isi} d_{mb} PE_{ib} Decisional X_{imt} PI_{ib} Y	$Min f_{1} = \sum_{i=1}^{I} \sum_{m=1}^{M} \sum_{t=1}^{T} \sum_{si=1}^{SI} \sum_{b=1}^{B} [(X_{imt} * ZE_{isi} * d_{mb} * PE_{ib}) + (X_{imt} * ZI_{isi} * d_{mb} * PI_{ib}) + Y + (U_{i,si,qc} + V_{i,si,qc})]$ i 1,…….,I ship index m1,……,M segments of berths t,1…....,T time periods si,1..….,Si Storage sections in the ship qc,1……,Qc Number of quay cranes b,1……..,B number of yard blocks X_{imt}=Binary variable. It take a value 1 if ship I is located in segment m in the time t, and 0 otherwise PE_{ib}=Binary vector with a length equal to b for each ship i. It takes a value equal to 1 to show the block b where containers are being stored to be exported in ship i. PI_{ib}= Binary variable. It takes a value equal to 1	• This paper deal the berth allocation problem as a **dynamic berth allocation problem**, the authors propose a mixed integer model considering the distance travelled by handling means. They develop a heuristic procedure, based on a genetic algorithm, to solve the corresponding mixed integer problem. • The objective is to minimise the total service time, which includes waiting time of the ship to come into the port, and loading and unloading operation time.	(Arango et al., 2013.)

	if the containers of ship i are located in the block b, and 0 otherwise. Y= Binary variable. It takes a value equal to 1 if the section s of the ship i is operated with the quay crane qc in the time t, and 0 otherwise. $U_{i,si,qc}$ =Auxiliary variable. $V_{i,si,qc}$ =Auxiliary variable.		
T c_d t_{ei} Decisional $t_{i,m}$ β_i	$Minf_{1=}\sum_i c_d * (\Sigma_m t_{i,m} - \beta_i * T - t_{ei})$ $Minf_{2=}\sum_i c_d * \left(\Sigma_m t_{i,m} - \beta_i * T - t_{ei}\right) + \sum_i c * (t_{fi-} t_{si})$ β_i= Binary variable for considering the periodicity of schedules $c*(t_{fi}- t_{si})$= The penaly cost related to the rushing cost for increasing the productivity so as to shorten the operation time	- This paper investigates the tactical-level berth allocation scheduling models. First a deterministic model for tactical BAP is formulated with considering the periodicity of schedule, and then a stochastic BAP is formulated considering a significant uncertainty with respect to the operation time (dwell time) of ships, which further complicates the traditional berth allocation decisions.	(Zhen, 2015)
$t_{i,h}$ A_i Decisional x_{ip}^m	$Minf_{1=}\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{p=1}^{P}\left[(i - p + 1) * t_{i,h} + s_m - A_i\right]x_{ip}^{m} + \sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{t=1}^{T}(i - p + 1)t_{sm}$ x_{ip}^m= Binary variable equal 1 if ship I is assigned at position p to berth m MDVRPTW formulation: $Minf_{2=}\sum_i\sum_m c_d * (t_{i,m} - A_i + t_{i,h} * \sum_{i' \epsilon I} x_{ii'}^{m})$	- Two formulations and a tabu search heuristic are presented for the discrete case. The first one is the **dynamic berth allocation problem**, the second one is a Multi-Depot Vehicle Routing Problem with Time windows (MDVRPTW). - The objective function minimizes the sum of service time for each ship.	(Cordeau et al., 2005)

ETA_i EFT_i Qc Decisional ΔETA_i ΔEFT_i u_i r_{itq}	$Minf_{1=}\sum_i c_i{}^1 * \Delta ETA_i + c_i{}^2 * \Delta EFT_i + c_i{}^3 * u_i + c^4 * \sum_i \sum_Q Qc * r_{itq})$ u_i= Binary variable , set 1 if the finishing time of ship exceeds the latest finishing time, 0 otherwise r_{itq}= Binary variable, set to 1 if exactly Qc quay cranes are assigned to ship I at time t c_i^1, c_i^2 ,c_i^3= Services cost rates for ship i per hour c^4= Operation cos rateper Qc per hour	• The authors presents a integrated mathematical model to solve the berth allocation and crane allocation problem solve the problem a construction heuristic, local refinement procedures, and two meta-heuristics are presented. These methods perform well on a set of real world like instances.	(Meisel and Bierwirth, 2009)
t_{si} $t_{h,i}$ A_i Decisional x_{imo} y_{imo}	$Minf_{1=}\sum_i \sum_m \sum_o - a_i[(t_{hi,m} + t_{si,m} - A_i)x_{imo}] + y_{imo}$ i 1,…….,I ship index m1,……,M segments of berths o 1,……,O service orders index x_{imo}= Binary variable, set 1 if ship I is serviced at berth m, 0 otherwise y_{imo}= Idle time of berth m between departure of ship I an its immediate predecessor a_i=weight of ship i	• In this paper the discrete and **dynamic berth allocation problem** is formulated as a linear MIP problem with linear constraints, with the objective to minimize the weighted total service time using the allocation policies with service priority, applicable in situations that involving various vessel sizes, different handling volumes and different service strings.	(Boile, 2020) (Imai et al., 2003)
Decisional y_j r_{itq}	$Minf_{1=}\sum_{j\in\Omega} Col_j * y_j + c^4(\sum_i \sum_t \sum_Q Qc * r_{itQ})$ r_{itq}= Binary variable, set to 1 if exactly Qc quay cranes are assigned to ship i at time t y_j=Binary variable,set 1 if column j is used , 0 otherwise c^4= Operation cos rate per Qc per hour Ω= Set of columns j= Represent an element of the matrix	• The authors improve the formulation of [19], proposing a variant of the model where the number of QCs assigned to a ship is fixed throughout the ship's stay. • The generalized set partitioning model is used, where it is represented by columns to assignment of a single vessel to a position in time and space , obtaining a matrix with Ω number of columns.	(Iris et al., 2015)

Decisional m_i	$Minf_{1=}\sum_i c_{ec,i} * \Delta m_i + c_{ec,i} * \Delta m_i + P_{d,i} * \Delta m_i$ c_i=The penalty cost incurred if there is a deviation between the allocated berthing position of ship i $P_{d,i}$	• This work presents a planning model that integrates berth allocation, quay crane assignment, and internal truck assignment problems. To solve realistic problems, a Lagrangian relaxation-based method was developed.	(Karam et al., 2020)
$t_{i,m}$ $t_{h,i}$ t_{fi} ϒ Decisional ξ	$Minf_{1=}\gamma\sum_i * \rho^+{}_i + (-\xi)$ ξ= The length of buffer time. ρ_i^+=max[0, $t_{i,m}$+ $t_{h,i}$+ξ- t_{fi}] ϒ= Weight in the objective function ≤ 1	• The authors formulate a robust berth scheduling algorithm, which considers the uncertainty of vessel arrival delay and handling time, the authors add a buffer time after the estimated completion time of each vessel to give room for uncertain delay. When making a baseline plan, the berthing position of a vessel is not available for the other vessels during its buffer time.	(Xu et al., 2012)
a_i A_i Decisional t_{fi}	$Minf_{1=}\sum_i a_i + (t_{fi} - A_i)$ a_i=weight of ship i	• Two mathematical formulations are considered where one is used to develop a tree search procedure while the other is used to develop a lower bound that can speed up the tree search procedure. Furthermore, a composite heuristic combining the tree search procedure and pair-wise exchange heuristic is proposed for large size problems	(Guan and Cheung, 2004)
$t_{h,i}$ t_{sm} A_i Decisional x_{imo}	$Minf_{1=}\sum_{i\epsilon I}\sum_{m\epsilon M}\sum_{o\epsilon O}[(O - o + 1)t_{hi} + t_{\mathrm{sm}} - A_i] * x_{imo}$ x_{imo}=Binary variable, set1 if ship i is serviced as the at berth m,0 otherwise	• The paper presents a heuristic procedure to solve the **dynamic berth allocation problem**. To obtain a good solution with considerably small computational, the authors developed a heuristic procedure based on the Lagrangian	(Imai et al., 2001)

		relaxation of the original problem.	

Variables	Quay crane assignment: Objective functions	Strategy	Paper
Decisional c_{jq} x_{jq} Γ_{jq} Qc_c	$Minf_{1=}\sum_{q}^{Qc}\sum_{j}^{J} c_{jq}x_{jq}$ Where: $\sum_{j}^{J}\Gamma_{jq}x_{jq} \leq Qc_c$ q 1,……..Qc Quay cranes index j 1,……..J Task index x_{jq}= Binary variable, set 1 if task j is assigned to quay crane q Γ_{jq}= Resource needed if task i is assigned to QC q Qc_c= QC capacity	• This paper deal the quay cranes taks assignment, which is considered NP-complete problem. This model minimizes the objective function which is the QC total holding cost and considering two constraints. The first one deal with the resourses capacity of Qc and the second one ensures that each task is assigned to only one Qc • Then proposes a meta-heuristic approach named Ant Colony Optimization, considering the spatial constraint for the resolution of it	(Azza et al., 2014)
D_{pi} Decisional D_{ri}	$Minf_{1=}\sum_{i}\max(D_{ri} - D_{pi}, 0)$ $Minf_{2=}\sum_{j}E_j^{tw}\sum_{j}E_j^{wq}\sum_{j}E_j^{wy}\sum_{j}E_j^{tr}$ E^{tw}_j =the traveling energy consumption of Task j E^{wq}_j = the energy consumption of an IT waiting for QC to handle Task j E^{wy}_j = the energy consumption of an IT waiting for YC to handle Task j E^{tr}_j = the transportation energy consumption of Task j	• This paper addresses the problem of integrated quay crane scheduling, internal trucks scheduling and yard crane scheduling. Firstly, this problem is formulated as a mixed integer programming model, where the objective is to minimize the total departure delay of all ships (*f*1) and the total transportation energy consumption of all tasks(*f*2).	(He et al., 2015b)
$Tc_{l'}^{u}$ $Tc_{l'}^{l}$ Tc_{h}^{-l} $Tc\__{h}^{u}$ $Tc\__{h}^{l}$	$Minf_{1=}w$ Subject to : $w \geq Tc_h^{-u}$ $Tc\__h^u \geq Tc_{l'}^u$ $w \geq Tc_h^{-l}$ $Tc\__h^l \geq Tc_{l'}^l$	• The aim of this study is to minimize the number of operation cycles of a QC for loading/unloading containers in a ship-bay, it	(Zhang and Kim, 2009)

Decisional $X_{l'm'}$ $Y_{l'm'}$	$w \geq Tc^{u}_{\_h}$ $\quad Tc^{u}_{l'} \geq Tc^{\ u}_{\_h} + n^{u}_{l'}$ $w \geq Tc^{l}_{\_h}$ $\quad Tc^{l}_{l'} \geq Tc^{u}_{l'} + n^{l}_{l'}$ $Tc^{-u}_{h} \geq Tc^{u}_{l'}$ $\quad Tc^{l}_{l'} \geq Tc^{-l}_{h} + n^{l}_{l'}$ $Tc^{-l}_{h} \geq Tc^{l}_{l'}$ $Tc^{l}_{m'} - Tc^{u}_{l'} + M(1 - X_{l'm'}) \geq n^{u}_{m'}$ $Tc^{l}_{m'} - Tc^{l}_{l'} + M(1 - Y_{l'm'}) \geq n^{l}_{m'}$ $X_{l'm'}$= binary variable for permutation of unloading stacks, set 1 if unloading for stack j is performed immediately after unloading for stack i 0; otherwise $Y_{l'm'}$= binary variable for permutation of loading stacks, set 1 if loading for stack j is performed immediately after loading for stack I 0; otherwise	mains to maximize the number of dual cycle operations. A formulation in QC scheduling problems is proposed as a mixed integer programming model. A hybrid heuristic approach is proposed to solve this model	
c^1_i c^2 c^3 $t_{i,m}$ Decisional q'^{q}_{it} it^{q}_{it} x_{it}	$Minf_{1=}c^1_i * \sum_i [\max(t * x_{it}) - t_{im} + 1) + c^2 \sum_i \sum_q \sum_t q'^{q}_{it} + c^3 \sum_i \sum_q \sum_t it^{q}_{it}$ c^1_i= service cost rate given in units of US$1,000 per hour for each ship i c^2= operation cost rate of the QC given in units of US$1,000 per QC-hour c^3= operation cost rate of the internal truck given in units of US$1,000 per IT-hour q'^{q}_{it}=1, if QC *q* is assigned to ship I in time period *t*, 0 otherwise it^{q}_{it}=integer number to represent the number of ITs assigned to QC *q* when it works on ship i in time period *t* x_{it}=1, if ship i is handled at time period *t*, 0 otherwise	• This paper presents a mathematical model, used to solve the quay crane assignment problem, and the assignment of internal trucks to each quay crane simultaneously. The proposed model considers important practical aspects such as the limited availability and operation cost of the internal trucks. A Lagrangian relaxation, and subgradient optimisation procedure-based heuristic is proposed for the model.	(Karam and Eltawil, 2016)
Decisional L^q R^q X_{jq}	$Minf_{1=}W_{makespan}$ Subject to: $\sum_Q X^q_j = 1$ $R^q + L^q = 1$ $R^v = R^w, L^q = L^w \qquad v, w \in Q$ $Z_{jj'} \geq X^q_j + X^q_{j'} + R^q - 2$ $Z_{jj'} \leq 3 - X^q_j + X^q_{j'} + R^q$ $Z_{jj'} \geq X^q_j + X^q_{j'} + L^q - 2$ $Z_{jj'} \leq 3 - X^q_j + A^q_{j'} + L^q$ $T_{cj} + t_{jj'} + pr^q_{j'} - T_{cj'} \leq M * (3 - X^q_j + X^q_{j'} - Z_{jj'})$	• This study provides a rich model for quay crane scheduling that covers important issues of practical relevance like crane-individual service rates, ready times and due dates for cranes, safety requirements, and precedence relations among container groups. Focus is put on the incorporation of so-called unidirectional schedules into the model, by which cranes move along	(Legato et al., 2012)

	$T_{cj} + X_{j'}^{q} * pr_{j'}^{q} - T_{cj'} \leq M * (1 - Z_{jj'})$ $T_{cj} - X_{j'}^{q} * pr_{j'}^{q} - T_{cj'} \leq M * Z_{jj'}$ $X_{j}^{v} - X_{j'}^{w} \leq 1 + Z_{jj'} + Z_{j'j}$ $T_{cj} + \Delta_{jj'}^{vw} + pr_{j'}^{w} - T_{cj'} \leq M * (3 - Z_{j'j} - X_{j}^{v} - X_{j'}^{w})$ $T_{cj'} + \Delta_{jj'}^{vw} + pr_{j}^{v} - T_{cj} \leq M * (3 - Z_{j'j} - X_{j}^{v} - X_{j'}^{w})$ $r^{q} - t_{0j'}^{q} + pr_{j}^{q} - T_{cj'} \leq M * (1 - X_{j'}^{0} * q)$ $T_{cj'} - d^{q} \leq M * (1 - X_{j'}^{q})$ $T_{cj} - W_{makespan} \leq M * (1 - X_{j'}^{q})$ X_{jq}= Binary variable, set 1 if task j is assigned to quay crane q L^{q}=Binary variable, set 1 if crane q moves from right to left in the service process R^{q}= Binary variable, set 1 if crane q moves from left to right in the service process	the same direction, employing a branch-and-bound scheme being the best available solution method for a class of less rich quay crane scheduling problems. Moreover, a novel Timed Petri Net approach is developed and incorporated into the scheme for determining the starting times of the discharge and load operations in a schedule • The objective is to minimize the makespan of the schedule to provide the fastest possible service to the ships	
Decisional St_{μ}	$Minf_{1=}St_{\mu}(n, n') + St_{\mu-1,n'}$ St_{μ}= Is the minimum total number of setups from stage 1 through stage μ under the condition that the state of stage μ is *n*. And, *S* μ (n, *n'*) is the number of setups when the states at stage (μ − 1) and μ are n' and n, respectively.	• An integer programming model is formulated by considering various practical constraints. A two-phase solution procedure is suggested for solving the mathematical model. The first phase determines the Berthing allocation. In the second phase, a detailed schedule for each Quay crane is constructed based on the solution found from the first phase. The dynamic programming technique is applied to solve the problem of the second phase. Is presented the formulation for the second phase • The objective is minimize the total number of setups for cranes to start the transfer operation of vessels. The crane-	(Park and Kim, 2003)

		assignment problem can be formulated by dynamic programming (DP). Two types of events are used to define the stages for DP. One is the arrival of a ship and the other is the changing of the number of cranes assigned to a ship. Then, the time when either event occurs is considered as a "stage" of DP	
Qcs Ycs Decisional $x_{ib't}$ $z_{b't}$	$Minf_{1=}w * \sum_i \sum_{b'} \sum_t x_{ib't} + (1-w) * \sum_b \sum_t z_{b't}$ $x_{ib't}$=Binary variable, number of quay cranes allocated to ship i, bay *b'* at time *t* $z_{b't}$=Integer variable, number of yard cranes allocated to sub-block b in time period *t* w=weight w is assigned, which varies between 0 and 1, this consider the relative cost of the yard crane compared to quay crane	• This paper investigates the integration between the quay and yard sides for multiple berthing ships with transshipment containers. An integer linear programming model is formulated to minimize the total number of cranes used in both quay and yard sides for all berthing ships with transshipment containers unloading during a finite and discretized time horizon. • The model objective is to determine the number of quay cranes needed for every ship at every time period, concurrently with the number of yard cranes needed at every time period, from a set of available cranes, in a way that minimizes the crane usage cost.	(Nehme et al., 2019)
ec_Q ef L_{AVG} ef_{AGV} Fc Decisional Em_Q Em_l	$Minf_{1=}Min\ Em_l = Em_1 * L_{AVG} + Em_Q * q$ Where: $Em_Q = ec_Q * ef$ $Em_1 = Fc * ef_{AGV}$ Em_l=the mean CO2 emission per AGV per hour at idle state in queue, Fc=is the mean fuel of AVG consumption per AGV per hour at idle state in queue ef_{AGV}=the CO2 emission coefficient	• In this paper, a convex mathematical programming model is proposed for the QC assignment problem, in which the queueing theory is used to model the queueing behavior of automatic guided vehicles (AGVs). The objective of the proposed model is to minimize CO2 emission during an unloading process	(Liu, 2018)

	L_{AVG}=queue length of AGV in the front of Qc	of containers from QCs to AGVs by optimizing the number of QCs.	
M Q I r_q c_m Decisional x_{qm}	$Minf_{1=}W_{makespan}$ Subject to: $\sum_{q=1}^{Q} x_{qm} = 1$ $\sum_{m=1}^{q-1} x_{qm} \leq 0 \quad \forall q \geq 2$ $\sum_{m=(M+1)-(Q-q)}^{M} x_{qm} \leq 0 \; \forall q \leq Q-1$ $x_{qm} \leq \sum_{l=m+1}^{M} x_{l,q+1} \; \forall m \leq M-1, q \leq Q-1$ $x_{qm} \leq \sum_{l=1}^{q-1} x_{l,q-1} \; \forall m \geq 2, q \geq 2$ $W_{makespan} = \max \sum_{m=1}^{M} \frac{x_{qm} c_m}{r_q}$ x_{qm}=Binary variable, set 1 if quay crane q is assigned to berth m, 0 otherwise c_m= number of containers on bay m	• This paper presents a simple approach for the integrated quay crane assignment and scheduling problem (QCASP), by transforming it into a crane-tobay assignment problem, and develops a Lagrangian relaxation algorithm based heuristics to solve it	(Theodorou and Diabat, 2015)
Decisional	$Minf_{1=}\min\,(\alpha * Tc + \beta * YC_o)$ $Tc = \max\,(Tc_r^l, Tc_r^u)$ Subject to : Tc_r^l= The completion time of loading operations in row r Tc_r^u= The completion time of unloading operations in row r α,β= weight coefficients.	• The model considers the stowage plan of outbound containers and the operation sequence of quay cranes, considering the quay crane dual-cycling scheduling. To solve the model, a heuristic method, called bi-level genetic algorithm, is designed.	(Zeng et al., 2015)
Decisional x^t_{qm} $y^t_{qm'}$ f^t_m	$Minf_{1=}W_{makespan}$ Subject to: $W_{makespan} \geq t * f_m^t$ $Uh_m^t \leq M * Uh_m^t \leq f_m^t$	• This paper presents a novel MIP formulation of the QCSP that takes into account vessel stability constraints.	(Al-Dhaheri et al., 2016)

	$Uh_m^t \leq f_m^t$ $\sum_M x_{qm}^t \leq 1$ $\sum_Q x_{qm}^t \leq 1$ -For other constraints please refer to the paper x_{qm}^t=Binary variable, set 1 if quay crane q is assigned to berth m at time t, 0 otherwise $y_{qm'}^t$= Binary variable, set 1 If quay crane q starts moving from bay m to bay m' at time t, 0 Otherwise f_m^t= Binary variable, set 1 if bay m is not completed at time t, 0 Otherwise	Furthermore, the proposed model is very flexible in handling various settings of the QCSP, such as those related to crane traveling time, task preemption and unidirectional quay crane operating mode.	

B.2. Innerside

Index:

t= time

i=ships

n=trucks

j=task group

b=yard block

k=truckers

s=time slot (on opening gate)

w= commodity

a=arc

sb=subblock

Derived variables/Parameters:

e= Ships' time slot

d= distance of unloading/loading route of containers

pi= Penalty on ship time

t_{tm}= Travel time of tug masters

m=The weight group of the arriving container (heavy,medium,light)

X_{st}= The input state of the stage, this consists of the number of empty slots in each row and the weight group of the heaviest container, which we call the high-weight group, stacked in each row of a yard-bay.

PC'=Unit penalty cost when the waiting time of TM request exceeds its threshold

PC= Unit penalty cost when the waiting time of trucks request exceeds its threshold

Cwy=Waiting cost of a truck at yard block

C'wy=Waiting cost of a tug master at yard block

Ɵ= A binary parameter which represents the type of truck request "n"; θn = 1, if request is internal (TM); θn = 0, otherwise(T)

WT_{TM}= the waiting time threshold of each tug masters request;

WT_T= the waiting time threshold of each external truck request;

C_o= Operating cost of a YC

$C_{bb'}$= YC moving cost from block "b" yo block "b'"

Decision Variables:

s=The start time of trucks request j

z= number of containers

y= binary variable

ATA_i=Actual time of ship arrival

ATD_i=Actual time of ship departure

R_{st} = the row number assigned to the arriving container at stage

RE=Amount of retrieval earliness for each move

RL= Amount of retrieval lateness for each move

STL= Amount of storage lateness for each move

Variables	Yard Storage: Objective functions	Strategy	Paper
Pi t_{tm} Decisional: Y_{sb} ATA_i ATDi	$f_{1=}Min \sum_i \sum_z \sum_{sb} pi * (t_{tm} * y_{sb})$ $f_{2=}Min \sum_i (pi * (ATD_i * ATA_i)$ Y_{sb}=Binary variable representing the storage block i 1,…….,I ship index z 1,…….,Z containers index	- This paper investigates container storage allocation and the sequencing and scheduling of handling operations in the port. An integrated approach is proposed to minimise ship service time, that concerns about the distance travelled by TMs; the scheduling and the sequencing of container process. Consider an initial storage allocation plan, given an initial processing sequence, the objective value of the best schedule can be found using marshalling area or without marshalling area, new processing sequence is effectively generated by simply re-arranging container storage locations. In storage allocation model, the objective value will not be affected by exchanging the storage positions of containers (on the ship or in the yard) of the same ship and loading/unloading position. Storage allocation model: Minimise the total travel time of tug masters (f_1) Container process model: Minimise the weighted penalty on ship service time (f_2)	(Wong and Kozan, 2006)
Decisional: Travel Setup	$Minf_{1=}Max \ \sum_{TM}(travel_z + Setup_z)$ z 1,…….,Z containers index	- This paper presents an iterative search algorithm that integrates a container- transfer-model (schedule), with container-location model (storage), to determine the optimal	(Kozan and Preston, 2006)

	$Travel_z$=The time required to transport container "n" between the storage area, marshalling area, track area and/or intermodal terminal $Setup_z$=This is the time required to move the container(s) stored above the next scheduled container; if the desired container is on top, there is no setup time. If the desired container is not on top of the other containers, the setup time incorporates the time required to move these containers to an adjoining position.	storage strategy and container-handling schedule. • Container-transfer model(CTM): Minimise the berthing time of the ships • Container-location model(CLM): Determine the optimal storage location for various schedules by minimising the total throughput time of containers Firstly, CTM is solved for container transfers using random initial storage locations. The output, handling schedule, is then used as input for CLM. The optimal locations of containers determined are then subsequently used as input to CTM	
Decisional Z_{Dsbt} Z_{Lsbt} Z_{Psbt} Z_{Gsbt} $Z_{sbit'}$	$f_1 = Min \sum_t \Phi_1 * [\max(Z_{Dsbt} + Z_{Lsbt}) - min(Z_{Dsbt} + Z_{Lsbt})] + \Phi_2[max(Z_{Dsbt} + Z_{Lsbt} + Z_{Gsbt} + Z_{Lsbt}) - min(Z_{Dsbt} + Z_{Lsbt} + Z_{Gsbt} + Z_{Psbt})]$ Z_{Dsbt}= The total number of inbound and transit containers stored in block "sb" that are discharged from ships during period t	• The yard storage problem is discomposed into two levels and each level is formulated as follow: • At the first level, the total number of containers to be placed in each storage block in each time period of the planning horizon is set to balance the workloads among blocks (f_1) • The second level determines the number of containers associated with each ship that constitutes the total number of containers in each block in each period, in order to minimize the total distance to transport the containers between their storage	(Zhang et al., 2003)

	Z_{Lsbt}= The total number of outbound and transit containers stored in block “sb” that are loaded onto ships in period t Z_{Psbt}= The total number of containers stored in block “sb” that are picked up by customers in period t Z_{Gsbt}= The total number of containers stored in block “sb” that arrive at the terminal in period t Φ = The weights of the two terms, that are adjusted according to the relative importance of the ship related containers within the total number of containers $f_{2=}Min \sum_i \sum_i \sum_{sb} d_{sbi} * Z_{sbit'}$ d_{sbi}=Distance between storage block “sb” and the berthing place of vessel “i” $Z_{sbit'}$=The number of containers discharged from vessel “i" in period “t” to be picked up by customers or loaded onto other vessels in period t+t’ that can be stored in block “sb” / The number of containers arrived at the terminal in period “t” to be loaded onto vessel “i" in period t +t’ that can be stored in block “sb”	blocks and the ship berthing locations (f_2)	
$d^U_{i'sb}$ d^L_{isb} Decisional $z_{ii'sbp}$ y_{isbp}	$f_{1=}Min \sum_i \sum_E \sum_{sb} (\sum_{i'} d^U_{i'sb} * z_{ii'sbp} + d^L_{i'sb} \sum_{i'} z_{ii'sbp})$	-The objective is to minimize the transportation cost related to the number of transported containers and the length of the containers flow, following two strategies:	(Zhen et al., 2016)

	$f_{2=}Min \sum_i \sum_e \sum_{sb} y_{isbp} * ((\sum_{i'} d^U_{i'sb} * z_{i'isbp}/sb_{ip}) + d^L_{i'sb} * \sum_{i'} z_{i'isbp}/sb_{ip})$ i 1,…….,I ship index i'1,..…..,I' ship index e1, ……,E group of time steps that belong to the p period of Vessel i $d^U_{i'sb}$ = Distance of the unloading route from the berth where Vessel "i'" moors to Subblock "sb" d^L_{isb}= Distance of the loading route from Subblock "sb" to the berth where ship "i" moors $z_{ii'sbp}$=number of containers unloaded from Vessel "i'" to subblock "sb" that are reserved for Vessel "i" during Period p y_{isbp}=set to 1 if Subblock "sb" is reserved for Vessel "i "during Period "p", and 0 otherwise	• Optimizing the tactical level yard template taking into account the operational level yard storage allocation decisions • Optimizing the yard template using a practical policy of equally allocating unloaded containers to the reserved subblocks	
C_o $C_{bb'}$ Decisional y^t_ω $z^t_{bb'}$	$f_{1=}Min(C_o \sum_t \sum_{\omega \in \Omega} y^t_\omega + \sum_{b \in B} \sum_{b' \in B} \sum_{i'} C_{bb'} * z^t_{bb'})$ t,1…..,T time periods ω,1…,Ω Yc deployment profiles b,b',1…..B set of Yard blocks	• This paper integrates the space allocation and yard crane deployment decisions together with the consideration of container traffic congestion in the storage yard. The integrated problem is formulated as an integer linear programming model with the objective of minimizing the yard crane operating cost and the yard	(Jin et al., 2016)

		crane interblock movement cost. • The objective function is to minimize the sum of YC operating cost and YC interblock movement cost over the planning horizon (f_1)	
Decisional $r(X_{st}, R_{st}, m)$	$f_1 = \sum_m \left[min \prod_{st} p(m) * \sum_m r(X_{st}, R_{st}, m) \right]$ $r(X_{st}, R_{st}, m)$: the marginal expected number of relocation movements added at stage "st" (an unfilled slot in a yard-bay) when an incoming container of weight group "m" p(m): the probability of arrival of a container of weight group "m".	• The authors present a methodology to solve the storage location of an arriving export container considering its weight. They present a dynamic programming model to determine the optimal storage slot in a yard-bay for an arriving container in order to minimize the expected number of relocation movements for an arbitrary configuration of the container stack • The objective function, minimizes the total expected number of relocation movements	(Kim et al., 2000)

Variables	**Yard crane scheduling: Objective functions**	**Strategy**	**Paper**
Decisional RE RL STL	$f_1 = Min\ \alpha 1 * \sum_M RE + \alpha 2 * \sum_M RL + \alpha 3 * \sum_M STL$ m=container moves, 1,………M α1= The weight assigned to total retrieval earliness α2= The weight assigned to total retrieval delay α3= The weight assigned to total storage delay	• The authors develop a model for YC scheduling by taking into account operational constraints such as inter-crane interference, fixed YC separation distances and simultaneous container storage/retrievals. They apply a rolling-horizon algorithm to sequence jobs (YC task) based on job target times. Jobs are scheduled at each iteration until all jobs	(Li et al., 2009)

		are fixed. This allows unscheduled new jobs to be inserted among the existing set of jobs. - The objective is to minimize the linear combination of the retrieval earliness and storage and retrieval delays	
ξ μ V YC_s Ub_k $t_{kk'}$ $d_{kk'}$ Decisional YC_{st} $X_{kk'}$	$Min\ f_1 = \sum_K \max\left(YC_{st} + YC_s - Ub_k\right)$ YC_{st}=The start service time of a customer k by a yard crane YC_s=The service time of customer k by a yard crane Ub_k=Upper bound of the time windows on customer k - Minimize the total energy consumption of all task groups $Min\ f_2 = \sum_M \sum_M \sum_M X_{kk'} * (t_{kk'} * \xi + d_{kk'} * \zeta) + \sum_K (YC_S * \xi + * \mu)$ ξ=Non working energy consumption of a YC [kW] μ=The working energy consumption [kW] ζ =The moving energy consumption of a YC per unit distance[Kwh/m]	- the YC scheduling problem is firstly converted into a vehicle routing problem with soft time windows (VRPSTW), formulated as mixed integer programming model with two objectives: - Minimize the total completion delay of all task groups (f_1) - Minimize the total energy consumption of all YCs(f_2)	(He et al., 2015a)

	V=The handling volume of customer k $X_{kk'}$= X=1, if arc (k,k') is traversed by YC; 0 otherwise		
Wt_{bt} Wd_{bt} Decisional X_{byt} W_{ybt}	$f_1 = Min \sum_K \sum_K (Wt_{bt} + Wd_{bt} - \sum_K W_{ybt})$ Wt_{bt}= Total workload of Block "b" within Period t Wd_{bt}= Delayed workload of Block "b" within Period t – 1 W_{ybt}=The workload allocated for YC "y" in block "b" within period t $f_2 = Min \sum_K \sum_K \sum_K X_{byt}$ Or= 0; if yard crane j is not deployed to Block i within Period t 1; if the sequencing of yard crane j at Block i within Period t is 1 2; if the sequencing of yard crane j at Block i within Period t is 2 Z= 0; if yard crane j is not deployed to Block i within Period t 1; if yard crane j is deployed to Block i within Period t X_{byt}= binary variable	• -A Decision-making strategy, which considered the loading and unloading workloads, using rolling-horizon approach to develop a yard crane scheduling model: At each planning period, they plan for a fixed horizon in immediate future and execute the plan accordingly up to the next planning period; then formulate a new plan based on the latest information; this pattern goes on continualy. The objective functions are: • To minimize the total delayed workload among all blocks at each planning horizon (f_1) • To minimize the total times that YCs move from one to another block at each planning horizon(f_2)	(He et al., 2010)

	B: The block where Yard Crane j is at before being deployed to Block i within Period t. X_{byt} = 0; if i = B and Z = 1; or Zijt = 0 1; if i ≠ B and Z = 1		
Decisional C_{tmax}	$f_{1=}Min\ C_{Tmax}$ C_{tmax}=maximum completion time of all the unloading tasks	• The authors develop a mixed integer programming model wich considers the handling procedures, noncrossing constraints, the safety margin and traveling time of yard cranes . A metaheuristic named backtracking search algoritm is utilized to solve this problem. • Minimize the maximum completion time of all the unloading operations of the container train(f_1)	(Zeng et al., 2017)
Decisional C_{tmax}	$f_{1=}Min\ f = maxC_{Tmax}$	• This paper presents a mixed integer programming model for the yard crane scheduling problem with non-interference constraint that. Optimization methods, like branch and bound algorithm, has no sufficient efficiency to solve this model and become perfectly useless when the problem size increases. Using an advanced search method like genetic algorithm may be suitable	(Javanshir and Seyedalizadeh Ganji, 2010)

		• Minimize the completion time of all slots in a container terminal	
r_n Cwy C'wy ϴ PC' PC WT_{TM} WT_T Decisional s_n	$Min\, f_1 = C'wy * \sum_N \theta_n(s_n - r_n) + Cwy * \sum_N (1 - \theta_n)(s_n - r_n) + PC' * \sum_N \theta_n * max\{s_n - r_n - WT_{TM}, 0\} + PC * \sum_N (1 - \theta_n) * max\{s_n - r_n - WT_T, 0\}$	• This paper develops a yard crane scheduling of a hybrid storage container terminal whose import and export containers are stored at the same blocks. They propose a mixed integer linear programming model, which jointly optimizes trucks' waiting costs and penalty costs caused by exceeding waiting time thresholds. • The objective function (f_1) is to minimize the total waiting cost, including the waiting and penalty costs of all requests.	(Yu and Yang, 2019)

B.3.Landside

Index:

t= time

i=ships

n=trucks

j=task group

b=yard block

k=truckers

s=time slot (on opening gate)

w= commodity

a=arc

Derived variables/Parameters:

Pys=Penalty cost for insufficient yard space

Cwy=Waiting cost of a truck at yard block

Cwg=Trucks waiting cost at the gate and fuel consumption of engine idling

Cl=Labour cost per gate lane

Cyf=Yard fee and storage time cost

Tta= Trucks expected arrival time

S= Trucks appointment periods

st=Storage time of one container

Tw_p=most preferable time window

Nd= average number of trucks departing from yard block

TR=Total number of trucks arrivals within window period t

x= Flow commodity on arc a

Decision Variables:

C= Total system cost

C_{oc}=Total operational cost of outbound containers

Cg=Total hourly gate system cost

c= Cost of arc for each commodity

Tw=Length of time window

Tw_{start}= Starting-point of time window

Tw_{end}=Ending-point of time window

TRs= Trucks appointment quota for every time period

Z=Total gate and yard waiting time

v= Binary variable

Lq_g= Average queue number trucks at gate

Lq_y=Average queue number trucks at yard

G=number of gate lanes

TRy=Number of trucks which are deployed to yard block

Variables	Objective function	Strategy	Paper
Cyf Cwg Pys Decisional: Tw Tw_{start} Tw_{end} C_{oc}	$f_1 = max\sum_i Tw_i = \sum_i \sum_t t(Tw_{end_{it}} - Tw_{start_{it}})$ $f_2 = minC_{oc} = \sum_i \sum_t (Cwg_{it} + Cyf_{it}) + \sum_t Pys_t$ i 1,…….,I ship index t 1,……,T time step	• The authors propose a solution of managing truck arrivals with time windows based on the truck-ship service relationship, specifically trucks delivering containers for the same ship share one common time window, these can be optimized with different strategies: • Greedy algorithm strategy (*f1*): Maximize the sum of the length of all time windows, based on the yard capacity • Fixed ending-point and variable ending-point strategy (*f2*): Minimize the total system cost of outbound containers	(Chen and Jiang, 2016)
Cwg Cyf st_{it} Lq_g TR_{it}	$f_1 = minC = Cwg * \sum_t Lq_g + Cyf * \sum_i \sum_t (TR_{it} * st_{it})$ i 1,……,I ship index t 1,……,T time step	• This paper proposes a method called vessel dependent time windows (VDTWs) to control truck arrivals, which involves partitioning truck entries into groups and assigning different time windows to the groups. • Minimize the total system cost (*f1*): trucks waiting time and the idling fuel consumption, storage time of the container cargos, and the yard fee	(Chen, 2013)

Cwg Lq_g Cl Decisional: G	$f_1 = minCg = (Cl.G + Cwg.Lq_g)$	- This paper applies a multiserver queuing model to analyse gate congestion and to quantify the truck waiting cost. - Minimize of the total hourly gate system cost (*f1*)	(Guan and Liu, 2009)
	$f_1 = minC_{TAS} = \sum_j \sum_b (C_j^+ . \sum_s TRy_{jbs} . (TRs - Tw_p) + C_j^- . \sum_s TRy_{jbs} . (TRs - Tw_p) + Cwy . \sum_s ((Lq_y)_{jbs} + \frac{r_{jbs} - TRyd_{jbs}}{2})$ j ϵ J (k) j= task group J= Set of task groups for trucking company TRy_{jbs}= number of trucks for task group *j* which are deployed to yard block *b* at time interval *s* $TRyd_{jbs}$= number of trucks for task group *j* departing from yard block *b* at time interval *s* C_j^+=Cost of late arrival compared with the preferable window of task j C_j^-=Cost of early arrival compared with the preferable window of task j	- Minimize the cost of delaying or advancing the appointment time, when the appointment times of trucks of task group *j* are adjusted to arrive at time *s* at yard block *b* which may be later and earlier than the most preferable time window *(f1)* - Strategy: When a trucking company receives a delivery order for an outbound container from a shipper, it submits a proposal for the delivery of the container at its most preferable time window. Then, the truck appointment system estimates the queue length at the corresponding time interval and yard block, which can be estimated based on their workload. Then, a new application of the appointment for the container is made, considering the waiting cost, the available number of trucks at various time windows, and the cost of changing the time window for the delivery, and submitted to the appointment system again by the trucking company. This process is repeated until all the trucking	(Phan and Kim, 2015)

		companies confirm the appointments.	
w_{az}	$f_1 = min\sum_{(a,z)}\sum_{w}c_{az} * w_{az}$ c_{az} =Costs of arc (a,z) for commodity w w_{az}=Flow of commodity on arc (a,z)	- The authors propose a mixed integer linear programming model to determine the number of appointments to offer with regard to the overall workload and the available handling capacity. The model is based on a network flow representation of the terminal and aims to minimize overall delays at the terminal. The objective function minimizes the cost of commodity arc flows (*f1*)	(Zehendner and Feillet, 2013)
Tw_p TRs Decisional: v	$f_1 = minTR\ delay = \sum_{n}\sum_{s}(v_{ns} * TRs - Tw_p)$ 1,……..N Trucks index 1,……..S Time slot	- Minimize the truck delay trough the difference among the time slot assigned and the truck expected arrival time (*f1*)	(Caballini et al., 2018)
S Decisional: Lq_g Lq_y	$f_1 = minZ = \frac{(\sum_t Lq_g + \sum_t Lq_y)_t}{S}$ 1,……T Time period	- Minimize the total gate waiting time and yard waiting time of trucks (*f1*). Genetic algorithm is designed to search the optimal solution. A method based on Point wise Stationary Fluid Flow Approximation (PSFFA) is designed to calculate the truck waiting time.	(Zhang et al., 2013)