Port Choice Model for Feeder ship, based on a Dynamic Accessibility Indicator (PCM-DAI)

POLITECNICO DI BARI

D.R.R.S.

09

PhD Programming in Environmental and Building Risk and Development

2018

Coordinator: Prof. Michele Mossa

XXXI CYCLE
Curriculum: Transportation

DICATECh
Department of Civil, Environmental, Building Engineering and Chemistry

Port Choice Model for Feeder ship, based on a Dynamic Accessibility Indicator (PCM-DAI)

Prof. Eng. Mauro Dell’Orco
DICATECh
Polytechnic University of Bari, Italy

Stefania Sinesi

POLITECNICO DI BARI

D.R.R.S.

09

Dottorato di Ricerca in Rischio e Sviluppo Ambientale, Territoriale ed edilizio

2018

Coordinatore: Prof. Michele Mossa

XXXI CICLO
Curriculum: Trasporti

DICATECh
Dipartimento di Ingegneria Civile, Ambientale, del Territorio, Edile e di Chimica

Modello di Scelta del Porto per navi Feeder, basato su un Indicatore Dinamico di Accessibilità (PCM-DAI)

Prof. Ing. Mauro Dell'Orco
DICATECh
Politecnico di Bari, Italia

Stefania Sinesi

EXTENDED ABSTRACT *(eng)*

Since the introduction of the container, in 1956, the maritime transport became the most widely used mode for freight, thanks to its low costs.
Both the maritime container trade issues and the ports competitiveness have attracted more and more interest from researchers.
In literature, the issue of the port choice was widely discussed; particular attention is placed both on the interaction of the decision-maker with the transport system, and on how the port's competitiveness could influence his choice.
On this regard, some authors have found that the port's accessibility may provide a possible parameter to evaluate the destination port in the decision-making process; in fact, according to them, during this process, the Accessibility of a port is one of the most important factors considered by the companies.
In maritime transport, different factors can influence the accessibility; some of them show a low variability, such as the number of berths and their depths, the number of cranes, storage area, etc., while others are characterized by high within-day dynamicity, such as the number of free berths, the delay time in freight loading and unloading operations, and weather conditions.
The maritime companies, before leaving, have to choose the route and the port of destination for calling, in accordance with the final destination of the cargo; they aim to maximize their utility, reducing the transportation costs and the delay times.
During a period prior to the present study, for several months, the maritime traffic in the Mediterranean Sea area was monitored and some anomalous feeder ships' behaviors were found. Often, during the journey, the ship modifies its route, to plan a

new one and select a port of destination, different from the one initially planned, where the subsequent handling operations will take place.
This path exchange is due to reasons not well known, probably relating to issues of political, commercial and logistics nature.
Following the knowledge proposed in literature, this research has the objective to formulate a Port Choice Model, based on a Dynamic Accessibility Indicator (PCM-DAI), designed to support the decisions of the shipping companies about the destination port, both in the planning phase of the journey preceding the departure, and also on course.
Merging the main maritime transport system characteristics and some port service-related parameters, the PCM-DAI model represents an attempt to foresee the accessibility of the port from the human perception point of view, regardless of the phenomena that may influence the choice but which are not easily identifiable. To describe the human judgments or preferences expressed by a linguistic variable, an important contribution is provided by the Fuzzy Theory.
The proposed model can be used on-line, even en-route. Starting from the inputs communicated by the shipping company about the GPS current position, the selected ports as possible destinations that would like to reach, and the estimated travel time to reach each one, the PCM-DAI model recognize in which geographical area the ship is sailing and extrapolates the necessary information from the different databases, distinguishing high dynamic parameters to low. The model is based on the Fuzzy-Logic methodology, carrying out the ranking of ports "closer" to the ship company requirements, on the basis of the dynamic accessibility indicator, as expression of a human perception.
In this study, a calculation system has been created that processes all input data and converts some of them in Fuzzy numbers, taking into account the uncertainty, or possible errors made by companies in data communication.
The PCM-DAI was tested in three different cases, varying both the geographical area of the survey and the period of application. The first test of the model was realized during the third week of March 2017 and only three ports overlooking the Mediterra-

nean Sea as possible destinations were considered. In the second test, the model was applied during the entire month of April 2017 in the same area. Instead, the third and final test was realized considering two different areas, having different characteristics and trades: the Mediterranean Sea area and the North Sea area. In this latter test, the set of choices includes seven and eight alternatives respectively, and the period of the application was May 2017.

During all the tests, the model has acquired the real data from GPS sources and ran every hour for each port considered, obtaining 504 outputs in the first test, 2.160 in the second, and 81.360 in the third.

In order to validate the results, during the three periods of application, also the real-time monitoring of the maritime traffic was perform. In particular, has been calculated the real choice percentages of each analyzed port, for each day; the results carried out from the PCM-DAI were compared with real data coming from GPS sources.

To evaluate the quality of the obtained results, for each test has been evaluated some performance indicators, such as Mean Error, Mean Absolute Deviation, Mean Absolute Percentage Error, Mean Squared Error, proving a good accuracy of the PCM-DAI results.

The PCM-DAI model could have a further skill. It could be used in container terminals, also, in order to predict the choices of ships sailing and better plan the handling activities before its arrival.

key words

Port Choice Model, Accessibility Model, Ports' Competitiveness, Container Transport, Maritime transport.

EXTENDED ABSTRACT *(ita)*

Dall'introduzione del container, nel 1956, il trasporto marittimo è divenuto la modalità più utilizzata per il trasporto merci, grazie ai suoi costi bassi.
Sia le problematiche relative al commercio marittimo dei container, che la competitività dei porti hanno attratto sempre più interesse da parte dei ricercatori.
In letteratura, il tema della scelta del porto è stato ampiamente discusso; particolare attenzione è rivolta sia all'interazione del decisore con il sistema di trasporto, sia a come la competitività del porto potrebbe influenzare la sua scelta.
A tal proposito, alcuni autori hanno riscontrato che l'accessibilità del porto, nel processo decisionale, può rappresentare un possibile parametro di valutazione del porto di destinazione; infatti, secondo loro, durante questo processo, l'accessibilità di un porto è uno dei fattori più importanti considerati dalle compagnie.
Nel trasporto marittimo, diversi fattori possono influenzare l'accessibilità; alcuni di essi mostrano una bassa variabilità, come il numero di banchine e il loro pescaggio, il numero di gru, l'area di stoccaggio, ecc., mentre altri sono caratterizzati da un'elevata dinamicità nell' arco della giornata, come il numero di banchine libere, il tempo di ritardo nelle operazioni di carico e scarico e le condizioni meteorologiche.
Le compagnie marittime, prima di partire devono scegliere la rotta ed il porto di destinazione, in funzione della destinazione finale del carico; Esse mirano ad ottimizzare la propria utilità, riducendo i tempi di trasporto ed i tempi di ritardo.
Durante un periodo antecedente al presente studio, per diversi mesi è stato monitorato il traffico marittimo nell'area del Mar Mediterraneo e sono stati riscontrati alcuni comportamenti anomali delle navi feeder. Spesso, durante il viaggio, la nave modifica la sua rotta, ne pianifica una nuova e seleziona un porto di destinazione diverso da

quello inizialmente pianificato, dove avverranno le successive operazioni di movimentazione.
Questo cambio di percorso è dovuto a cause non ben note, probabilmente legate a problematiche di natura politica, commerciale e logistica.
Seguendo le conoscenze proposte dalla letteratura, questa ricerca ha come obiettivo formulare un Modello di Scelta del Porto, basato su un Indicatore di Accessibilità Dinamico (PCM-DAI), progettato per supportare le decisioni delle compagnie marittime in merito al porto di destinazione, sia in fase di pianificazione del viaggio antecedente alla partenza, sia durante il viaggio.
Fondendo le principali caratteristiche del sistema di trasporto ed alcuni parametri relativi ai servizi, il modello PCM-DAI rappresenta un tentativo di prevedere l'accessibilità del porto dal punto di vista della percezione umana, senza tener conto dei fenomeni che possono influenzare la scelta, ma che non sono facilmente identificabili. Per descrivere i giudizi umani o le preferenze espresse da variabili linguistiche, un importante contributo è dato dalla Teoria Fuzzy.
Il modello proposto può essere utilizzato on-line, anche durante rotta. Partendo dagli input comunicati dalla compagnia marittima a proposito della posizione GPS corrente, dei porti selezionati come possibili destinazioni che vorrebbe raggiungere, e del tempo stimato di viaggio per raggiungere ciascuno di questi, il modello PCM-DAI riconosce in quale area geografica la nave sta viaggiando ed estrapola le informazioni necessarie da diversi database, distinguendo i parametri altamente dinamici da quelli meno. Il modello è basato sua metodologia Fuzzy-Logic, che restituisce la classifica dei porti più "vicini" alle richieste della compagnia marittima, sulla base dell'indicatore dinamico di accessibilità, come espressione di una percezione umana.
In questo studio è stato creato un sistema di calcolo che elabora tutti i dati di input e converte alcuni di questi in numeri Fuzzy, tenendo conto dell'incertezza o di possibili errori commessi dalle compagnie nella comunicazione dei dati.
Il PCM-DAI è stato testato in tre casi diversi, variando sia l'area geografica di indagine ed il periodo di applicazione. Il primo test del modello è stato realizzato durante la terza settimana di Marzo 2017 e come possibili destinazioni sono stati considerati solo

tre porti che si affacciano sul Mar Mediterraneo. Nel secondo test, il modello è stato applicato alla stessa area durante l'intero mese di Aprile 2017. Invece, il terzo ed ultimo test è stato realizzato considerando due aree diverse, che hanno caratteristiche e commerci diversi: il Mar Mediterraneo ed il Mare del Nord. In quest'ultimo test l'insieme di scelta comprende rispettivamente sette e otto alternative ed il periodo di applicazione è stato Maggio 2017.
Durante tutti i test, il modello ha acquisito i dati reali da fonti GPS ed ha funzionato ogni ora per ogni porto considerato, ottenendo 504 risultati nel primo test, 2.160 nel secondo, e 81.360 nel terzo.
Al fine di validare i risultati, durante i tre periodi di applicazione, è stato effettuato anche il monitoraggio in tempo reale del traffico marittimo. In particolare, è stata calcolata la percentuale di scelta reale per ogni porto analizzato, per ogni giorno; i risultati ottenuti dal PCM-DAI sono stati confrontati con i dati reali provenienti da fonti GPS.
Per valutare la qualità dei risultati ottenuti, per ogni test sono stati valutati alcuni indicatori di performance, come l'Errore Medio, la Deviazione Assoluta Media, l'Errore Medio Assoluto Percentuale, l'Errore Medio Quadratico, che provano una buona accuratezza dei risultati del PCM-DAI.
Il modello PCM-DAI potrebbe avere un'ulteriore applicabilità. Può essere usato anche nei terminal container al fine di prevedere le scelte delle navi in navigazione e pianificare al meglio le attività di movimentazione prima del suo arrivo.

key words

Modello di scelta del porto, Modello di accessibilità, Competitività tra porti, Trasporto di Container, Trasporto marittimo.

INDEX

TABLES INDEX

FIGURES INDEX

INTRODUCTION

In recent years, the international freight transport and port handling of maritime containers are among the most dynamic economic sectors. Nowadays, thanks to its low costs, the maritime transport is the most widely used mode for freight.
The container is defined as a multipurpose box, usable in different kind of freight transport and that allows the handling and transport of freight as a single piece, without having to move single ware individually. Furthermore, the use of the container reduces the risk of cargo damage and considerably reduces the number of handling operations. The advantages of freight containerization have had a considerable influence on the development of maritime transport and trade between Continents.
Since the introduction of the container, in 1956, both the international maritime trade of products and the number of handling operations in the ports have increased considerably; over the world, from 1970 to 2006, an increase in the number of port handling operations was noted of about one hundred times its value.
In order to intensify the activities of the existing infrastructures, and generate additional capacity for them, is very important to join all the significant transport system elements, using updated information and communication technologies.
In the last two decades, the requirement of applying the operational research techniques or simulation for the planning of handling operations in container terminals, has become increasingly pressing, especially in large terminals. The main objective is the operational planning, with the purpose of increasing the efficiency and productivity of the terminal, which is understood as the most crucial part of the logistics chain.

However, it is notable that the automation of the operations in the terminals implies, in turn, the need to monitor every activities and control techniques of the handling operations in real time, in order to cope with any complication quickly and also optimize the decisions in the near future.

Unfortunately it is not possible to extend the decision-making period to a longer time than the near future because the input data to the port, even if communicated always in advance, are affected by external disturbances, which causes are not foreseeable; for example, the exact instant of ship docking is never predictable much earlier, because of weather conditions or other particular problems that have occurred during the ship's trip.

The continuous monitoring and planning of port handling activities is not only useful for optimizing terminal operations, but it is also essential for shipping companies or carriers that manage the cargo from its origin to its destination. In fact, they can enhance their service using the Intelligent Transportation Systems (ITS) as supports to track the cargo in real-time, even in terminals' area.

Another aspect to consider is that the companies, before leaving, have to set the route and the port of destination for calling, in order to reduce the transportation costs.

The choice can differ and depend with respect to different aspects such as the port position, the destination of for the loaded freight, the connection between port and inland modes of transport, the presence of a shipping route, the characteristics or on-time performance of infrastructure.

However, sometimes, the shipping companies, during the trip, have to modify the route and select the new port of destination in which the subsequent handling operations will take place. The reasons connected to this exchange are not well known, but it happens above all to feeder ships. Several authors have studied in deep this issue and some of them have found strictly relations between the shift of the destination port and the characteristics of the port itself. In this case, the ship has to communicate its no arrival at the planned destination port, and it has to call the new one.

Companies make the new choice in relation both to the ship location and to other factors. During this decision process, the *Accessibility* of a port is one of the most im-

portant factors considered by the companies. The *Accessibility Indicator* is generally deemed as the parameter that better represents the degree of interactions between a port and its hinterland.
In maritime transport, different factors can influence the accessibility; some of them show a low variability, while others are characterized by high within-day dynamicity. The first group regards the technical characteristics of ports, such as, for example, the number of berths and their depths, the number of cranes, the storage area, etc.; instead, the second one includes characteristics varying hour-by-hour during the day, like the number of free berths, the delay time in freight loading and unloading operations, and the weather conditions.
The main goal of this research was to set up a *Port Choice Model* (PCM) of the destination port for Feeder ships, based on a port's *Dynamic Accessibility Indicator* (DAI). The studied model merges the main maritime transport system characteristics and some port service-related parameters. Through the real-time extraction of the information about the ships' location, and the schedule of ports' calls, the PCM-DAI is able to calculate the probability that a Feeder ship may choose a port than other as the final destination, after modifying its route. The PCM-DAI uses both GPS, Radar signals, and the specialized website, MarineTraffic.
Furthermore, another interesting aspect of the proposed PCM-DAI is the possibility to be used online by the maritime companies, as a useful tool in the route planning process. In particular, they can indicate their origin port, current GPS position, *n* selected ports as potential destinations that would like to reach, and the relative travel time between the current position and each destination.
In this case, the PCM-DAI's output is the port "closer" to the requests expressed by the companies, or drawn from the mentioned website, in term of Dynamic accessibility indicator (DAI). Then, the result could be understood as a suggestion for the feeder ships about the destination port which present the highest DAI's value, or as forecasting of port's call. Consequently, the maritime company can plan the trip, choose and call the new preferred port of destination. At the same time, after the ship's call, the port can organize the handling operation.

The PCM-DAI was tested in three different cases, varying both the origin and destination ports and the period of application. In order to validate the results of the model, in that periods the real-time monitoring of the ports considered in the test was also carried out. In particular, in each monitoring period, has been calculated the choice percentages of each selected port for each day and compared the results carried out from the PCM-DAI with real data coming from GPS sources.

The first test of the model was realized during the third week of March 2017, considering only three ports overlooking the Mediterranean Sea as possible destinations and one port as origin located in the same area. In this case, since the first days of monitoring, it immediately emerged that the route change phenomenon has a daily frequency.

The second test was also in the same area, considering the same ports, but was applied during the entire month of April 2017; it confirmed the daily frequency of phenomenon above.

Instead, the third and final test was realized considering two different area, having different characteristics and trade of freight: the Mediterranean Sea area and the North Sea area . In this latter test, the period of monitoring was May 2017, and after some consideration, which will be explained in the next chapters, the number of ports surveyed was fifteen: seven in the first area, and eight in the second one. Also in the last case of application and monitoring the day-to-day change of route and consequent port calling is noticeable for both areas.

In order to evaluate the quality of the obtained results, for each test have been considered some performance indicators, such as *Mean Error*, *Mean Absolute Deviation*, *Mean Absolute Percentage Error*, *Mean Squared Error*. Analyzing these indicators, it is possible to observe a good accuracy of the PCM-DAI results.

In particular, the lower *Mean Absolute Percentage Error* (MAPE) value, measuring the prediction accuracy of the forecasting model proposed, was obtained in the third case of study; it assumed value around the 9-10%.

In the first chapter of this Ph.D. thesis, the current scenario of maritime freight transport in Europe is framed.

To understand how the single maritime port can insert in the transport network of container, in the second chapter, the operations related to the planning of the activities in port are explained in a general way; the detailed planning of all activities is very important and has as main objective the optimization of the times of movement of the container volumes in import/export and the improvement of the port performances service-related. The third chapter focuses on the literature review that traces the steps of knowledge on models of choice and accessibility, both from a purely theoretical point of view and applied to the port context and the freight transport. Instead, in the fourth chapter, the PCM-DAI model is explained in detail and in the fifth, its three numerical applications are shown; the results obtained are analyzed in chapter 6.

CHAPTER I
THE MARITIME TRANSPORT

The maritime freight transport is defined as the activity of moving goods from an origin to a destination, using navigable infrastructures in both sweet and salty waters: ocean, lakes or rivers. This kind of transport is very flexible and versatile because it allows the use of ships with different characteristics and sizes, suitable for the ware type they must lead to their destination. Anyhow, regardless of the vessel kind used or of the navigation path, the maritime transport must comply with customs, legal, commercial and insurance rules. The sea establishes the access to the world's largest transport way; in fact, it is through the sea that most of the raw materials and consumer goods are moved among different Countries and Continents.
Nowadays, the maritime freight transport is one of the strengths of world trade and it is the most widely used shipping method for long distances, especially thanks to its competitive cost and its high load vessels' capacity. Currently, there are more than 50,000 merchant ships worldwide, most of which carry containers and are capable to handle thousands of tons of ware each.
The maritime transport in international trade, the global production and distribution logistics systems have undergone a strong development since the introduction of containers, when Malcolm McLean, owner of a large US transport company, organized the transfer of 58 aluminum boxes, which sized 35 foot, from the port of Newark (New Jersey) to Houston's port (Texas), using "Ideal X", an old oil tanker employed during the second world war and adapted for the event. Since the sixties, the importance of international maritime container shipping, connected with the world econ-

omy globalization, has been increasing year by year. In every world's region, the relationship between containers' movements and the development of liner shipping companies has been strengthened more and more. During the years, companies had expanded and strengthened their shipping network on a worldwide scale, not only by deploying larger containerships but also by merging with each other or forming alliances.

While the considerable competitiveness among shipping companies had a fundamental role in the growth of the trade by sea, on the other hand, the increase in the productivity of the terminals and their connection with the hinterland, has confirmed the competitiveness between multiple seaports as focal points in international container shipping. Furthermore, the new technologies and the traffic modernization have created a profound transformation in the international sale of freight way by sea, obtaining considerable advantages. Technological processes and the organizational innovation have been characterized by the use of specialized equipment for carrying out terminal operations, in order to speed up loading and unloading operations thereby reducing the general cost of vessels staying in ports.

In addition, the new technologies have made it possible to limit emissions to the environment, so much so that today the sea is the most polluting form of freight transport. In fact, nowadays, the polluting emissions coming from the maritime transport are significantly low, if compared with other transport systems.

Among the most important advantages of maritime transport, we recall the very low transport cost compared to other transport modes. For example, for long journeys, it is not convenient to shift a load which weighs more than 500 kg by plane. Moreover, the freight transport by plane is subject to many more rules and restrictions than maritime, especially about dangerous freight. While compared with road transport, it is possible to underline that the maritime transport saves about half of the road costs thanks to lower fuel costs and lower vehicle wear; furthermore, embarking the vehicles, they avoid traffic and long road queues, thus reducing transit times and pollution.

The main characteristic of maritime transport is the large load capacity; in fact, with a ship is possible to shift large masses of ware or, in any case, a large number of containers; for example, just think to the large ULCC tanker, having a total capacity of 500,000 GRT (Gross Registered Tons).
Moreover, since the loads are stored in closed containers, the probability of freight thefts and/or damages also decreases, with consequent reductions in insurance costs.
In conclusion, the advantages of sea transport, with the use of new technologies, are represented by the low environmental impact, the economic savings, and the resources optimization.
However, there are some disadvantages. Among these, there are both the lack of reliability of the load on some routes deemed dangerous because of piracy and the low speed. In fact, the moves by sea spend much longer times compared to plane or train, even though in recent years many improvements were obtained, thanks to faster ships and the customs procedures computerization.

1.1 THE CONTAINER SHIPS

The ships used in maritime transport have different characteristics depending on the kind of freight they load: solid bulk, liquid bulk, oils or containerized freight. In particular, container ships are ships whose entire cargo consists of containers, which represents the most common cargo unit to move large quantities of ware. These are aluminum boxes with standard shape and size, inside which a large assortment of freight can be stored, till about 28000 kg. It is estimated that 90% of maritime transport is carried out by the containers, which can be easily handled by land vehicles.
The first container ships were made by modifying oil tankers, which in turn were derived from Liberty Surplus Ships, which worked in the Second World War. However, today, the oil tankers belong to an own class and they fit among the largest ships in the world.

Depending on the size and length of the route, container ships can be divided into two classes: Motherships and Feeder ships. The first ones are transoceanic ships, connecting Continents and docking in large ports, highly specialized for container handling operations.
Instead, feeder ships have smaller dimensions and can move over short distances between ports having lower capacity. The fundamental size limitation for the vessels is dictated by the *Panama Canal*. Until 2014, ships with the following characteristics could across it: the maximum draft (the height of the part of a float that remains submerged in water) of 12 m, the maximum length of 249.1 m, the maximum width of 32.3 m, and the maximum capacity of 65,000 tons. In fact, the Motherships are divided into two macro categories: *Panamax*, compatible with the across of the Panama Canal; and *Postpanamax*, to whom this passage is not allowed.
Since 2014, after the expansion works of the Panama Canal, it was allowed the transit to ships 399 m long, 49 m wide and with a maximum draft of 17 m. At present, there are seven types of containerships in service worldwide, including *Small-Feeder*, *Feeder*, *Feedermax*, *Panamax*, *Post-Panamax*, *New Panamax* and *Ultra-large Panamax.*
In addition to the Panama Canal, other sea stretches represent obstacles to navigation. Among all, the *Suez Canal* and the *Strait of Malacca* are particularly important. The Suez Canal allows the passage of ships with the maximum draft of 16.1 m, the maximum width of 60 m, and the maximum capacity of 150,000 tons, like the Suezmax ship. Instead, in the Malacca Strait, vessels with the length of less than 470 m, the width of less than 60 m, and the draft of fewer than 21 m can transit, like the Malaccamax ship, whose gross capacity is around 300,000 tons.
Between 2000 and 2006, *Super-Postpanamax* and *Mega-Postpanamax* vessels were introduced, whose the lengths range between 364-397 m, the width of 50-56 m, the draft 15-16 m and the capacity equal to 8˙000 - 14˙000 containers. While, between 2014 and 2015 the *Super ULCV* (*Ultra Large Container Ship*) ships entered service, capable of shifting around 18,000 containers at the same time. The ULCV ships can transit in the Suez Canal, thanks to the draft of 14.5 m.

Actually, the *OOCL Hong Kong* is the newest ULCV container ship in the fleet of the Chinese shipping firm Orient Overseas Container Line, popularly known as OOCL. With a length of about 400 meters, it is the first ship to cross the capacity of 21,000 containers.
The new ULCV vessels are also called "Triple-E ", so named for the three main characteristics: Economy of scale, Energy efficiency, and Eco-compatibility; in fact, this new generation of container ship has further improved both the value of fuel consumption, and CO_2 emissions for each container loaded.
Currently, the ports equipped for this purpose are very few: Rotterdam, Felixstowe, and Bremerhaven in the North Sea, Port Said in the Mediterranean Sea, and five other ports in Asia, such as Shanghai, Ningbo, Xiamen, Yantian, and Hong Kong.

1.2 THE MARITIME NODES

The Port is a transport node considerably complex both from a functional and managerial point of view. A port is defined as a set of infrastructures and services designed to receive vessels within a pool of water. Furthermore, under conditions of maximum safety and rapidity, the port also must allow the necessary operations for freight loading and unloading, for passengers boarding and disembarking, for stationing ships, and for ship construction.
A port cannot be conceived as isolated from the context in which it is located, but it must be included in a wider transport system, including both interactions with other port systems, and connections with ground transport systems. In fact, from the transport point of view, a port is the most complete node of the transport network, since different transport modes can converge in it, such as maritime, fluvial, railway, road and airplane.
The Ports can be split both according to their location and according to the functions performed within them. From the location point of view, the ports can be identifying into two groups: *Internal ports* and *External ports*; the first ones arise along rivers, or

within lakes, or lagoons; instead, the latter are located along the coast with direct access to the sea. However, the External ports, in turn, can be differentiated into *Artificial ports*, if built entirely by man and equipped with works protecting them from exposure to the high seas; and *Natural ports*, built taking advantages from a morphology of the coast, such as bays offering a natural protection for the dockings.
As mentioned above, the ports can also split regarding the specific activities carrying out within them; for example, there are *Military ports*, *Industrial ports*, *Passengers ports* (usually dedicated to the docking of passenger ships solely), *Fishing ports*, *Commercial ports,* and *Intermodal ports* (finalized and equipped for intermodal transport).
In general, a port is composed of External and Internal works. The External structures have the aim of shape the internal pool of water and they have the port's protection function. The port, in turn, is endowed with a large entrance area. Instead, the internal structures are destined to ships' docking, such as for example, piers, docks, and berths; in addition, in each terminal, there are some other services intended for the sector operators, like banks, restaurants, hotels, and others again.
The activities performed in a port are closely joined to its function in the transport network and trade in which it is inlaid.
The different shipping systems and the different kinds of freight require specific handling schemes. The management of freight and passengers takes place in the maritime *Terminals*, constituting the port structures interfacing between the maritime and ground transport modes.
The terminals are divided into the following categories:

- *Cruise terminal*
- *Bulk freight Terminal*
- *Packaged freight Terminal*
- *Tourist Terminal*
- *Container terminal*.

In this thesis, only *Commercial ports* and *Container terminals* are discussed, since this research aims to evaluate the accessibility for those ports equipped with handling features for containerized ware.
Over the years, the terminals sizes have supported both the increase in freight flows and the ships capacity growth. However, both the good infrastructural endowment of a port area and of the intermodal logistic centers joined with it, would not be enough to satisfy the demand for freight transport if they are not accompanied by a strategic and operational planning of all the activities carrying out within both. In addition, in order to improve the commercial port's performance, the concept of Accessibility to port facilities, both for ships and for land vehicles, is fundamental.
In this thesis, the attention is directed to understand how the accessibility of a port is perceived of incoming vessels and how this can influence the choice of the destination port, made by maritime companies.

1.2.1 THE HUB & SPOKE SYSTEM

In general, the maritime transport system is characterized by the length of the path traveled by ships, called *Routes*. It is possible to make a distinction between *Long routes* when navigation follows an oceanic route; *Medium routes*, as the Mediterranean Sea routes; and *Short routes* connecting closer ports belonging to the same Country or to adjoining Countries.
The commissioning of big container ships connecting all Continents with *Round-the-world routes* has led to the introduction of the *Transhipment* activities in ports, which is the set of procedures related to the transfer of containers from large container ships, called *Motherships*, to the smaller vessels, called *Feeder-ships*, with the aim of bringing the cargo to closer and smaller ports, not accessible by Motherships.
This system is named *Hub & Spoke*. In this system, the *Hub* port is a larger port, equipped with technologies and infrastructures to receive Motherships and to discretize the cargo, in order to transfer it on the Feeder-ships intended to a smaller port, called *Spoke*. Anyhow, in the considered ports the network's core, the transshipment

can take place from Mothership to another Mothership, with the aim of enlarging the number of intercontinental connections.

Therefore, the Hub & Spoke system can be defined as a model of the international trade, giving to the ports a central role in feeding the same trade. Over the industrialized world, this pyramid scheme is now present, and it is increasingly serving the Asian and North American import-export trade to and from Europe. This is the key to understand the enormous development of the ports of the Southern area, as Gioia Tauro, Algeciras, Malta, etc., which subtract more and more containerized traffic to the Hub ports located in the Northern area, like Rotterdam, Hamburg, and Antwerp.

It is obvious believing that maritime companies may prefer port-to-port direct services for handling operations, because of the increase of the overall shipping time, of the container movements' number in the port, and of the consequent unit costs.

Nowadays, to the classic direct path from port to port, more and more different routes intersect each other, creating some strategic points. The *Short Sea Shipping* (SSS) is increasingly developing; this means the short sea routes between national ports, or between European ports, or between these latter and other non-European ports, but overlooking on the same European coastline.

In recent years there has been a significant change in the SSS system that allowed the full entry of this modality in the intermodal transport chain, as an innovative and competitive element for the entire freight transport system in Europe.

It is therefore beyond doubt that the SSS system and the transshipment activities have made a big contribution to the insertion of medium-small ports in the network of international traffic of goods.

However, while the huge investments in the port terminals and the fact that many terminals are controlled by shipping companies lead to the obvious conclusion that the transshipment is destined to increase; on the other hand, it is also indispensable to consider the factors deriving from the increase in port congestion phenomena; in this case the transshipment could become less and less reliable and the "exchange" ports are not always provided with suitable equipment.

1.2.2 THE COMBINED TRANSPORT SYSTEM

In the last decades, the *Intermodal transport* has acquired an increasingly important role in the field of freight transport. This kind of transport is not a new transport technique, but it is a new approach to the transport system, thanks to which it was possible to pass from the use of a single transport mode to an integrated use of more transport modes, allowing optimal use of them and a significant abatement of their functions' overlapping. In fact, as its name implies, the intermodal transport is carried out with the aid of a combination of different transport modes; usually, the main path is traveled by rail, or by waterway or by sea, while in the initial and/or final section it is traveled by road. It is clear that the intermodal transport is a "method" of transport useful when the ware has to travel long distances.

A fundamental characteristic of this "method" is that the cargo is stored in a container in the place of origin or of production, from where it is not removed until the final destination is reached; the unit load, in this case, the container, is shifted using at least two different transport modes, without breaking the load inside, but the container is only moved from a mean of transport to another one. The lack of intermediate handling operations guarantees not only lower risks of damage of cargo but also a lower cost for transhipment operations.

Since the years of the development of railway techniques, in the nineteenth century, it was planned to realize a combination between rail and road transport. The first attempts date back to the second half of the nineteenth century when entire postal vehicles were loaded and transported on railway carriages for long journeys, thus avoiding the problems associated with the poor condition of many roads. In the same period some detachable containers were used, both for road and rail transport.

The development of the intermodal transport began in the 20th century when the need to cross the US territory on the North-South route became more insistent; in order to bypass administrative and fiscal obstacles present in that time, it was thought to make the journey by sea, loading the road vehicles on ferries. However, the long times and the excessive costs of loading and unloading from the ferry, its limited hold capacity, made shelve the simple ferry solution shortly after.

In 1959, in France, special carriages for semitrailers were introduced, named *Kangourou wagons*, with fixed pockets. Instead, in Germany, they started using *Wippen wagons*, similar to the French version but with a tilting pocket. The introduction of this two wagons allowed a new development of the intermodal road/rail transport. In the course of the sixties, the American railroads realized a four-axle flatbed wagon, 89 feet long (about 27 m) suitable for the transport "*Piggy-back*", ie combined transport road/rail, still used today.

In general, when intermodal transport requires transportation to take place mainly by rail, or by waterways or by sea routes, while the initial and/or final section is carried out by road, we can speak of *Combined Transport*.

The objective of *Combined transport* is a division of tasks between rail and sea transport (for the main section) and road transport (for the previous and subsequent routes to the destination terminal), which minimizes the transport costs and travel times, increases the punctual deliveries, and improve the environmental impact.

The transhipment operations of containers from a transport mode to another one take place in the *Intersports*.

The *Interport* represents the attempt to group into a single entity some of the many realities of the field of freight transport. It constitutes a nodal point of confluence of freight traffic flows which are interesting to a plurality of vectors and performs multiple functions, like providing equipment also for accessory services. In fact, within the interport, the intermodal terminal is allocated, which is an integral part of it and represents a sort of "junction" between the different modes of transport.

Nowadays, the interports and the intermodal and/or combined transport nodes are becoming increasingly important. In the last years, it has come to be understood that the different transport modes are not in competition with each other, but can be complementary.

The innovation lies in exploiting the merits of every mode giving life to an intelligent transport chain.

The understanding of this novelty has given rise to a combined transport system that sees as actors the freight forwarders, who remain the only representatives of the freight transport to their customers, and the companies that deal with the purchase and rental of cargo units.

Over the years and thanks to the technological evolution, the companies have also arisen that monitor cargo along the journey, from origin to destination, with the aim to support shippers and forwarders.

However, one of the main discriminating factors for choosing whether or not to use the combined transport with respect to classic road transport, remain the costs and times for the cargo shift.

This occurs especially when the intermodal terminal and place of goods' production are not so far away and is not convenient to use rail or sea transport. Therefore, the carrier is forced to use road transport, with an increase in costs and time. For this reason, it is fundamental that the position of the intermodal terminal is barycentric with respect to the places of production of the territory in which it is located so that the origin-terminal and terminal-destination routes are not too long.

In fact, along these routes, it would make no sense to imagine the use of rail or sea transport, since the number of load units would be low (four or five).

In this phase, convenience falls on road transport, which is more flexible, capillary and economical compared to other transport modes.

In general, as mentioned above, the conditions for configuring the combined transport depend on the length of the path to travel. In road/rail or road/sea combination, the road transport has to be run in the initial and terminal section; while, the longest route has to be cross by rail or sea, or by inland waterway. Usually, the railway line is at least 100 km as the crow flies, while the road section is at least 150 km, always as the crow flies. The same limits are observed in the road/sea combination. The compliance with these indications allows the optimization of the times and costs for the load units' transport.

1.2.3 THE COMBINED TRANSPORT SYSTEM IN EUROPE

The introduction of the Intermodal transport in Europe originates in the seventies when the Community Directive 75/130/EEC of 17.02.1975 defines it as "Road transport of goods between Member States for which the towing vehicle, the truck, the trailer, the semi-trailer or their removable superstructures are transported by rail from the appropriate loading station of the vehicle nearest the point of loading of the goods, to the appropriate station for unloading the vehicle nearest the point of unloading of the goods".

This directive was subsequently replaced by Directive 92/106/EEC, in 1992, according to which the concept of combined transport is expanded and understood as: "Transport of goods between Member States, where the truck, the trailer, the semi-trailer with or without tractor, the mobile or container (with size of 20 feet and above) run the initial or final section of the journey by road and the other part by rail, by waterway or by sea, when this path exceeds 100 km as the crow flies and carry out the initial or terminal journey on the road".

In 1984, the "General conditions for international intermodal transport" were created thanks to the UIRR (International Union of combined Road-Rail transport companies), in force since July 1, 1984.

In 1992, thanks to an action by the European Union Commission in favor to the transport liberalization, the rule that container companies could transport only containers and combined transport companies only swap bodies and semi-trailers, was eliminated. Therefore each company became free to use all the combined transport techniques (Directive No. 106/92 of 07.12.1992).

At the beginning of the nineties, the challenge that the European community had set itself consisted of the development of a European combined road-rail transport network. With this aim, the cooperation between sector operators and institutions was fundamental, as was the impetus given by the liberalization of rail transport, which strongly influenced combined transport.

Today, when it comes to intermodal transport and/or combined transport, it refers to combined road/rail transport (called Piggy-back or Ferroutage), since it is the most widely intermodal transport combination used in Europe for the wares, even if it represents a subsystem of intermodality.
As regards the technical aspects of combined road/rail transport, in Europe the two transport techniques offered are:

- *The Rolling motorway (accompanied combined transport);*
- *Unaccompanied combined transport.*

Through the *Rolling motorway*, the road vehicles are transported by rail.
The loading and unloading (about 20 minutes per unit) always take place horizontally through a fixed or mobile front ramp and are performed by the driver himself, who escorts the cargo and travels in special accompanying carriages. No special equipment is needed in the terminal, but only a rail track inserted into the road pavement allowing the operation of loading and unloading of vehicles by means of a ramp. Therefore, in this case, also the transhipment's costs per unit in the terminal are very low. The use of this technique is particularly indicated when there is the need to overcome road nodes with particular complexity (called Crossing points) or nodes characterized by congestion problems such as some connections with Eastern Europe, or when there are some nodes where the road transport is often taxed due to the legislation.
Instead, in the unaccompanied combined transport, the road vehicles or the containers can be transported without the driver accompanying. The cargo units are handled using the gantry cranes or the pneumatic cranes in a terminal. With this technique, only the cargo units are moved. The driver and the tractor remain at the place of loading. At the destination, the loading units are taken over by another driver for traction, who bring them to the final destination with another tractor. In this transport technique, two drivers arrange the road transport before and after the terminals.

Unaccompanied combined transport is the variant of combined transport, which introduces greater potential in terms of rationalizing freight transport, making it an alternative to traditional forms of transport.
The current European combined transport system is the result of a ten-year standardization process. Currently, the European system has:

- 350,000 loading units (coded);
- 20 million containers worldwide;
- 60,000 wagon flat cars and pocket wagons with different technical characteristics;
- 700 transhipment terminals;
- 2,000 cargo locomotives;
- railway infrastructures throughout Europe that take into account the combined traffic requirements.

In Europe, the combined transport is an emerging trade, with a volume of over 190 million tones of wares; for over long distances from 500 km and in Alpine transit way from 300 km, the combined transport mode results very competitively compared to the road transport. The existing restrictions on road freight transport, the favorable conditions of transport policy and a positive environmental balance are the determining factors for the further market development.
The *Trans-European transport networks*, in the acronym *TEN-T*, are a set of integrated transport infrastructures designed to support the trade, to guarantee the free movement of goods and people and strengthen the growth, the employment and the competitiveness in the European Union. Then, the TEN-T policy has oriented European funds towards the realization of an infrastructural network that is fundamental for European trade, which lays its legal basis on the Treaty of Amsterdam initialed on 2 October 1997.

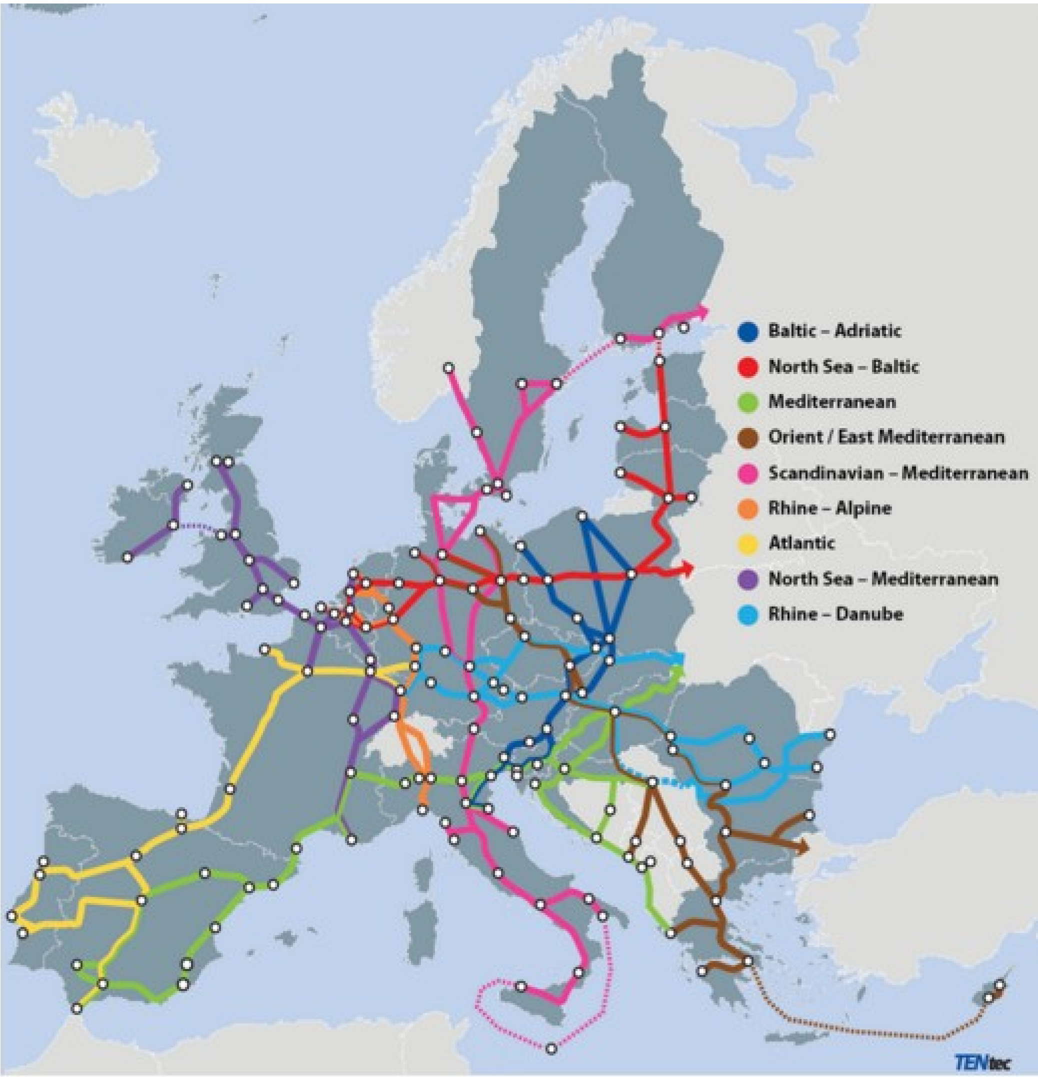
Recently, the European Commission has published an illustrative document regarding the state of progress of the nine Corridors of the TEN-T network and their future development. The network will include 94 major ports and 38 large airports, all connected to the railway network and more than 15,000 km of high-speed railway lines. The studies highlight the need to optimize the use of existing infrastructures thanks to the Intelligent Transport Systems (ITS), the effective management and promotion of the use of multimedia transport, innovative and non-polluting and the necessity to develop new infrastructures to complement the existing network.
Moreover, there are problems common to all the nine Corridors, the most important of which are the implementation of the ERTMS railway safety system, that actually seems lacking or even absent in more than half of the railway sections. An additional aim is reaching a certain harmonization of the standards, regarding, for example, the maximum authorized length of freight trains or barges, the implementation of the River Information Service (RIS) system or the road infrastructure in favor of refueling in alternative fuels.
The following table summarizes the characteristics of the nine TEN-T corridors; while the Figure 1.1 shows the nine corridors on the Map the Europe.

1	Corridor Scandinavian - Mediterranean	It is the largest of the nine corridors. It extends between the Baltic Sea from Finland and Sweden, passing through Germany, Italy then Sicily to Malta. It includes more than 9,300 km of railway lines and 6,300 km of roads, 19 airports, 25 ports, and 44 road/rail terminals.
2	Corridor North Sea - Baltic	This includes the connection of Finland with Estonia by ferry, modern road and rail links between the three Baltic States, with Poland, Germany, the Netherlands, and Belgium. The corridor also includes river connections between the river Oder and the ports of Germany, the

		Netherlands, and Belgium, such as the "Mittelland-Kanal". About 3,200 km long, the Corridor includes 17 large cities, 16 large airports, 13 seaports and 18 internal and 17 road-rail terminals. It connects eight Member States, touching each of their Capitals.
3	Corridor North Sea - Mediterranean	The Corridor covers six Member States, crossing the Netherlands, Belgium and Luxembourg, including inland waterways in the Benelux and France, creating a North-South axis from Amsterdam to Marseille, with a detour to London and Dublin.
4	Corridor Baltic - Adriatic	It hits the industrialized areas ranging from southern Poland to Vienna and Bratislava, to the Eastern Alps and northern Italy. About 1,800 km long, it connects Gdansk to Ravenna along the North-South axis, touching six Member States. It includes 13 large airports, 10 ports, and 30 road-rail terminals. It has the particularity of not including inland waterways.
5	Corridor Orient/East Mediterranean	It connects the ports of the North Sea, Baltic Sea, Black Sea, and the Mediterranean; in particular, it connects Northern Germany, the Czech Republic, the Pannonian region and the southeast of Europe. It involves a total of around 13,000 km of communication routes among roads, railways, and inland waterways.
6	Corridor Mediterranean	It crosses South Europe from East to West through six Member States, linking the Iberian Peninsula with the Hungarian-Ukrainian border, passing south of the Alps. Excluding the Po, it is an essential road and rail Corridor which includes 13 major cities, 17 airports and 12 ports

		and about thirty multimodal terminals. It includes three major ports, 13 large airports, and around 60 multimodal terminals.
7	Corridor Rhine - Alpine	This corridor makes a connection between the North Sea ports of Rotterdam and Antwerp with the Mediterranean Sea port of Genoa, through six countries, including Switzerland, a non-EU state. The inclusion of the Rhine as a waterway makes it a multimodal corridor. Its strategic position means that the largest number of goods in Europe will move along its axis.
8	Corridor Atlantic	It passes the ports of Le Havre and Rouen in Paris, also including the Seine as an inland waterway. It is spread across three states (Portugal, Spain, and France), linking the western part of the Iberian Peninsula with the North and East of France. Consisting of high-speed rail lines and parallel conventional railway lines, the maritime part plays a crucial role in this corridor.
9	Corridor Rhine - Danube	It crosses southern Germany to Vienna, Bratislava and Budapest to finally reach the Black Sea. Important is the section between Munich and Prague, Zilina, Kosice and the Ukrainian border.

Table 1.1 – The characteristics of the nine TEN-T corridors.



Note: the nine TEN-T core network corridors are based on the CEF and TEN-T Regulations (1316/2013 & 1315/2013); they have been created as a coordination instrument to facilitate the completion of major parts of the core network of strategic importance.
Source: European Commission, Directorate-General for Mobility and Transport, TENtec Information System

Figure 1.1 – The nine TEN-T corridors.

CHAPTER 2
STRATEGIC AND OPERATIONAL PLANNING OF THE CONTAINER PORT

Generally, both in the case of the *Hub* or *Spoke* port and taking into account that the same port can have both functions, the port's physical characteristics and the equipment have to be able to accommodate the big container ships and to handle the high amounts of containers shifted by them.

Depending on the ships' size that the port is usually able to receive, its access channels and docks must have a depth of about one and a half meters more than the draft of the ship; this measure is referred to the case of first stop ports, with a fully loaded vessel, and in low tide conditions.

A port that is never the first port of loading, or is the last port of unloading, does not necessarily need to provide the same depth requirements; only a few ports in Europe have the depth measure suitable to be Hub and Spoke port simultaneously.

In the following tables are shown the depths, in meters, of the main European ports object of the present study.

North Europe	
Antwerp	15.5 m
Hamburg	16.7 m
Rotterdam	16.6 m
Felixstowe	15.0 m
Le Havre	14.5 m

Mediterranean Sea	
Algeciras	16.0 m
Barcelona	16.0 m
Malta	15.5 m
Valencia	16.0 m
Genoa	15.0 m

Table 2.1 – The depths, in meters, of the main European ports object of the study.
Sources: Port Authorities website.

The activities dedicated to the reception of a container ship begin when it arrives in the port. A commercial port, in fact, must be equipped with a large space near the port's entrance where big ships can realize their maneuvers or can wait for the arrival of tugs, that help them in the maneuvers of entry into the port and of approach to the docks of a container terminal. Then, the subsequent operations can take place in the terminal, and concern:

- The freight loading and unloading from the ship to the embankment;
- The storage in the dedicated area;
- The handling and the split up of the cargo;
- The loading of freight on other transport modes connected to the terminal, in order to deliver them to the final destination.

Therefore, the structures placed inside the terminal require both connections with other transport modes and spaces for the movement of freight and ground vehicles.
Regarding the sizing of the terminals, it is possible to consider different kinds of *Capacity* with respect to the typology of the operations that the cargos undergo:

- Ship-Berth and vice versa;
- Leaving from the port with other transport modes;
- Storage area capacity.

Furthermore, about the capacity of the ship-berth area, also called the *Yard*, three different capacity measures are used:

- *Maximum instantaneous capacity*, useful for the sizing of handling equipment;
- *Maximum annual capacity*, which defines the maximum capacity of a terminal considering a 100% employment. It is calculated over a long enough period identifying the average hour capacity, the number of working hours per day and the number of working days per year;
- *Optimal annual capacity* indicated during the planning phase of the port activities and normally calculated according to the economic efficiency for the transfer of one ton of cargo.

Instead, the berth's equipment is completely equal to that of a generic intermodal terminal and, therefore it is composed by:

- The *Trailer tractors*;
- The *Rider elevators*;
- The *Gantry* or the *gantry crane*;
- The *Fork elevators*.

The only equipment feature of the container terminals is the *Portal crane* for loading and unloading the containers on the container ships. The following image shows the different areas present a container terminal:

- The *Rail area* dedicated to the containers' movements. It has to be at least 2.5 meters from the dock;
- The first *Storage area*, served by tractors and forklifts;
- The Storage area served by yard cranes;

• The *Warehouses* for eventual opening and reorganization of container loads;
• The area for the storage of empty containers;
• The area for possible repair of containers;
• The *Railway terminal*;
• The *Motorway terminal*;
• The storage area for containers for ground terminals;
• The areas dedicated to various services (internal roads, car parks, customs areas, shipping offices, etc.).

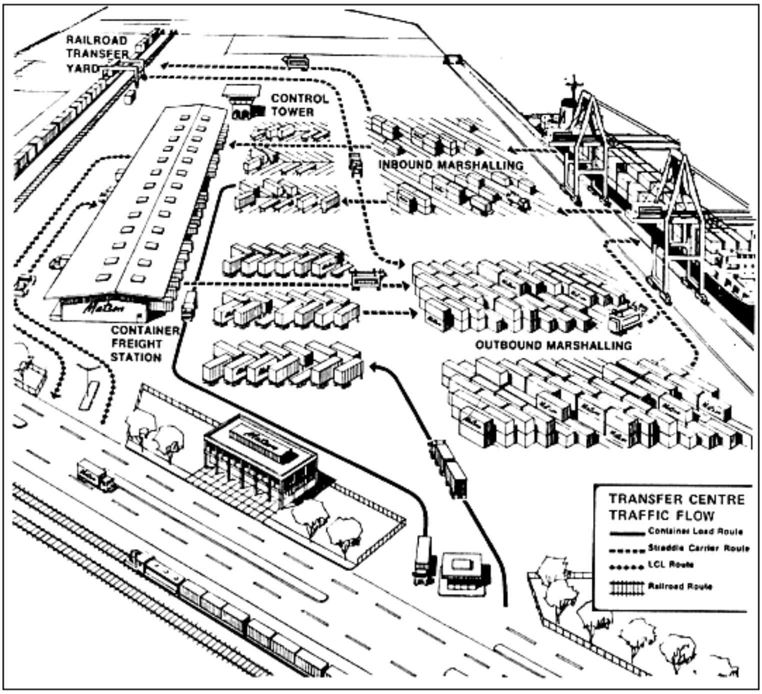


Figure 2.1 - Scheme of movements in a container terminal – Source: web

The use of different handling units and the large volumes of containers trade that transit in a terminal, require a careful design of the backport areas, or those areas destined for the container's storage.

A very important resource of the container terminal is the space on the berth; for each ship, it is necessary to assign a berth allocation and a time slot in which it can dock and station.

In general, the berth allocation is made known about two or three weeks before the ship arrival, when it is known. However often, once on the ship, the shipowner is the only one who has the power to make decisions about the boat; for any reason related to safety or loading/unloading sequence, the shipowner may decide to change the route. In these situations, the call to the destination port could arrive much later, enabling the terminal of studying new operations planning in a shorter time.

In the technical slang, these problems are named *Berth-allocation* and *Berth-scheduling*. These two problems are closely related to the *Quay-crane allocation* problem, ie the assignment of cranes to the ships; the time slot in which a crane could be assigned to a ship, depends on how many cranes are assigned to the same ship. Although dependent on each other, due to their computational complexity, the two problems are often analyzed separately.

A possible approach to the *Berth-allocation* problem is the formulation of a Multi-depot VRPTW problem, in which the ships are considered as customers, instead, the berth as depots. The objective function consists of the minimization of a weighted sum of the service times for the different ships. While, the more complex models tend to minimize ships delay times; in this case, the problem is associated with a two-dimensional space, whose axes correspond to space and time respectively.

Besides assigning cranes to a specific ship, it is important setting the cranes to its single sections and decide with which sequence they have to work in the different sections.

In this case, the problem is called *Crane Split - Quay Crane Scheduling*.

Usually, between three and five cranes are assigned for loading/unloading a Mothership, and one or two cranes to handle cargo of a Feeder ship.

Starting from technical data about ships and cranes, and from the port's accessibility, the main objective of such planning is the minimization of the delays of all the ships docked in the port, with the consequent maximization of the performance of the terminal.

Another aspect to focus on is the sequence setting of containers to be loaded and unloaded, and on defining their optimal position on the ship.

The stowage of the ship takes place in two phases, managed by the shipping company, the first, and by the terminal operator, the second. These phases are called *Stowage-planning* and *Stowage-sequencing*, respectively.

The *Stowage-planning* phase consists in defining the position of the containers on the ship, on the basis of the sequence of ports in which the ship has to stop. Moreover, the containers are not considered individually, but as groups of them, identified by length, weight, typology, and destination port.

The second phase, the *Stowage-sequencing*, is ran starting from the input data, carrying out from the stowage plan made by the shipping company, and then transferred to the terminal operators, through computerized systems. Actually, the *Stowage-sequencing* is the result of an off-line optimization, but it would be preferable to optimize it online, because of the complex characteristics of the processes taking place in a terminal; often, the containers do not arrive in time and in the sequence provided, or they arrive with non-standard measures, thus requiring special equipment, and creating additional lines for the handling vehicles.

In addition, technical and operational disturbances must also be considered. These latter could vary the load/unload sequences and the vessel's stability, which must always be checked during loading/unloading operations.

Based on the stowage plan, the terminal planner assigns a slot to each container placed on the ship, and he sets up the sequence of the loading and unloading operations of them. This planning is different and differently detailed depending on whether it can take place a *Direct transfer* or an *Indirect transfer* of containers between ships or between ship and another ground vehicle; for example, in the latter case, could be temporarily allocating the container in the yard area, before loading it on the successive vehicle.

Once positioned in the yard area, the containers must be picked up by the gantry cranes and placed in the storage area.
This is defined as a *Pickup-scheduling* problem, which allows determining both the number of optimal movements per each gantry crane and the number of containers to be picked up per each section of the yard area. In this case, the objective function consists in minimizing crane moving times.
Regarding the yard area, a fundamental aspect consists in determining where and how to position the containers (*Space - allocation problem*), in order to optimize the performance of the handling operations and avoid unnecessary waiting times or congestion for the handling ground vehicles.
The containers are stored in the yard near the section where they will be loaded on the ship, according to the sequence in which they will be loaded and in order to minimize transport distances. This operation is usually run when the ship has to be loaded as soon as possible, but since it requires additional movements and increased costs, it is not always performed.
The efficient use of the yard area is very important because the space in the terminals is becoming a scarce resource if compared to the daily traffic of containers; in the large terminals, around 15,000 of containers are daily moved with an average parking time of about three-five days for each one.
To maximizing of the yard area, the *Terminal Operating System* (TOS) is often used; Through appropriate optimization techniques, TOS allows to record the position of each container located on that area and to plan the subsequent handling operations.
However, the effectiveness of this tool is often limited due to several reasons. The first of all is bound to the method of communication about the state of the yard area. The communication happens via radio from the operator that is working in the area at that moment, and often he does not notify the re-handling operations, because of the rapidity of the operations; about the 30% of the operations are not notified by the operators.
Therefore, the aim of TOS is to maximize the use of the yard area and minimize the re-handing operations.

The optimization problems of storage operations are called *Space-allocation* problems and are essentially divided into two categories: *Yard-planning* and *Scattered-stacking*.
In the first one, inside the yard area, a certain number of slots is assigned to a specific ship. Generally, for the export containers, a row is assigned to containers having the same characteristics and destined for the same port; for stability reasons, in that row, the heaviest containers are stored on top of the lighter ones, so that they are loaded first on the ship.
Instead, for imported containers, since the containers' data and the handling vehicles are not known at the unloading time, no special scheme is executed, but only a part of the storage area is reserved for those containers. But, on the other hand, when the successive transport modes are known, the area reserved for the import containers, is divided according to a scheme aimed to shift them faster on the ship.
Often, the *Yard-planning* is not very efficient, because the container arrivals follow a stochastic process; consequently, a very high number of re-handling operations is also obtained.
The *Scattered-stacking* operations are different from those of *Yard-planning*. In this case, the sections are not assigned to a ship but are associated with an area along the berth. In particular, when an export container arrives, in real time the system identifies the berth section where it will be placed and then, automatically, it calculates its optimal ranking on it. The containers belonging to the same category are positioned in the same area, one above the other; a category of containers is defined by those having some common characteristics, such as the type of cargo, the destination port, and the weight.
The *Scattered-stacking* system allows greater performance of the operations in the yard area and a notable reduction in the number of the re-handling operations.
It is obvious that the management efficiency of the yard is mostly obtained by optimizing the assignment of the tasks among others handling systems (*Equipment-assignment process*); in fact, there are other problems regarding the connection op-

erations among the terminal's subsystems: *Quay-side* (connection between quay and yard) and *Land-side* (connection between railway terminal and yard).

In general, the greater difference between the technical productivity and the actual cranes' performance, depends on their work shift breaks, on different kind of technical and operational disturbances, and on congestion of the handling vehicles.

The minimization of the vehicles congestion is fundamental for the optimization of the whole system and for the productivity of the ship; possible strategies to assign ground vehicles to the single cranes could be based on the *Single-Cycle* or on the *Dual-cycle*.

In the case of *Single-cycle*, each ground vehicle serves, alternately, only one crane and moves the import containers from the dock to the yard and export containers in the opposite direction. In this case, there are no empty movements and the only decisional aspect regards the position of the container in the yard area.

Instead, the handling of import containers is more rigid. In fact, there is more leeway for the optimization of the export cycle, because the handling sequence within the yard is not exactly the same as the sequence of the containers' loading on the ship. However, any re-handling operations and the transport of special containers must be taken into account.

On the other hand, in the case of *Dual-cycle*, each vehicle serves more cranes, which are in the same loading/unloading cycle, then combining the handling of containers in import and export both. This is a much more complex and difficult system to organize.

As explained, the different operating phases taking place in a container terminal require many optimization approaches. Although it would be more advantageous to optimize the system as a whole, practically it is an impossible problem to solve. Usually, the different phases are optimized separately, and each one is analyzed as a detailed operational problem.

At the level of operational planning, the most useful tool is the Simulation, which is used as an integrative tool to optimize the activities in the terminal. In addition, the

simulation is useful for the real-time testing of the impact of any delays in the ship arrivals or of any port calls not well planned in advance.
Moreover, in the strategic planning of a new container terminal it is essential for deciding:

- The number of docks along the berths; if this number increases, the construction operating costs increase too, but ship waiting times decrease;
- The number of cranes; this is one of the most important characteristics for port sizing, given the high purchase cost of the equipment; as the number of cranes increases, also the terminal performance increases;
- The size of the yard area; if the area size decreases, then the structural costs decrease, and it is necessary to reduce the containers parking time in that area or to increase the ground vehicles performance;
- The type and number of handling vehicles.

From the theoretical point of view, for strategic planning, the most used approaches are based on optimization models, such as *Queue Theory*, *Probabilistic approaches*, and *Nonlinear programming*. The aim is to determine, for example, the optimal number of the berths in a terminal, the optimal number of the cranes, the minimum number of the handling operations, and so on.
On the other hand, *Discrete Event Simulation* models are used to compare different scenarios, allowing to evaluate the efficiency, the costs and other parameters of system performance in real

CHAPTER 3
LITERATURE REVIEW

3.1 THE CHOICE MODELS

In order to analyze the agents' behavior, in the transport sector, the Discrete choice models are widely used. For decades, this class of models has been applied in other fields too, such as, for example, labor market, sociology, political science, medicine, tourism, environment, and some others.

Like all other models, also discrete choice models provide a simplified vision of reality so that it can be better understood.

However, in the transport sector, the discrete choice models have a significant importance, primarily because usually, in this field, the decisions involve choices between the discrete alternatives; then, often the use of traditional methods is not fruitful. In fact, the discrete choice models allow describing explicitly the set of choice and the individuals' behavior who choose among the available, discrete and finite alternatives within the whole set of choice. Therefore, these models are useful when the aim of the study is discovering the behavioral relationships between individuals and choice alternatives.

Furthermore, identifying the appropriate model for a specific case of study requires not only a great analyst's familiarity with the topic but also his in-depth knowledge about the methodological and practical implications entailed by the different theoretical assumptions. The greater the complexity characterizing the case of study, the greater must be the simplifications to carry out in order to make the model serviceable. Furthermore, if appropriately calibrated, a model allows making predictions about the future states of the analyzed system, to check its progress and to intervene in its trend in order to optimize its applicability.

In particular, in the transport trade, most decisions influence or are influenced by other individuals, or those involve the interaction between several decision-makers, both in the case of goods or passenger transport. Thus, the individual choices are affected by the surrounding environment in which the decision-maker is in; this produces a correlation between the choices of the individual decision-maker and those of the others.

An example of the interdependent decisions are those analyzed sequentially by a person who wants taking a trip and has to choose the transport mode to use, the departure time, the path to travel, the destination to reach. In this case, the decision-maker jointly considers all these aspects, optimizing the choice over time and space and on the basis of his economic, technological and temporal constraints and preferences.

In the last decades, beyond the discrete choice models, the literature saw a very wide range of studies concerning the interdependent decisions, following different approaches, including the Game theory and the Decision theory.

After several years from the attempts establishing the theoretical basis for the study of collective decisions, the prevailing theory is the General economic equilibrium model, introduced by the theorists Robert Arrow and Paul Samuelson. This model takes into account the hypothesis of the isolated decision-maker and it appears unable to grasp the crucial elements of social interaction between decision-makers themselves. However, the concept of an isolated decision-maker is a theoretical simplification, motivated by the analytical convenience necessary to analyze the several problems.

3.1.1 THE DISCRETE CHOICE MODELS

The discrete choice models base their historical roots in a psychophysical study by Fechner (1860) concerning the analysis of the relationship between physical stimuli and sensory responses.

A successive study enabled these models to be applied in the field of biology in order to analyze the relationship between stimuli and the corresponding responses of individuals. By their nature, these responses are discrete because a given event can take place or not; then, for the first time, the assumption of models with discrete responses was asserted. Since then, discrete models have undergone considerable evolution aimed at enhancing their analytical skills based on the principle of maximizing the utility of the individual decision-maker.

In fact, according to the neoclassical economic theory, the decision-maker tends to maximize his own well-being and this process is, for various reasons, governed by properties, generally consistent with each other.

In the classic opera by Hicks and Samuelson, the concept of rational consumer's behavior has been clearly defined; in particular, the "self-interest" is defined as a set of innate and stable preferences. Also, Simon (1978) affirms that the man is rational and he is a "maximizer" that is not satisfied except for the optimum.

Therefore, according to the neoclassical theory, the individual has a perfect capacity for discrimination and an unlimited capacity to process the information allowing him to order the alternatives between which he has to choose in a well-defined and consistent way. In the hypothesis according to the choice takes place in identical choice contexts, the individual is able to determine what is best for himself and will always choose the same option he prefers.

This approach was a lot criticized by many psychologists (Thurnstone 1927, b, Luce 1959, Tversky 1969) and by some economists (Quandt 1956, Mcfadden 1981); according to them the hypothesis of the perfect discrimination capacity and information processing it does not constitute a correct and realistic description of human behavior. Instead, it seems much more realistic assuming that, given a set of alternatives, the individual's choice is not unique but follows a probability distribution.

In other words, the behavior of a human can vary according to some factors external to the decisional context without his preferences changing in any way. From this point of view, the decision-making process assumes a probabilistic character.

According to Tversky (1972a), this behavior, which at first might seem irrational, would instead be considered possible and rational if the inconsistency of choices was supposed to be linked to a probabilistic process associated with the behavior itself.
Quandt (1956) explains that the probabilistic hypothesis is realistic if it is assumed that an individual on certain occasions can forget to evaluate some characteristics of a given alternative and/or commits an assessment error about the importance of one or more specific characteristics of a given alternative.
From this point of view, the circumstances characterizing the choices' context can alter the perception and/or the desirability of a given alternative.
Instead, it can be assumed, as Manski (1977) does, that the lack of adequate information induces the analyst to hypothesize that individuals choose according to probabilistic rules; in this case the choice of probabilistic rules is not intended to explain the decision-makers irrationality, but it aims to take into account the analyst's lack of information about the characteristics of the alternatives and/or the agents.
As mentioned above, the discrete choice models assume the decision-maker as represented by a utility function, which must respect certain constraints and objectives, strictly linked to the type of choice to be taken.
However, Griliches (1957) was the first who pointed out that the elements included in the constraints or objectives have a random nature; thus these are subject to errors caused both by the observed behavior and the measurements by the analyst.
Generally, the analysis of the individual discrete choices uses the Random Utility maximization models (RUM) proposed for the first time by Marschak (1960) and Block and Marschak (1960).
Today, the acronym RUM indicates all the models in which deterministic decision-making rules and random utilities are assumed.
In particular, in the RUM models, the utility errors are the sum of two independent random variables, where one of them follows a Gumbel distribution.
The structure of a RUM model is based on four fundamental components:

I. The Decision-maker: who is the agent taking the decision according to a certain decision rule and its aspects characterizing.
II. The set of choices: what are the possibilities actually available for the decision-maker when he is called to choose.
III. The Attributes: the aspects characterizing both the agents and the alternatives.
IV. The decision rule: what are the characteristics of the decision-making process employed by the agent to arrive at his final choice.

The RUM, widely used in economics, allows to estimate the monetary values of those attributes of goods and services influencing the economic choices; in addition, it enables to predict about the behavior of individuals in scenarios different from those actually observed.
In the field of transport, the discrete choice models have become increasingly consolidated over the years and today allow to represent in a detailed and realistic way the complex aspects influencing the transport demand (Bierlaire, 1997), also taking into account the interactions between it and the supply (Hensher and Pukett, 2004). Moreover, in recent years, these models have imposed themselves in a lot of sectors thanks to the development of dedicated software on a larger scale.

3.1.2 THE PROBABILISTIC CHOICE MODELS

In reference to the work of Block and Marschak (1960), it is possible to distinguish the probabilistic choice models in two categories, depending on the nature of the random mechanism governing the choice. The first ones consider the decision rule as stochastic (random orderings Tversky); instead, the seconds consider the agent's utility as stochastic (random utilities - McFadden and Thurnstone). In both, in keeping with the neoclassical approach, the aim is the utility maximization.
In the following image, the distinction between the two models mentioned is graphically reported.

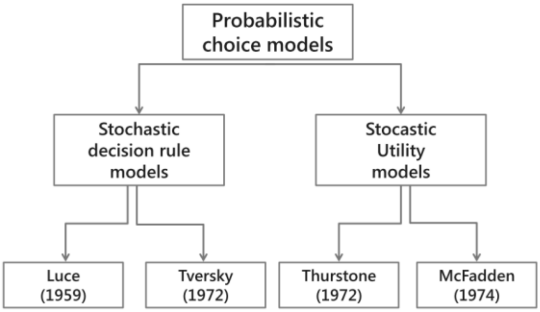


Figure 3.1 – The probabilistic choice models.

3.1.2.1 THE STOCHASTIC DECISION RULE MODELS

In general, in this class of models, it is hypothesized that the decision rule applied by individuals is stochastic; this implicitly assumes a deterministic assumption about the usefulness deriving from the various alternatives of choice.
A very significant contribution to the evolution of these models came from the work of Luce (1959), introducing the axiom of the independence of irrelevant alternatives (IIA). This assumption led a process simplification of gathering information. In particular, given the choice universe, including the choice sets, that contain in turn the alternatives of choice, the IIA axiom establishes that the ratio between the probabilities of choosing alternatives is the same for each set of choices that includes the same alternatives.
According to the Luce's model (1959), the decision-maker has the ability to evaluate the elements of the universe of choices, and according to some comparative methods, he is also able to choose some finite choice subsets that he considers superior to others.
On the other hand, the validity and applicability of this axiom is limited to the cases in which the set of choices consisting of distinct alternatives (Ben Akiva and Lerman, 1985), since the model can not take into due consideration all those situations in which a new alternative reduces more or less proportionally the probability of choosing alternatives similar or dissimilar to it.

Also, Amos Teversky in 1972, proposed a model in which the decision-making process is assumed stochastic and takes place through the successive elimination of alternatives present within the set of choice. The probabilistic view of the choice is precisely helpful to explain the inconsistency and the uncertainty reported by the agents themselves during their decision-making process.
Before the publication of Tversky's work (1972a), much of the theoretical literature focused on the notion of independence among alternatives (Luce, 1959).
Tversky develops the Elimination by Aspects model (EBA), in which it is assumed that each alternative can be described through a set of characteristics that distinguish it. These characteristics are binary in such a way that each alternative either owns them or does not possess them. In the case in which the characteristics do not have an intrinsically binary nature, they can be turned in binary values; so it is possible setting the thresholds allowing to subdivide the alternatives into classes that exceed or not the established threshold and that, therefore, possess a certain characteristic or not.
First of all, the selecting mechanism of alternatives requires to select a characteristic; all the alternatives do not possess it, are eliminated from the set of choices. Then, a second characteristic is selected by the agent, and it is adopted as a criterion to eliminate other alternatives, among those remained after the first round. The selecting process ends when it is no longer possible eliminating any other alternative. When only one alternative remains, that will be the alternative chosen by the agent.
Instead, if at the end of the elimination process, more alternatives remain within the set of choices, those will all have the same probability of being chosen.
The main weakness of the EBA model is the inability of the model to ensure that the alternative overcoming all the elimination rounds, actually, has the utility superior to all those eliminated previously.

3.1.2.2 THE STOCASTIC UTILITY MODELS

The Thurstone's fundamental contribution lies above all in the intuition that the subjective variability in stimulus evaluation can be explicitly modeled. Thurstone of-

fered a simple and easily understandable framework within which it is possible to analyze many empirical phenomena; for this reason, it has shown also interesting results in other sectors.
Thurstone (1927,b) assumed a normal distribution to represent the perceptions since in many cases this distribution satisfactorily approximates the responses to certain stimuli.
While, what is called McFadden's model is, in fact, an econometric interpretation of a probabilistic choice model with the deterministic rule and aleatory utility. Also, this model aims to maximize the agent's utility in the decision-making process.
In particular, McFadden proposed a geometric characterization of the problem, in which all the possible alternatives are ranked, to which a probability distribution is associated, excluding the possibility of break-even results among the probabilities of choosing different alternatives.
The model initially called Conditional Logit by McFadden, now it is more commonly known with the name of Multinomial logit (MNL).
Later McFadden himself developed a nested version of the MNL in which nesting levels correspond to the separable utility structure; instead, the impact of lower decision-making levels on the higher ones was represented through the inclusive values (McFadden 1974b).
Ben-Akiva in 1972 demonstrated a formula, known today as the Log-sum formula (Ben-Akiva, 1972), accurately representing the inclusive values.

3.2 THE DECISION-MAKERS IN THE PORT CHOICE

During the last twenty years, the quest for economies of scale in the maritime container trade has generated unprecedented effects on ports, forcing large and rapid investments on the port, aiming both to accommodate new vessel sizes and preserve their competitiveness (Imai et al., 2006). Nowadays, a port unable to accommodate mega-vessels risks being ruled out from the maritime network of the container and to become a hub instead of a direct call port.

Thus, the economies of scale emphasized the role of intermediate hubs (Rodrigue & Notteboom, 2009) and the safeguarding the port's operational performance has stimulated the growth in the number of container dedicated terminals, in order to ensure a smoother cargo transfer from sea to land.
A good or bad performance of ports service system may affect the user's port choice behavior, or even influence the cost of the whole fleet or shipper, so the port choice is an important part of port transportation demand behavior.
However, despite the extensive literature concerning the port choice and the high number of researches dedicated to shedding some light on this topic, there are still some important points where researchers are not united.
One of the main points is to identify the real decision-maker in the port choice.
Despite some researchers' results in this topic, it is not easy to determine the real decision-maker because it depends on their participation on transport decisions throughout the supply chain, and it can vary between countries and between industries.
Magala and Sammons (2008) affirmed that the decision-makers are shippers, freight forwarders, shipping lines; they make the port choice differently respect to their different goals, and also depending on the role played by ports to develop their activities.
While, according to other researchers, the shipping lines design their service network in order to make the most of the scale economies (Guy & Urli, 2006) by making the decision that maximizes their profits (Talley & Ng, 2013). Tongzon (2009) and Ogwude (2006) indicated that only shippers without contracts with freight forwarders can be considered as the real decision-makers of ports. Furthermore, the study by Guy and Urli (2006) suggests that the port infrastructure, the costs, the services, and the geographical location are the criteria guiding the shipping line's decisions in the context of North America port competition.
The dynamics in the port industry have demonstrated there are a lot of opportunities for a port to attract the shipping lines. On the other hand, there are also a lot of risks of losing important customers when liner shipping companies rationalize their shipping schedules and adjust their shipping routes and port choices. Thus, to protect

their market shares, the port operators seek to improve the attractiveness of their ports.

Slack (1993), Notteboom and Winkelmans (2001) advocated that ports must understand and adapt themselves to meet their customers' demands, which frequently change.

Since the work of Slack (1985), the agents' behavior in the port choice is analyzed predominantly to identify the port competitiveness and the port choice determinants.

In order to accurately identify and quantify the determinants of port choice, it is necessary first to better understand what are the drivers of port competitiveness analyzed in the technical literature.

3.3 THE DRIVERS OF PORT COMPETITIVENESS

The notion of competitiveness is not a univocal concept, even though it has been widely debated in the academic literature.

Porter (1990) defines the competitiveness as the skill acquired knowledge, able to generate and sustain a superior performance as well as face competitive dynamics.

Although the concept of competitiveness is widely used to refer to competition among trades, in the maritime literature, a port can be considered as a part of a wider dynamic business network (Van der Lugt et al., 2007) where its value highly depends on its ability to accommodate a certain volume of containers.

There is a significant number of factors that drive the port's competitiveness and they may be both internal and external to Port Authorities' control. For example, according to Teng (2004), the port competitiveness at international level is profoundly affected by a country's political, legislative and economic background, which represent an external factor to the Port Authorities' control.

On the contrary, in the case of ocean carriers, the costs play a crucial role in the port choice, whether for commercial traffics or transhipments (Chou, 2010; Park & Min, 2011); then, the Port Authorities who want to become hubs have to pay particular attention to their pricing policy.

Ng et al. (2013), reached the conclusion that the Ports Authorities' strategies are focused on the increase in the number of shipping lines calling at their facilities and not on improving the level of service perceived by the landside users.
During the years, some models of competitiveness have been developed, in which the Port Authorities try to increase their attractiveness, not only by investing in infrastructure and equipment, but also by improving their intermodal connections, and by fostering the cooperation among port community members.
Since from the 1980s, academic researches on port competitiveness focused on the identification of the drivers of port competitiveness (Pearson, 1980; Yeo et al., 2008), and the measurement of them (Tongzon 2001; Teng et al., 2004). At this regard, some authors concentrated their efforts on the analysis of some operational, organizational and strategic dimensions related to this business, to investigate the drivers in the port competitiveness. Some authors (Willingale, 1981; Collison, 1984) have identified several drivers of port selection including the sailing distance between ports, the proximity to hinterland cities, the connectivity and port infrastructures, the port tariffs, the average waiting time, the geographic location of ports, the hinterland transportation networks, the land and container shipping routes, etc.
Furthermore, the inland infrastructures, the implementation of port's facilities and their efficiency constitute a remarkable factor, which might alter competitive dynamics among ports ensuring the higher level of competitiveness.

3.3.1 THE PORT CHOICE CRITERIA

A further research topic, which has been investigated within the studies on the drivers of the port competitiveness, relates to port choice criteria (Yeo et al., 2008).
There are several studies in the port literature, which attempted to investigate the considerations taken by the shipping companies in choosing the ports of call.
Among the first port choice models proposed in the 80s, there is the work by Slack (1985) who found that the decision-makers are influenced more by inland's charges and services than by the perceived differences in the ports of entry and exit. In this

study, Slack used eleven criteria to describe the port selection, such as: the port security, the size of port, the inland freight rates, the port charges, the quality of Customs handling, the free time, the congestion, the port equipment, the number of sailings, the proximity of port, and the possibility of inter-modal links.
Ten years later, Hayuth (1995) affirmed that the most common criteria to select a port are related to its location, operation (high productivity, frequent port of call, reasonable transportation, and port-user costs, and high level of inter-modality), the state of the art of its infrastructure and superstructure, and the large back up space at the terminal.
Thomson (1998) found as choosing criteria the length of berthing time, the loading/unloading rate, the available number of berths, the quantity of containerized cargo, the port facility, and the working hours of ports.
Sternberg (2000), studying the port of Gioia Tauro in southern Italy found the keys of its success. According to this study, the keys are the geographical location, the knowledge of market of marine container operators, a flexible operation process, the continuous investment in the infrastructure and facility, and the operation of related businesses.
Instead, Frankel (2001) found that the major criteria to evaluate by the maritime companies are the increase in service frequency, the build-up of shipping and inter-modal alliance, and the sharing of space on each other's ships, inland depots, feeders, container terminals, and container inventories.
The mentioned studies, rely on surveys to obtain information on factors affecting the port choice. These studies are helpful to identify and rank the factors affecting the shipping companies' choices but are unclear what extent the identified factors affect the final port choice; unfortunately, most of the above-mentioned papers proposing port choice models using a mathematical programming, which cannot be used to accurately explain the present behaviors of shippers.
An extension technical literature is the use of the Analytic Hierarchy Process (AHP) model to analyze the data. In this case, the responses of the survey are ordered in

some manner so that weights can be attached to various factors affecting the port choice (Song and Yeo 2004; Lirn et al. 2004).

As Schoner and Wedley (1989) have pointed out, the AHP approach relies on strong assumptions to generate weights, depending on various factors; the rank changing among ports may occur when any of the alternative port is added or deleted.

About the use of surveys, two studies must be mentioned. The first one is by Tiwari et al. (2003), who studied the port selection behavior in China by applying a set of shipper's survey data on the discrete choice model and concluded that the distance and port congestions are the primary factors influencing.

The second one is by Nir et al. (2003), who utilized survey data as compared to competition, frequency, route, port facilities or service, in order to investigate the reason of a choice rather than another.

The geographical are also important factors affecting the decision.

In this sense, while the shippers and the freight forwarders try to minimize the door-to-port distance/cost (De Langen, 2007; Steven & Corsi, 2012; Ng et al., 2013; Tongzon, 2009), the shipping companies seek to achieve a balance between land distance to main production/consumer centres (Chang et al., 2008; Lirn et al., 2003; Ng, 2006; Wiegmans et al., 2008; Yuen et al., 2012) and location of the port with respect to major shipping routes.

On the other hand, the inland transport costs (Anderson et al., 2009; Nir et al., 2003; Veldman et al., 2011) and maritime transport costs (Ng et al., 2013; Veldman et al., 2011) undoubtedly represent an important indicator of the connection of a port to its inland services. In port choice models which consider both variables, the coefficients' estimates of inland transport costs appear more influence than those obtained for inland distance (Anderson et al., 2009; Ng et al., 2013; Yeo et al., 2008).

Another aspect to underline regards the performance or the quality of the port services. The port performance is a very broad concept that is determined by multiple items. There is not a single way to measure the port performance, but specifically, two components can be distinguished: the port efficiency and port effectiveness (Brooks & Pallis, 2008).

The port efficiency is a key determinant of port choice for the decision-makers. About this, Steven and Corsi (2012) approximated the port efficiency through the crane productivity, obtaining that this variable is the second most valued in port choice processes by shippers.

Instead, Tiwari et al. (2003) used the number of berths and cranes as indicators of the port efficiency. According to their results, while the number of berths is the most important variable, the number of cranes is not significant.

In 2009, Tongzon carried out a more detailed analysis of the determinants of port efficiency from the freight forwarder perspective and found that crane productivity is the one that best approximates port performance.

Moya et. al (2016) proposed an interesting literature review concerning the port choice in the container market, both from the freight forwarders and shipping line point of view; from this work the following tables have been extracted. As can observe from both the Table 3.1 and 3.2, during the years, many authors recognized the port choice criteria in the port location characteristics.

	Port location					Port effectiveness					Port connectivity				
	Dist.	Transit Time	Cost	Location	Port efficiency	Congestion	Reputation	Cargo damage	QRCN[a]	Others[b]	Frequency	Intermodality	Other	Port charges	Port infras.
Slack (1985)			X	X		X				X	X	X		X	X
Malchow and Kanafani (2001)	X										X				
Nir et al. (2003)		X	X								X		X		
Malchow and Kanafani (2004)	X										X				
Song and Yeo (2004)				X						X					X
Guy and Urli (2006)				X						X				X	X
Anderson et al. (2009)	X	X	X							X					
Onut et al. (2010)				X	X					X		X		X	X
Veldman et al. (2011)			X							X					
Yuen et al. (2012)				X	X					X	X	X	X	X	X

[a]QRCN: quick response to customers' needs.
[b]Others: service quality, customs handling, port safety and security, port management.

Table 3.1 – Port choice criteria studied. - Source: Moya et. al (2016).

	Port location					Port effectiveness					Port connectivity				
	Dist.	Transit Time	Cost	Location	Port efficiency	Congestion	Reputation	Cargo damage	QRCN[a]	Others[b]	Frequency	Intermodality	Other	Port charges	Port infras.
Murphy et al. (1992)								X		X					X
Lirn et al. (2003)				X						X				X	X
Veldman and Bükmann (2003)		X	X							X	X	X			
Lirn et al. (2004)				X						X				X	X
Tai and Hwang (2005)			X	X	X					X	X			X	X
Ng (2006)				X	X		X	X		X				X	X
Acosta et al. (2007)					X							X			X
Tongzon and Sawant (2007)				X	X					X			X	X	X
Chang et al. (2008)				X			X			X		X	X	X	X
Wiegmans et al. (2008)				X	X		X			X		X	X	X	X
Yeo et al. (2008)	X		X			X			X	X		X			X
Tongzon (2009)				X	X			X	X		X			X	X
Chou (2010)			X		X						X	X		X	X
Caillaux et al. (2011)		X	X		X									X	
Park and Min (2011)				X						X				X	X
Yeo et al. (2011)	X		X			X			X	X		X			X
Tang et al. (2011)					X					X	X	X		X	X
Yuen et al. (2012)				X	X					X	X		X	X	X
da Cruz et al. (2013)				X	X							X			X
Ng et al. (2013)	X		X		X					X				X	

[a]QRCN: quick response to customers' needs.
[b]Others: service quality, customs handling, port safety and security, port management.

Table 3.2 – Shipping line's port choice criteria studied. - Source: Moya et. al (2016).

3.4 THE PORT CHOICE MODELS

In the past, some models for port choice are proposed.

During the years, Chang (1974), Zong (1978), Wan (1980) and Gleave (1981) assumed that the international trade container transportation market could be analyzed as an Equilibrium market, in which shippers aim to maximize their revenues when they choose their ports.

Also, Chou et al. (2003a) proposed an Equilibrium model for port choice, assuming the same view of the maritime transport market. In this latter study, the objective function of the Equilibrium model and the constraints are the same as that in the Satckerlberg model for port choice.

In particular, the Stackerlberg Model, used to explain the port choice of shipping companies and shippers, allows to simulate the flow of foreign trade container cargo, using a mathematics program. The Stackerlberg method also considers that the carrier aims to maximize his net revenue, using strategies of routing, different vessel type, call port and frequency of call on each route.

Chou (2003a) considered the following assumptions:

- Only foreign trade container cargo is considered;

- Competition between shipping companies is not taken into account, but only a single carrier is assumed;
- The carrier aims to maximize his net revenue;
- Shippers aim to minimize their cost when choosing their port, including the port access cost;
- Port access time is neglected.

In the same year, using the Multinomial Logit model, Nir et al. (2003), proceed to the analysis of shippers' choice behavior. In this study, the collected data used come from the direct observation of the maritime companies' behavior during the travel, or from the survey questionnaire of the travels' behavior. This study clearly shows that shippers' last choice experience will influence their future port choice behavior; however, they will not be affected by the different competition factors such as the frequencies, the routes, the port facilities or the level of port service.
Moreover, many researches on port selection uses disaggregate behavioral analysis (Tongzon, 2009; De Langen, 2007; Malchow and Kanafani, 2004), which limits the geographical scope of the models' application, because of the high costs of data acquisition involved.
On the other hand, Transportation literature presents a limited number of aggregate models for the routing of seaborne freight (Tang et al., 2008; Giannopoulos et al., 2007; Leachman, 2006; Aversa et al., 2005; Frémont, 2005; Veldman and Buckman, 2003). The aggregate models could be applied at a global level, if the specification of the model is such that data needs do not become prohibitive.
However, most of these models have been shown to be operable or valid at a global scale and suffer from additional shortcomings. For example, the absence of elements describing the aggregate choice behavior of shippers and preferences related to the generalized costs of freight and the value of time of goods; these models are deterministic (applying all-or-nothing techniques) without accounting for heterogeneity in choices, do not include the value of time or are not estimated to replicate observed flows.

In addition, the aggregate models assume the stochastic independence between alternative routes, and use the basic multinomial logit approach to discrete choice modeling. Due to this assumption of independence between routes, choices will be heavily biased towards groups of routes that overlap, unless the choice model is adapted for use in a network situation.

In this regard, in 2011 Tavasszy et al. introduced a new strategic choice model for container shipping routes which explicitly takes into account port selection criteria. The model combines a worldwide coverage and a description of route selection made within a comprehensive network of maritime services, based on shippers' preferences. The calibration shown that the model is able to predict quite well the yearly container flows to and from all countries using major and minor container ports around the world.

The limitation of the model proposed in this study is the assumption that congestion does not significantly affect the routing of freight flow; short-term congestion in port could be caused by several conditions such as strikes or bad weather conditions. Moreover, structural congestion could be caused by a chronic underinvestment in ports and terminals.

Woo et al. (2011), in their study of methodological issues in seaport research, counted 16 publications using logit models applied in the areas of port competition and performance; instead, Paixao et al. (2010) identified 56 applications of port choice, among which 11 using logit models.

Instead, a recent research on the port competition by Veldman et. al (2013) applied a two-phase choice nested logit models showing that inland transport costs, maritime transport costs, port specific dummy variables and proxies for quality of service aspects have a statistically significant impact.

In conclusion, the logit and multinomial logit are the widely used for the port choice models. Many of these studies considered port location, performance, and charge as the most important variables.

3.4.1 THE FUZZY PORT CHOICE MODELS

As explained, the port choice is an important issue to investigate from the maritime companies' point of view. The selection of appropriate ports to handle the containers is crucial not only for stakeholders, but also for port administrators, and cargo shippers. The problem is essentially multiple decision-making processes, requiring agents to make rational decisions. Often, because of its nature, this process is affected from uncertain or it is characterized by incomplete data related to different quantitative and qualitative determinants.

An important contribution of the Fuzzy theory is that provides a systematic procedure for transforming an uncertain knowledge expressed by a linguistic variable, in a fuzzy number.

The concept of the linguistic variable is very useful to describe the human judgments or preference in many situations. For example, in the container port choice problem, the importance weight of various criteria and the preference of each port could be considered as linguistic variables.

Chou et al. (2003b) proposed a fuzzy multiple criteria decision-making model (FMCDM) for the port choice. The study proposed two solution process stages. The first one allows computing each port's transportation demand split rate by fuzzy multiple criteria decision-making method (MCDM). Instead, in the second stage, each port's transportation demand split is obtained by the mathematics programming.

This paper compares three models for port choice: the Stackerlberg model, the Equilibrium model, and the Fuzzy MCDM model. These three approaches are tested by a Taiwanese case; the results coming from the models, compared with the real data, showed lower errors for the Fuzzy model. Then, the Fuzzy model proved to be more skilled in modeling the shipping companies' port choice.

Recently, Yeo et. al (2015) proposed a new conceptual port choice method by explaining the rule Fuzzy logic in Evidential Reasoning (ER) in a complementary way, in which various forms of real data collected to evaluate port performance can be, at first, converted into a fuzzy number, defined using linguistics terms; at second, this fuzzy numbers can be combined using evidential reasoning to produce a port choice preference score.

The combination of ER and Fuzzy Logic can provide the appropriate foundation to model any type of port selection scenarios in an uncertain environment and propose a reasonable solution.

For example, if the stakeholders who are going to make the choice only based it on the available data and ignore the information of having a qualitative nature, there will be a high possibility for them to make the wrong and costly decisions. In this regard, the ER approach enables the decision-makers to make use of both tabular and graphical data and make decisions based on any necessary comparison.

In general, the Fuzzy Evidential Reasoning (FER) by combining two main uncertainty theories: the Fuzzy logic and Dempster–Shafer theories. The FER is widely used to solve complex decision problems in various applications, including those in maritime sector (Yang et al. 2009; Yang et al. 2005; Wang 1997; Liu et al. 2005; Godaliyadde et al.2010).

3.4.2 THE ACCESSIBILITY PORT CHOICE MODELS

Academic literature on port choice identifies a multitude of service-related and cost factors influencing the shipping lines and shippers' decisions. These factors relate primarily to port infrastructure, but the accessibility both over land and via the sea has an important role in the decision-making process.

In fact, in the current practices of transport policy, the accessibility is one of the most important aspects to evaluate, because it represents the interaction between land and transport.

In literature, the accessibility is related to the activities located on territory and to the performance of transport mode.

In 1959, Hansen presented the first attempt to link the transport network to the land use and activities.

In general, the term accessibility defines the ease with which any land-use activity can be reached from a location using a particular transport system (Dalvi et. al, 1976).

Then, the accessibility measures represent the degree of interconnection between a particular reference location and all, or a set, of other locations in the same area (Gutiérrez, 1998; Morris, 1979; Pooler, 1994).

However, during the years, many researchers redefined the term accessibility and categorizing its measures.

In particular the classification proposed by Geurs et. al (2001) laid the basis for the successive discussions about the accessibility measures. Their categorization of accessibility measures is as follows:

- The Infrastructure-based measures. These allow analyzing the network performance in relation to the traffic demand conditions, without any spatial element; the level of accessibility itself could be connected with the travel time, the trip length, the congestion severity and the average operating speed.
- The Activity-based measures. These take into account both transport and location components. The distance measures belong to this category, representing the degree to which a point is connected to all other points within the area of study. These particularly useful measures when only connections are important, rather than distance or travel times.
- The Contour measures reflecting the number of opportunities that can be reached within a given travel time, distance or cost. Alternatively, they can provide a measure of the average or total time or cost required to access a fixed number of opportunities.
- The Potential measures. These incorporate some specification of the gravity model and, as such, are sometimes referred to as a gravity-based measure. These revolve around the estimation of the accessi-

bility of zone to all other zones in which smaller all opportunities provide diminishing influences.

- The Space–time measures, taking into account the individual point of view about time and space constraints These person-based accessibility measures are used to show the potential areas or opportunities that can be reached given the individual constraints.
- The Utility-based measures. These assess the economic benefits people derive from having access to spatially distributed activities.

Geurs and Van Wee (2004) describe the logsum function as the method that best allow to indicate the desirability of the full choice set. Furthermore, they found that the accessibility measure is composed of four main components: land-use, transportation, temporal and individual.

Dong et al. (2006) proposed an activity-based accessibility (ABA) measure, which is related to the logsum accessibility measure. They did not examine a particular trip, but all trips and activities within the day.

Technical literature offers several accessibility measures in urban planning, which are often automobile-based (Handy, 2001).

In the field of maritime transport, the accessibility of a container port is a particularly relevant aspect of port competitiveness; it is correlated both to the degree of port's services dedicated to the handling containers and to the role of the port in the container shipping network.

Cullinane et al (2009) presented a formulation for an index measuring the accessibility of individual container ports and to provide a detailed example application of the measurement of nodal accessibility in the liner shipping context. They confirm the thesis proposed by Rietveld and Bruinsma (1998), according to which the attractiveness of any particular node in a network takes into account the accessibility of other nodes and the costs to reach those nodes via the network.

Thus, the concept of accessibility understood as a fundamental aspect the for ports competitiveness has flowed the publication of studies, which use the accessibility measures in the application of the port choice models. Also, Wang et al (2006b), analyzed the port's accessibility as a potential discrimination for the shipping' port choice. The port attributes examined in this study are: the number of port calls, the draught, the trade volume, the port cargo traffic, the ship turnaround time, the annual operating hours, the port charges, and finally the availability of the inter-modal transports connections.

Tange et al (2011) contributes to the extant literature with the development of a port choice model indeed to the international shipping industry through a network representation. The Network-based Integrated Choice Evaluation (NICE) model required the development of a new connectivity index based on the concept of the network accessibilities (Hansen 1959; Taylor et al., 2006). In this study, the accessibility of the port can be viewed as a variation of the Hansen integral accessibility index, also described in Taylor et al. (2006). In particular, Tange et al developed a NICE model integrating the network characteristics of the port industry into the traditional multinomial logit model (MNL) through an accessibility index. Moreover, the NICE model also takes into account the endogeneity of port variables. The model's empirical results reveal that while port efficiency is most influential in increasing the attractiveness of ports.

In 2013, Campos et al., for the first time, analyzed the freight transport and inland port accessibility in a regional context; They proposed a gravity-based accessibility index, applying some changes to the classical gravitational model of accessibility.

Recently, Liu et. al (2016) proposed a probabilistic port choice model, using the accessibility function, useful in traffic planning to predict the regional port cargo volume; the probabilistic approach used in this study is based on the logit method, and on the assumption of the Logit probability distribution, to forecast the agent's choice. Moreover, Liu et. al found that the port attractiveness is mainly affected by the port's accessibility, which depends, in turn by the port's service level.

Sinesi et. al (2017) proposed a Fuzzy Dynamic Accessibility Indicator to support the maritime company during the decision-making process en-route. The indicator proposed takes into account different port characteristics merged with the transport demand, the monitoring data by GPS and radar signals.

CHAPTER 4
THE PROPOSED MODEL: PCM-DAI

As widely discussed in the technical literature, the accessibility is one of the most important factors that the agent analyzes during his decision-making process. Many researchers found that if all other variables are equal among the different alternatives, the accessibility is the only one which can influence the final agent's choice.
Regarding the port competitiveness, the higher the level of total accessibility of a container port, the more attractive the port itself becomes, especially in comparison with other container ports within the relevant choice set of the decision-maker. Therefore, estimating a port's accessibility in comparison with those of the other ports belong at the same area, may provide a possible proxy characteristic for evaluating the container port competitiveness.
In maritime transport, different factors can influence the accessibility; some of them show a low variability, while others are characterized by high within-day dynamicity.
The first group regards the technical characteristics of ports, such as, for example, the number of berths and their depths, the number of cranes, the storage area, etc.; instead, the second one includes characteristics varying hour-by-hour during the day, like the number of free berths, the delay time in freight loading and unloading operations, and the weather conditions.
Starting from the analysis of the port choice models and of the accessibility models existing in the literature, in this research a Port Choice Model (PCM) based on a Dynamic Accessibility Indicator (DAI), is proposed.

Previous studies analyzed the accessibility as constant over time, like an own port's characteristic. The novelty introduced by the PCM-DAI model lies in the evaluation of the port's accessibility as a variable factor over the time, and therefore Dynamic.
The idea of formulating a model of accessibility of a dynamic type to support a model of destination port choice was born during a search for some data useful for the study of a static model type.
Although the container ships must communicate well in advance the arrival to the destination port (about one year for mother ships and at least three weeks for feeder ships), during this phase of data collection, strange ships' behaviors concerning destination ports' calls emerged.
In fact, often, container ships at the time of departure from the port of origin called a certain port of destination, but during the journey, they deleted the previous call and formulated a new one to another destination port. It is, therefore, possible that a ship can change the path during the trip, having to plan again the entire itinerary and the consequent handling operations for the container shift. At the same time, also the called port must reschedule the activities inside it, to accommodate the not expected incoming container ship, to move its cargo, not accumulating delay times.
But how is it possible that a ship having on board a load that has to move from a certain origin to a certain destination can divert the route and unload the cargo, or a part of this, to a further destination still? And again, what could be the causes of this detour?
At the beginning of the present study, for several months the Mediterranean Sea area has been monitored, through the *MarineTraffiche* website, to find out what the reasons for such behavior may be and whether these are exceptional or systematic events.
Through this website it is possible to know, in real time, not only the size of the container ship, but also its GPS position (or the radar signal to identify it), its initially planned itinerary, the first call to the destination port planned, the succession of calls to further destination or intermediate ports, and the times in which the calls occur.

In addition, in order to be always updated on calls and on changing container ships' route, it is possible to select the ports to be monitored, and to activate a subscription and notifications from the mentioned website.

After a few months of monitoring 24/24 hours of the ports facing the Mediterranean Sea, we can formulate the following considerations:

- Ships changing the path en-route are small-medium sized container ships, i.e. feeder ships operating cabotage routes, oriented to a more capillary distribution type of transport.
- Situations in which feeder ships modify the destination port call have a daily frequency. Moreover, often a feeder ship deletes the call and changes it more times during the same journey.
- The ports interested by this phenomenon are mostly ports having both the hub and spoke functions; they are highly specialized ports for container handling and show very high performance with very low delay times in handling activities.
- The ports interested are well connected with the inland inter-modal network; this allows containers that have not been unloaded to the first planned destination, to reach their final destination anyway, via the inland transport network.
- In days when there are bad weather or sea conditions, the phenomenon is more intense.
- There are some days when there is no particular criticality from the meteorological point of view, but despite this, the phenomenon has a high intensity and many ships modify the itinerary. Probably there are some other factors influencing the choice, such as political or costs related, of which is not possible to understand through this kind of monitoring performed.
- At least three days pass from the moment of the call to the port of destination to the actual arrival of the ship in port; this, however, allows to the port to plan

the handling operations in the interested terminals, through computerized systems.

- Often the no arrival planned of a ship in the port allows another ship to dock at the berth dedicated to that not arrived; this implies that the number unemployed equipment in a port may be an attraction factor towards that port for ships which are opting for a new port call.

In light of the above considerations, the model was formulated with the aim to merge the demand with both the main transport system characteristics and some port's characteristics, which are not only exogenous or structural, like geographic location, adequate infrastructure, local legislation, but also endogenous or service-related. The assumptions underlying the method developed in this research are:

- Only feeder ship for European container trade is considered;
- It is supposed that the move of ware within the same country runs via the inland network; therefore, only the containers volume for foreign trade is considered;
- The competition between shipping companies is not considered;
- Monetary costs are neglected, due to the difficulties in finding them;
- The times understood as costs incurred for transporting the cargo from the port of origin to the port of destination were considered; in addition to the travel time, waiting times of access to the port are also considered;
- The carriers aim to minimize their total travel time also in relation both to the waiting times of access to the port, the port delay time in the handling operations, and weather condition during the travel;
- Container trades among countries are considered.

In developing the model, the ships location, the destination area and the ports' technical characteristics data, both with low and high within-day dynamicity, have been considered.

In fact, the PCM-DAI model allows extracting day-to-day the information useful in the decision-making process about maritime freight transport and the ports' service-related parameters.

The variability of the above data is evaluated by a real-time monitoring, while the ships location is obtained by GPS and radar signals from shipping companies.

An important aspect of the DAI is the representation of the accessibility as a Fuzzy number, which allows considering the variability and uncertainty which affect the parameters extracted in real time.

Its dynamic nature allows the model to quantify the accessibility indicators (DAI) of the ports present in the examined area when the ships are along the route. In other words the model is able to evaluate the probability that a ship can select a port rather than another as the final destination of the trip, on the base of the accessibility perceived.

In this sense the PCM-DAI model is addressed mainly to shipping companies, as a support in the decision-making process, allowing the choice, even en-route, of the hub port of destination for the successive multi-modal operations.

The model can be used on-line by the maritime company, allowing the real-time monitoring of the accessibility indicator of the potential destination ports. The shipping company can indicate n selected ports as potential destinations that would like to reach, and the relative travel time between the current GPS position and each destination. The following figure shows a general configuration of hypothetical routes from a single origin port to all possible destination ports selected by the company.

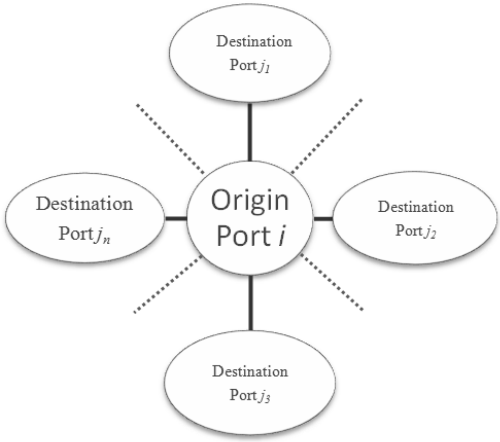


Figure 4.1 – The hypothetical configuration of routes from a single origin port.
Source: Sinesi et al (2017).

Starting from these inputs, the proposed model is able to obtain the port "closer" to the requests expressed by the companies, in term of DAI. The methodology carries out the ranking of the destination ports related to their accessibility indicator. Consequently, the maritime company can plane the trip and choose the preferred port of destination.

4.1 THE MATHEMATICAL FORMULATION

Following the model proposed by Campos et. al (2013) concerning the accessibility of the attractive/productive nodes in the freight inland transport network, in this research a gravity-based accessibility indicator is proposed, also considering some dynamic parameters. The indicator is a Fuzzy Logic-based one, in which we considered as fuzzy some parameters whose value depends on a human judgment, while the other ones have a precise (crisp) value.

Considering *i* the port of origin and *j* the possible port of destination, the mathematical formulation of the proposed DAI is the following:

$$\tilde{A}_j = Lc_{ij} \cdot [r_{ij}] \cdot \frac{\tilde{\gamma}_j}{\tilde{T}^{\lambda}_{i_1 j}} \tag{1}$$

where:
n is the number of possible destination ports;
i is the port of origin of the trip;

j is the j-th possible port of destination selected by the maritime company, with j ∈ [1,n];

$\mathrm{Lc_{ij}}$ is a crisp normalized index representing the annual volume of containers exchanged via sea between the Countries which the ports *i* and *j* belong to.

r_{ij} is the number of possible shipping routes between *i* and *j*;

$\tilde{\gamma}_{\mathrm{j}}$ is a parameter, calculated as a Fuzzy function of both static and dynamic characteristics of the *j-th* port;

$\widetilde{\mathrm{T}}_{\mathrm{i_1 j}}$ is a Fuzzy number representing the vessel travel time from the current GPS position (i_1) communicated by the maritime company, to the *j-th* port;

λ is an integer coefficient representing the traffic conditions along the route *i-j* chosen by the maritime company;

$\tilde{A}_j$ is the Fuzzy Dynamic Accessibility Indicator (DAI) of the *j-th* port.

4.1.1 FIRST PHASE: THE STATIC PARAMETERS

Acquired the radar signals, the ship's GPS position, and the *n* ports considered as possible destinations, in the first phase the model proceeds to the acquisition of the static variables considered in the calculation of the DAI.
For each of the *n* ports, the model calculates the volume of containers exchanged in the previous year via sea between the Countries belonging the *j-th* and *i* port,. Each of the calculated values is normalized, with respect to the sum of the values obtained from all considered alternatives; the index Lc_{ij} is obtained by the following mathematical expression:

$$Lc_{ij} = \frac{Lc_{ij_{imp}} + Lc_{ij_{exp}}}{\sum_{j=1}^{n} Lc_{ij_{imp}} + Lc_{ij_{exp}}} \tag{2}$$

Equation (2) is subject to the following constraint:

$$\sum_{j=1}^{n} Lc_{ij} = 1 \quad \text{with } Lc_{ij} \in [0,1] \text{ and } j \in [0,n] \text{ ;} \tag{3}$$

where:

n is the number of possible destination ports;
i is the port of origin of the trip;

j is the *j-th* possible port of destination selected by the maritime company, with j ϵ [1,n];

$Lc_{ij_{imp}}$ indicates the volume of containers, expressed in millions of dollars, imported via sea by the country *i* s from the country *j*;

$Lc_{ij_{exp}}$ indicates the volume of containers, expressed in millions of dollars, exported via sea by the country i from the country j.

Moreover, the Lc_{ij} value allows to quantify and compare, through a crisp number, the maritime container trade between the Country of origin and the those of the *j-th* possible destinations.
At the same time the PCM-DAI model draws up the number of shipping routes existing between *i* and each *j-th* port from a previously elaborated database.
The database contains information about all possible maritime connection between ports belonging to the same geographical area, represented by the Incidence Matrices. In the elaboration of these latter, only direct routes from one port to another were considered, assuming, therefore, that when a feeder ship stops in an intermediate

port, de facto it interrupts its journey. It will start another trip only after the end of the handling operations in that port. Given the long times and the complexity of the handling operations, the feeder ship could leave again in the successive days.

Thus, the interdependence of the maritime routes was hypothesized, even though they are in a hub and spoke system.

The Incidence Matrix is an origin/destination matrix type, which reports on the rows the origins and on the columns the destinations. The generic element of the matrix is a dummy variable that can assume the value 1 when there is a shipping line between *i* and *j*, and the value 0 otherwise.

Since in this study only the foreign maritime container trade is analyzed, the connections between ports belonging to the same Country are neglected. Therefore, in the Incidence Matrices, in addition to the values present on the primary diagonal, there are other null values; these are those referring to the case in which the origin and destination belong to the same Country.

Then, once known the *n* possible destinations, the model PCM-DAI extrapolates the vector $[r_{ij}]$ from the Incidence Matrices:

$$[r_{ij}] = \begin{bmatrix} r_{ii} \\ r_{ij_1} \\ r_{ij_2} \\ \vdots \\ r_{ij_n} \end{bmatrix} \qquad \text{with} \quad r_{ii} = 0; \quad \text{and} \qquad r_{ij} = \begin{cases} 0 \\ 1 \end{cases} \; i \neq j \, . \tag{4}$$

In this first phase, the PCM-DAI model elaborates other static variables, concerning the technical characteristics of the ports representing the *n* alternatives of choice. These regard the equipment dedicated to the accommodation of container ships and to the handling of their cargo, such as the number of cranes or berths container dedicated. The model draws up from another database the technical static data of each of the *n* ports and calculates the indicator $\tilde{\beta}_j$, representing the static rate of the $\tilde{\gamma}_j$ parameter.

The latter database consists of data recorded in the previous year and published on the websites of the Port Authorities. The $\tilde{\beta}_j$ indicator is expressed as a linear regression of the technical static characteristic of the *j-th* port; then:

$$\tilde{\beta}_j = f\ (FHc_j, AHc_j, Cc_j, Bc_j, Tc_j, SAc_j, Lc_j,\ DTc_j) \tag{5}$$

where:

FHc_j is the volume of handled container in the *j-th* port, expressed in tons;

AHc_j is the average handling container performance of the *j-th* port, expressed in TEU per square meter;

Cc_j is the number of quay cranes dedicated to handle the containers in the *j-th* port;

Bc_j, is the number of berths dedicated to the container ships in the *j-th* port;

Tc_j is the number of tugs owned by the *j-th* port, able to drive feeder ships in the maneuvers of entering the port and docking the berths;

SAc_j is the storage area container dedicated in the *j-th* port, expressed in hectares;

Lc_j is the number of labor unit employed in the container handling operations in the *j-th* port;

DTc_j is the average delay time recorded in the container handling operations in the *j-th* port, expressed in hours.

In this study a drastic change in the port's equipment from one year to the successive one is neglected; therefore, it was decided to take the technical characteristics of the ports of the previous year as valid.
Anyway, in order to take into account the uncertainty of some considered parameters, the $\tilde{\beta}_j$ indicator is a Fuzzy number.

In addition, with the aim to standardize the data and avoid errors due to the use of the measurement units, each of the variables present in the equation (5) is dimensionless and converted into a value between 0 and 1, according to the formula (6).

$$X_a = \frac{X_0 - X_{min}}{X_{max} - X_{min}} \qquad \text{with } X_a \in [0,1] \tag{6}$$

where:
X is the generic variable to dimensionless;
X_0 is the value assumed by the variable X;
X_{min} is the minimum value assumed by the variable X, among all alternatives considered;
X_{max} is the maximum value assumed by the variable X, among all alternatives considered;
X_a is the dimensionless value of the value X_0.

4.1.2 THE SECOND PHASE: THE DYNAMIC PARAMETERS

Depending on the forecast of the ship's arrival time in each of the indicated *n* ports, in the second phase, the PCM-DAI provides for the acquisition of the dynamic variables for each of these ports, in real-time using the data published on the *MarineTraffic* website, which take into account of the radar and GPS ships' signals.
In addiction the *MarineTraffic* website allows to have a complete vision of the situation in each port.
In fact, thanks to this, at the time of data acquisition, the model is able to calculate the $\tilde{\alpha}_j$ dynamic parameter, as linear regression of highly dynamic hour-by-hour variables on the basis of the number of ships in port, those departing and arriving, and the number of tugs employed in maneuvers with other container ships.
$\tilde{\alpha}_j$ is expressed as:

$$\tilde{\alpha}_j = f\left(fCc_j, fBc_j, fTc_j, SDc_j\right) \tag{7}$$

where:

fCc_j is the number of free quay cranes at the forecast time of the ship's arrival at the *j-th* port;

fBc_j is the number of free berths at the forecast time of the ship's arrival at the *j-th* port;

fTc_j is the number of free tugs at the forecast time of the ship's arrival at the *j-th* port;

SDc_j is the number of ships departing at the forecast time of the ship's arrival at the *j-th* port.

Also in this case, all variables are dimensionless according to the equation (6), and in order to take into account of their uncertainty, the $\tilde{\alpha}_j$ parameter is expressed as a Fuzzy number. It represents the dynamic rate of the $\tilde{\gamma}_j$ parameter.
Then it is possible to write the Fuzzy product, which allows to calculate the $\tilde{\gamma}_j$ parameter, including both static and dynamic port's characteristic.

$$\tilde{\gamma}_j = \tilde{\beta}_j \cdot \tilde{\alpha}_j \tag{8}$$

At the end, the last dynamic variables drew up by the model is the travel time from the GPS position (i_1), communicated en-route by the maritime company at the moment of the planning of the new itinerary, to each possible destination port *j-th* selected. This parameter is dimensionless according the equation (6).
Furthermore, $\tilde{T}_{i_1 j}$ is highly affected by uncertainty, because it depends not only on the net travel time, but also on the weather conditions, on the forecast of the waiting time to access to the port, which depends in turn on the availability that the port has to accommodate an unplanned feeder ship, and mostly on the perception that the

ship-owner has of these factors. In addition, some disturbances in communication could occur. For all these reasons, also $\tilde{T}_{i_1 j}$ is expressed as a triangular Fuzzy number.

In accordance to the classical gravitational model and that proposed by Campos et al (2013), in this research, the $\tilde{T}_{i_1 j}$ variable follows an exponential type law, according to the λ coefficient, which allows conveying the estimated travel time as a function of the traffic conditions, while not knowing in numerical terms the traffic component present on the possible routes.

This coefficient can range in the interval from 1 to 4; the value 1 indicates a low traffic condition, while the value 4 represents a high traffic condition, close to traffic congestion (Campos et al, 2013; Sinesi et al, 2017).

In the first case, the time necessary for the freight transport from the port *i* to the port *j-th* is low and it may mainly depend on weather and sea conditions.

Instead, in the second case, the existence of a congested traffic situation, due to a large number of ships reaching simultaneously to the same *j-th* port, produce an increase of the perceived travel time, which may not only depend on natural conditions, but also on requirement to wait for entry in the port and to make the maneuvers greater safety.

Moreover, if the *j-th* port is not sufficiently performing in terms of container handled per hour, the congestion could occur also inside the container terminal itself, generating additional delay times for the successive handling operations.

In conclusion, considering (2), (4), (8) it is possible to rewrite the equation (1) as follow:

$$\tilde{A}_j = \frac{Lc_{ij_{imp}} + Lc_{ij_{exp}}}{\sum_{j=1}^{n} Lc_{ij_{imp}} + Lc_{ij_{exp}}} \cdot \left[r_{ij}\right] \cdot \frac{\tilde{\beta}_j \cdot \tilde{\alpha}_j}{\tilde{T}_{i_1 j}^{\lambda}} \tag{9}$$

The algorithm (9) represents the DAI performed by the proposed model.

The innovations introduced by the model proposed in this study, compared to the previous attempt published by Sinesi et., concern:

- The substitution of the GDP parameter with a parameter that more specifically expresses the exchange of containers by sea between the countries of origin and destination, Lc_{ij} ;
- The substitution of the crisp number about the possible routes between *i* and *j*, with the linear vector $[r_{ij}]$;
- The elaboration of the Incidence Matrices intended as the database from which to extract the linear vector $[r_{ij}]$;
- Having considered the time variable as inclusive of the waiting time for access to the port and the approach to the dock, and not dependent on subsequent handling operations.

4.1.3 THE OUTPUT OF THE PCM-DAI

As explained in the previous paragraphs, often the destination port initially established for a feeder ship, does not coincide with the one really reached at the end of its journey.

Owing to the need to re-plan the itinerary to be run, the decision-maker, in the guise of the shipping company and/or the ship-owner, has to evaluate a set of alternatives and choose which port reaching, in order to minimize the time and costs of both travel and handling.

Then, the decision-maker will indicate n candidate ports as destinations that would like to reach, and the relative estimated travel time between the current position and each destination.

Starting from these inputs, the proposed model is able to extrapolate the necessary data from the databases mentioned in the previous paragraphs, distinguishing the static and dynamic variables. It processes these data and converts them in Fuzzy number, in order to take into account the uncertainty of some data, or possible errors made by companies in data communication.

The model calculates the dynamic accessibility indicator for each of the alternatives ports of destination indicated by the decision maker.

Subsequently, it performs the ranking of destination ports "closer" to the decision-maker requirements, on the basis of their dynamic accessibility indicator and represents the DAIs as Fuzzy triangles.

This latter represents the port accessibility as perceived by the decision-maker.

In this case, the intersection between two Fuzzy triangles represents the possibility that the perceived accessibility of a port is higher/lower than the other.

To pass from the obtained possibility measure to a choice probability measure, the PCM-DAI model uses the methodology proposed by Geer and Klir (1992).

Their methodology deals with transformations from probabilistic formalizations of uncertainty into their possibilistic counterparts that contain the same amount of uncertainty and, consequently, the same amount of information, expressed as a reduction of uncertainty (Geer and Klir, 1992).

Furthermore, the mathematical properties of the transformations are analyzed the assumption that probabilities and possibilities are connected via interval or log-interval scales.

After applying this mathematical transformation, at the end, as a further output of the PCM-DAI model is the ranking according to the obtained probabilities for each considered destination port *j-th* about the perceived accessibility.

Therefore, the proposed model can be a useful decision support tool for maritime agents who have to change their route during the trip.

The PCM-DAI can also be applied by a shipping company in the evaluation of the new shipping lines or agreements with other companies. In this case, the decision-maker will indicate the port of origin, through its GPS position, the n ports that it intends to evaluate as destinations, and the estimated time of travel from the origin to each of the selected destinations. In this case, the PCM-DAI works as a simulator. In other words, in order to evaluate the outputs of the model in different conditions, the decision-maker can interrogate the model by entering the inputs several times during a

time period defined; the different model outputs may be intended as "suggestions" for the final choice.
The PCM-DAI was tested to three cases of study, varying both the origin and destination ports and the period of application. In the follow chapter these are presented.

CHAPTER 5
NUMERICAL APPLICATIONS OF THE PCM-DAI

In this research, using the real data coming from GPS sources and the described above databases, the proposed model was applied in three different cases, with the aim to evaluate its performance in predict, en-route, the maritime agents' choices of the destination ports.

The three numerical applications differ for the time intervals of drawing the real data, for the selected ports as origins and destinations, and for the geographic areas investigated.

The three cases of study in more detail in the following paragraphs are described.

5.1 FIRST PCM-DAI NUMERICAL APPLICATION

The first numerical application of the model was realized considering the same study case proposed by Sinesi et. al (2017).

In fact, also in this case, the Mediterranean area was investigated, considering the Marsaxlokk Port in Malta as the origin port *i*, from which feeder ships leave to a destination port *j-th*.

In this case, only three possible destination ports are considered, which are located in different countries but along the same coast as Figure 5.1 shows, and are connected by a very efficient inland transport network. The selected possible ports as destinations are both overlooking the Mediterranean Sea, and are the following:

- j_1 is the Genoa port (Italy);
- j_2 is the Barcelona port (Spain);
- j_3 is the Marseilles port (France).

In Malta Island, the main maritime activities are carried out around the two main ports of the Country: the Valletta Port and the Marsaxlokk Port, leaving the landing of mainly tourist boats to the other smaller ports.
The commercial port is the Port of Marsaxlokk consisting of a container terminal and industrial storage complexes, managed by Malta Freeport Terminals; the container terminal is also well connected to the main national facilities for the production of energy, managed by EneMalta Corporation, that is a public company responsible for the supply of energy and import of oil.
Although the Island does not export and import large volumes of ware in comparison to other countries in the Mediterranean area, these its characteristics make its commercial port a coveted hub port.
In fact, the geographical position of Malta, at the center of the Mediterranean Sea and of the main lines of maritime connection between Europe, North Africa, and the Middle East, allows the whole archipelago to have a facilitated access to the Mediterranean trades and not only.

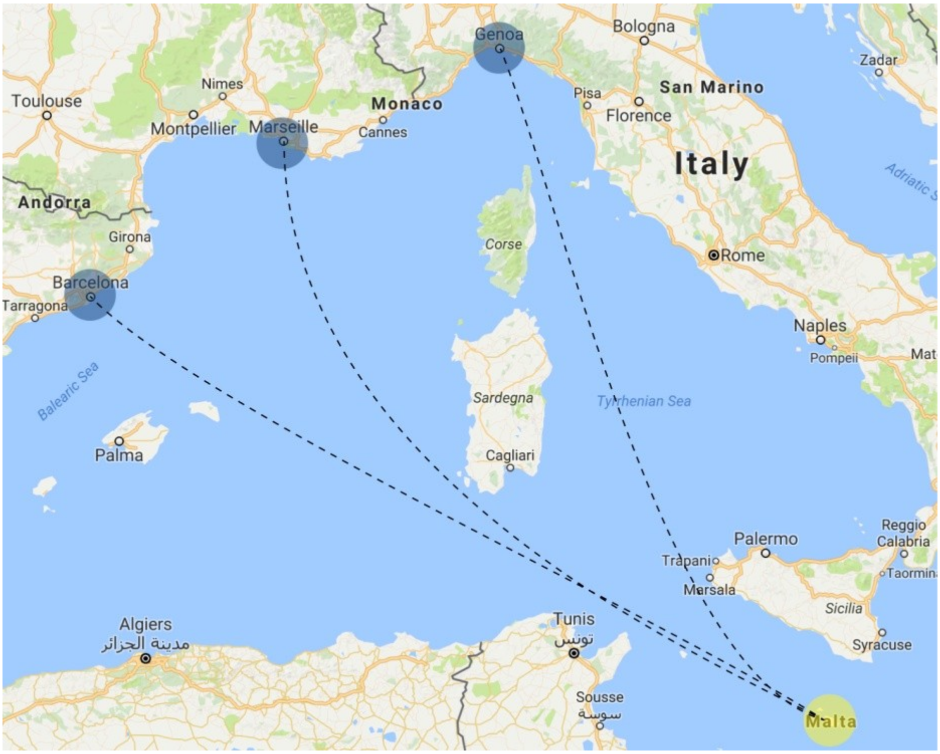


Figure 5.1 - Route Map from the considered orgin port (Malta) to the three destination ports (Genoa, Barcelona, Marseilles).

The following table 5.1 shows the distances from the Marsaxlokk Port to the ports selected in this application as destination, expressed in nautical miles.

i	**Marsaxlokk Port** (Malta)			
j_1	**Genoa Port**	(Italy)	571,36	nM
j_2	**Barcelona Port**	(Spain)	664,76	nM
j_3	**Marseilles Port**	(France)	613,77	nM

Table 5.1- Distance in nautical from the considered orgin port (Malta) to the three destination ports (Genoa, Barcelona, Marseilles).
Source: https://www.nauticando.net/servizi-per-la-navigazione/navigazione-waypoint/

In this first application of the PCM-DAI, the container maritime traffic in a time interval of one week was observed. In particular, the hour-by-hour acquisition of data regards the third week of March 2017, from the day 13th to the day 19th.

Once the port of origin *i* and the *n* possible destinations are known, the system has acquired the informations necessary for the application of the PCM-DAI algorithm, in the mentioned time interval, using the databases described in the previous paragraphs.

The first extrapolated data are of the static type and in particular concern the volume of containers that Malta Island has exchanged with Italy, France, and Spain, by the sea in the previous year (2016).

Table 5.2 shows the data, expressed in Millions of dollars.

i		**Marsaxlokk Port** (Malta)	
		$Lc_{ij_{imp}}$	$Lc_{ij_{exp}}$
j_1	**Italy**	1,417 M$	0,384647 M$
j_2	**Spain**	0,2398 M$	0,103338 M$
j_3	**France**	0,3379 M$	0,281309 M$

Table 5.2- Volume of container imported and exported from/to Malta to/from Italy, Spain, and France, via sea, in the 2016.

Source: The Observatory of Economic Complexity (OEC).

The data reported in Table 5.2 are useful to apply the formula (2).

Then, the vector of connections between the origin and the three destination (4), drew up from the Connections Matrices; it is as follow:

$$[r_{ij}] = \begin{bmatrix} r_{ii} \\ r_{ij_1} \\ r_{ij_2} \\ \vdots \\ r_{ij_n} \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \\ 1 \\ 1 \end{bmatrix} \tag{10}$$

In this case, since the origin port and the destination don't belong to the same Country, in accordance with the initial hypotheses, the linear vector $[r_{ij}]$ contains all element equal to 1, except for one, for which origin and destination overlap.
Instead, the parameters concerning the technical characteristics of the ports, referred to the previous year (2016), extrapolated from the websites of the three Port Authorities examined, are shown in the following Table 5.3.

	j-th Port	FHc_j *(ton)*	AHc_j *(TEU/ mq)*	Cc_j	Bc_j	Tc_j	SAc_j *(ha)*	Lc_j	DTc_j *(h)*
j_1	**Genoa** (Italy)	47.880.945	20,6	62	60	35	700	3200	0,7
j_2	**Barcelona** (Spain)	41.793.734	22,2	126	40	42	828	820	0,8
j_3	**Marseilles** (France)	86.000.000	20	10	33	16	262	1500	3,7

Table 5.3- Technical characteristic of the destination port considered, in the 2016.
Source: The Port Authorities.

The data indicated in Table 5.3, dimensionless according the formula (6) are the input for the linear regression (5) of the technical static characteristic of the three ports. Moreover, the results of the (5) was converted in a Fuzzy number, in order to take into account the uncertainty of some considered parameters.
Furthermore, the dynamic variables related to destination ports was drawn up using data coming from the *MarineTraffic* website for each day of the monitoring week, 24 hours per day. The real-time data exported from the database of the mentioned website are elaborated, in order to obtain the data useful to the PCM-DAI model application. For example in table 5.4 are shown the data obtained at 12 a.m. of the Monday 13th March 2017, the first day of the monitoring period.

		fCc_j	fBc_j	fTc_j	SDc_j
j_1	**Genoa** (Italy)	51	38	10	11
j_2	**Barcelona** (Spain)	115	18	23	11
j_3	**Marseilles** (France)	3	20	13	6

Table 5.4- Dynamic parameters of the destination port considered, obtained at 12 a.m. of the Monday 13th March 2017.
Source: Elaboration of data coming from MarineTraffiche website.

In this way, the model calculated the $\tilde{\alpha}_j$ values hour-by-hour as linear regression of dynamic variables for whole the observed period, applying the linear regression (7) after having dimensionless all variables according to the formula (6). Due to the uncertainty of the values, also $\tilde{\alpha}_j$ was fuzzified using triangular membership functions. Thus, $\tilde{\gamma}_j$ value is obtained through the fuzzy product according to (8).

Another input of the proposed model is the travel time $\tilde{T}_{i_1 j}$ estimated by the maritime company both before and during the travel, according to the chosen route. In the considered case, the travel time has been obtained using the GPS and radar signals sent by ships during the travel, acquired by the *MarineTraffic* website and available on its database.

In order to take into account the variability in the ship-owners perception of travel time, the change of the weather conditions, or possible errors in data communication, the model converts the travel time value in a triangular Fuzzy number.

Furthermore, the exponential time parameter λ indicating the variability of travel time according to the traffic conditions is set equal to 2, in order to indicate normal traffic conditions.

Thus, acquired all input data, both having low and high dynamicity, the PCM-DAI model returns the values of the dynamic accessibility indicator (DAI), for each destination port according to equation (9); the results are expressed in term of triangular fuzzy numbers.

As an example, the results refer to the first day of the observed week, at 12 a.m., is shown in Figure 5.2. and the numerical value of the DAI calculated are annotated in Table 5.5 as the ranking of the fuzzy value.

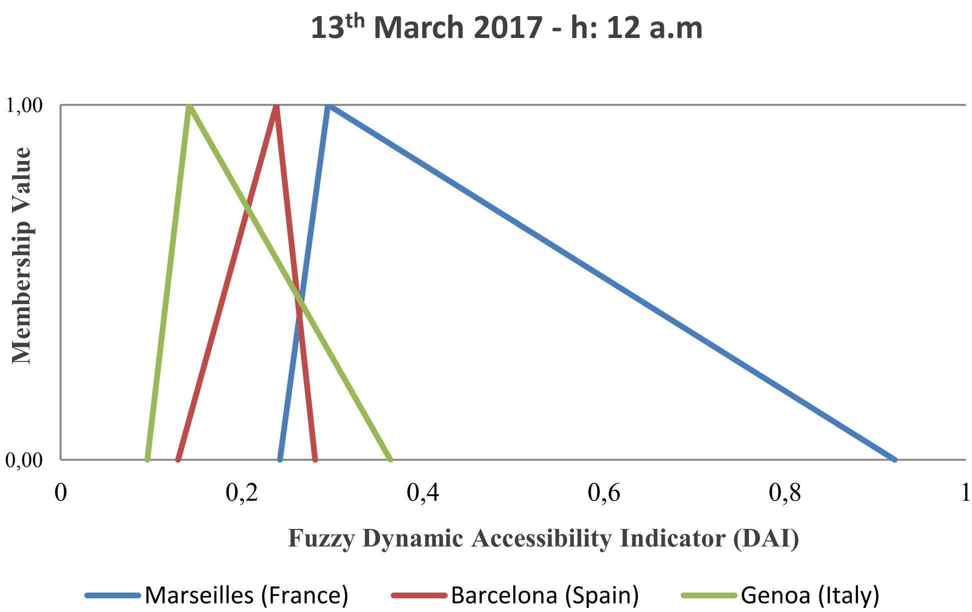


Figure 5.2- DAIs of the destination ports on 13th March 2017 at 12 a.m.

Origin Port		***Destination Ports***	$A_{j\,min}$	A_j	$A_{j\,max}$
Marsaxlokk (Malta)	j_1	***Marseilles*** *(France)*	0,242273014	0,29537474	0,921680576
	j_2	***Barcelona*** *(Spain)*	0,129655095	0,238180777	0,281018797
	j_3	***Genoa*** *(Italy)*	0,095750715	0,141610693	0,364264977

Table 5.5- Values of DAIs as fuzzy numbers of the destination ports on 13th March 2017 at 12 a.m.

Then, as explained in the previous chapter, the intersection between two Fuzzy triangles represents the possibility that the perceived accessibility of a port is higher/lower than the other.

From the Figure 5.2 is noticeable the three triangles, representing the DAI for the ports in exam, intersect almost in the same point; this means that, in this case, the accessibility of these three ports can be perceived more or less in the same way by the ship-owners who plan to arrive at the destination at that moment.

Then, the PCM-DAI model processes the obtained DAI as Fuzzy numbers and calculates the intersections.

In the specific case taken as an example and shown in the Figure 5.2, calculating the intersection between the blue and green triangles, i.e. the possibility that the accessibility of the Marseilles Port is perceived higher than that of the Genoa Port, the value 0.442391 is obtained. Instead, calculating the possibility that the accessibility of the Marseilles Port is perceived higher than that of the Barcelona port (blue and red triangles), the value 0.403855 is obtained. Finally, calculating the possibility that the accessibility of the Barcelona port is perceived higher than that of the Genoa Port (red and green triangles), the value 0.708406 is obtained.

The values thus obtained are further processed by the model, applying the method proposed by Geer and Klir (1992) to pass from the measure of possibility to the probability measure, taking into account the same uncertainty of the original data, as indicated by the authors of the method.

Table 5.6 shows the graphical interface about the status of the model at the time of transformation from the measure of possibility (p) to measure of probability (P). As can be observed in the following table, for each destination port, in the first row are shown the values of the intersections between fuzzy numbers previously calculated as measures of possibility.

		Genoa (Italy)	Barce-lona (Spain)	Marseil-les (France)	γ	U	H	P_{min}	P_{max}
Marseilles (France)	**p**	0,442391	0,40385		26,7851	0,4038	0,4024	0,0800	0,9199
	P	0,919910	0,08009						
Barcelona (Spain)	**p**	0,708406		0,40385	4,33211	0,4038	0,4042	0,0805	0,9194
	P	0,919419		0,08058					
Genoa (Italy)	**p**		0,70840	0,44239	4,86720	0,4423	0,4425	0,0918	0,9081
	P		0,90817	0,09182					

Table 5.6 – Application of the Geer and Klir method on 13th March 2017 at 12 a.m.

in which P, U, and H are expressed by Geer and Klir as:

$$P_j = \frac{p_j^{\gamma}}{\sum_{j=1}^{n} p_j^{\gamma}} \tag{11}$$

$$U = \sum_{j=1}^{n-1}(p_j - p_{j+1}) \cdot log_2 \left(\frac{j}{n} \cdot (1-\gamma)^{-1}\right) \tag{12}$$

$$H = -\sum_{j=1}^{n} P_j \cdot log_2 (P_j) \tag{13}$$

In this case *j* can assume integer value between 1 and 3, being three the destination ports considered as possible destinations.
Then, the system, through successive iterations of the value of γ, is able to calculate the values of the Probabilities (P_j) for each port, respecting the following constraint:

$$U = H \tag{14}$$

The minimum probability that the accessibility of the *j-th* port is perceived superior to that of all other ports contained in the set of choices is calculated with the (14):

$$P_{j\,min}^{PCM-DAI} = \frac{P_{j\,min}}{\sum_{j=1}^{n} P_{j\,min}} \tag{15}$$

Then, the final output of the PCM-DAI model proposed, applied in midday of the first day of the monitoring period, is the ranking according to the obtained Probabilities for each considered destination port *j-th* about the perceived accessibility; for the specific hour and day is shown in the following Table 5.7.

	$P_{j\,min}^{PCM-DAI}$
Genoa *(Italy)*	36,37%
Barcelona *(Spain)*	31,91%
Marseilles *(France)*	31,72%

Table 5.7 – PCM-DAI model output on 13th March 2017 at 12 a.m.

The final output is expressed in term of minimum percentage probability that the accessibility of a port is perceived superior than all others by the ship-owners, who left from the Marsaxlokk Port some days before, en-route have re-planned the itinerary setting both Genoa, Barcelona, and Marseilles as possible destination ports which would like to reach, and indicated their arrival time more or less at the same time of model rendering.

To verify the reliability of the model choice prediction, also the real ship-owners' choice ware valued.

In fact, in the first column of the table 5.8 are reported the PCM-DAI outputs, while the last column indicates the real choice percentage come from the elaboration of the *MarineTraffic* database regarding the ship-owners' arrival in each of the considered ports. In particular is reported the number of ships, as a percentage, that leaving from the Marsaxlokk Port have initially called one of the three considered ports and subsequently, during the trip have deleted the previous port call and formulated a new one, in favor of another of these same ports; the ships considered were those that arrived at the final destination at the same time of model running.

			PCM-DAI output Probability $(P_{j\,min}^{PCM-DAI})$	Real choice data
j_1	**Genoa**	(Italy)	36,37 %	37,80 %
j_2	**Barcelona**	(Spain)	31,91 %	31,85 %
j_3	**Marseilles**	(France)	31,72 %	30,35 %

Table 5.8 - PCM-DAI output on 13th March 2017 at 12 a.m., compared with real choice data.

As can be observe from the table, the initial hypothesis that the possibility that the accessibility of the three ports could be perceived more or less in the same measure by the ship-owners, is confirmed even after the transformation in probability measure; but especially for this specific case, it is also confirmed by the real data of choice.
The PCM-DAI model has ran at every hour of the monitoring week and, for each hour, a comparison with the real data was processed.
However, being the maritime traffic dominated by very long times, both about travel time and handling operation in port, often the PCM-DAI outputs, and also the real berthing data, remain unchanged for more consecutive hours, and sometimes during the whole day.
For this reason, both the model's outputs and the real daily choice percentage were expressed as the average of the daily values carried out hour-by-hour.
In the following Table 5.9 the model outputs are compared with the real choice percentage day-by-day for the whole week of monitoring.

	Genoa (Italy)		**Barcelona (Spain)**		**Marseilles (France)**	
March 2017	**PCM-DAI output Probability**	**Real choice data**	**PCM-DAI output Probability**	**Real choice data**	**PCM-DAI output Probability**	**Real choice data**
13	33,97%	33,33%	33,98%	33,33%	32,05%	33,33%
14	35,77%	37,80%	32,37%	33,85%	31,87%	28,35%
15	53,12%	51,25%	23,57%	26,50%	23,31%	22,25%

16	100,00%	97,00%	0,00%	2,70%	0,00%	0,30%
17	100,00%	98,00%	0,00%	1,87%	0,00%	0,13%
18	21,86%	24,00%	39,01%	37,50%	39,13%	38,50%
19	31,21%	30,30%	31,16%	30,20%	37,62%	39,50%

Table 5.9 - PCM-DAI output for the third week of March 2017, compared with real choice data.

To apply of the PCM-DAI model, an ad hoc calculation system has been created for the case study, capable of capturing hourly all the necessary inputs, obtaining the outputs, comparing them with real data and processing a daily average of both.

In order to have a more immediate parallel knowledge about the PCM-DAI daily output and the daily real data, at the end of the monitoring period, a further output of the system is the graphical representation of the daily data obtained from the model and that of the real data on the same radar chart, for each destination port, as shown in the following figures 5.3, 5.4, 5.5.

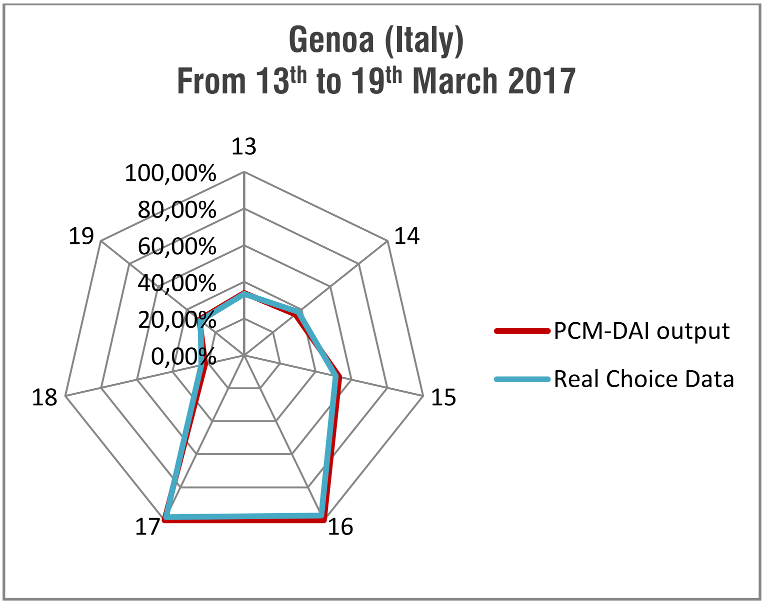


Figure 5.3- Comparison between PCM-DAI daily output and the daily real choice data, in the third week of March 2017, for the Genoa Port.

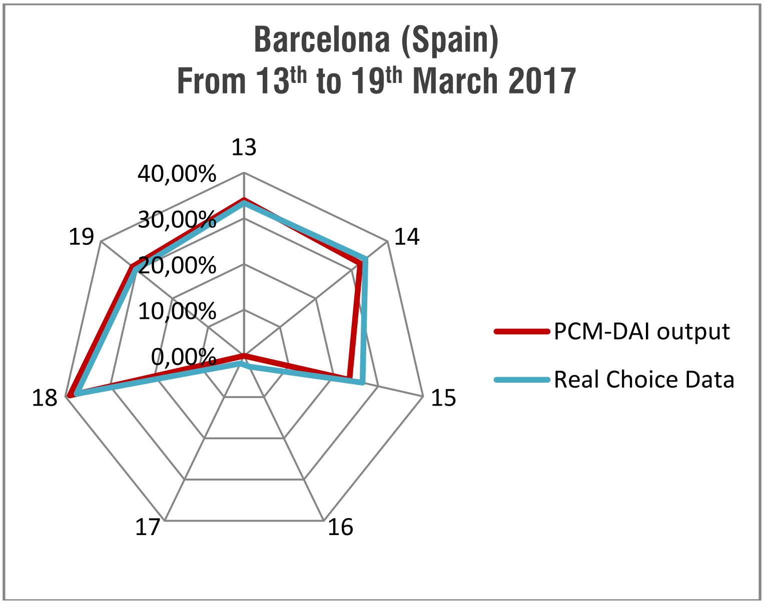


Figure 5.4- Comparison between PCM-DAI daily output and the daily real choice data, in the third week of March 2017, for the Barcelona Port

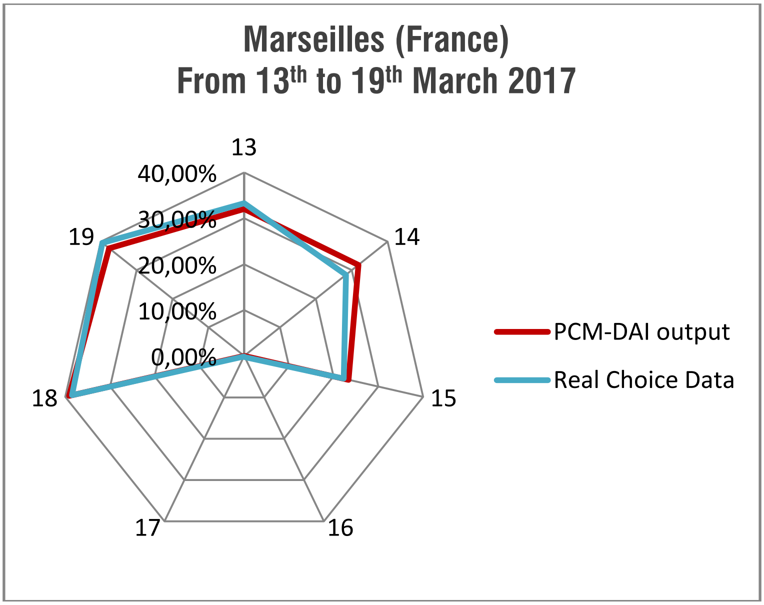


Figure 5.5- Comparison between PCM-DAI daily output and the daily real choice data, in the third week of March 2017, for the Marseilles Port.

From the figures 5.3, 5.4, 5.5, it is immediately clear that the PCM-DAI model, in this first application is able to predict with good approximation the choices of the decision-makers.
Moreover is evident the high level of competitiveness among this three port in that time interval.
However, the time interval of ports' monitoring considered in this first case of study is quite short for the maritime transport system. For this reason, this first case represents a preliminary attempt of the PCM-DAI model application, which was improved in the second case of study, taking into account a longer observation interval, as well as, a greater number of destination ports in the third one.

5.2 SECOND PCM-DAI NUMERICAL APPLICATION

The second numerical application was also in the same area, examining the same origin and destination ports of the previous case of study, but the model was applied for a longer period and then a longer monitoring was performed; more precisely, it refers to the whole month of April 2017.
Thence, all parameters defined as static parameters by the model, showing low variability, assume the same values of those considered in the first case of study, since they refer to the same year 2016. It means that the data indicate in Tables 5.2 and 5.3 are also some among the input for this second application.
Instead, regarding the acquisition of dynamic parameters, the same procedure explained in the previous paragraph was performed. Moreover, the same calculation system set for the previous case of study was also applied in this second case.
As an example, in the Table 5.10 the PCM-DAI model outputs are compared with the real choice percentage day-by-day for first seven days of April 2017, extracted from Table A1, in Appendix A.
For the same reason explained in the previous paragraph, both the model’s outputs and the real daily choice percentage were expressed as the average of the daily values carried out hour-by-hour.

The Figures 5.6, 5.7,5.8 show the graphical representation of the daily data obtained from the model and that of the real choice data on the same radar chart for each port considered in whole month of April 2017.

	Genoa (Italy)		**Barcelona (Spain)**		**Marseilles (France)**	
April 2017	***PCM-DAI output Probability***	***Real choice data***	***PCM-DAI output Probability***	***Real choice data***	***PCM-DAI output Probability***	***Real choice data***
1	36,08 %	40,00%	27,83%	20,00%	36,08%	40,00%
2	39,58 %	42,85%	20,75%	14,29%	39,66%	42,86%
3	41,66 %	42,85%	16,66%	14,29%	41,68%	42,86%
4	41,46 %	40,00%	17,05%	20,00%	41,49%	40,00%
5	27,68 %	33,33 %	36,16%	33,33%	36,15%	33,33%
6	40,33 %	37,5 %	19,37%	25,00%	40,30%	37,50%
7	38,61 %	40,00%	22,73%	20,00%	38,66%	40,00%

Table 5.10 - PCM-DAI output for the first seven days of April 2017, compared with real choice data, extracted from Table A1, in Appendix A.

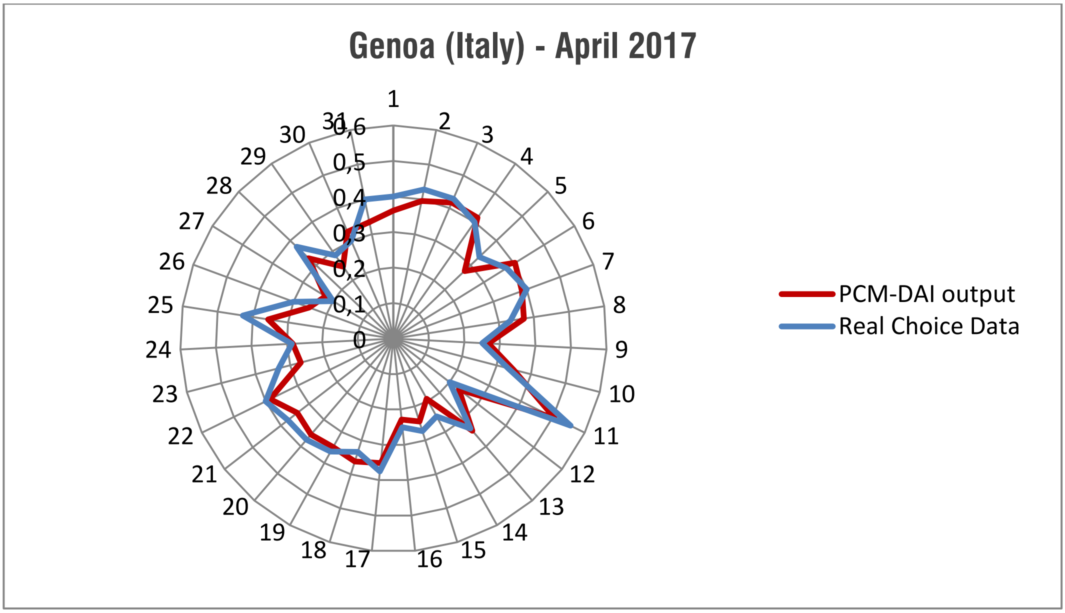


Figure 5.6- Comparison between PCM-DAI daily output and the daily real choice data, in the month of April 2017, for the Genoa Port.

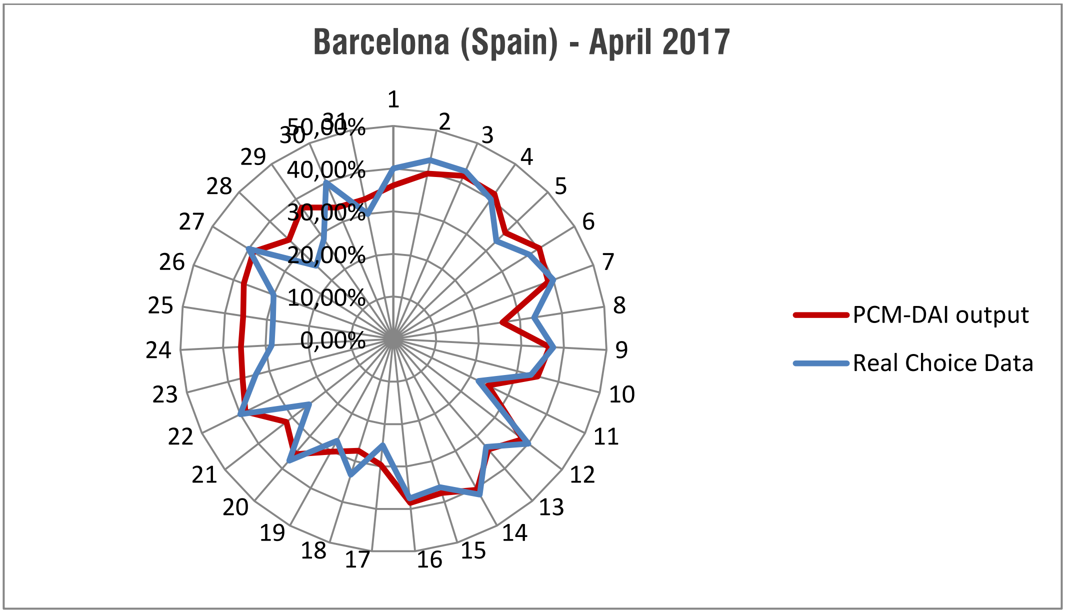


Figure 5.7- Comparison between PCM-DAI daily output and the daily real choice data, in the month of April 2017, for the Barcelona Port.

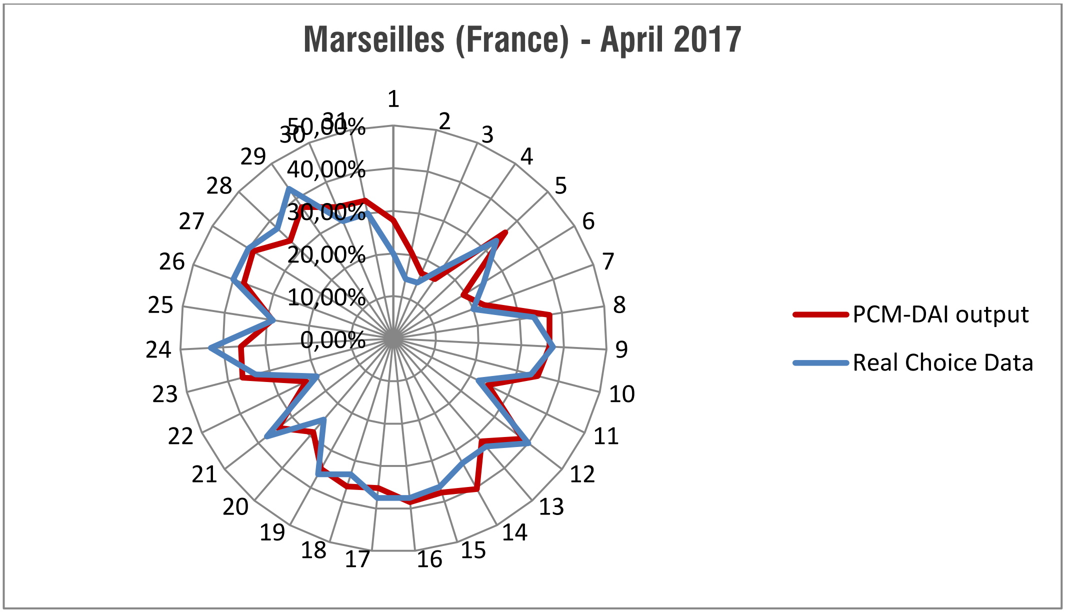


Figure 5.8- Comparison between PCM-DAI daily output and the daily real choice data, in the month of April 2017, for the Marseilles Port

As can be observed from the previous charts, even during the month of April 2017, a considerable intensity of the phenomenon about the re-plan of the route was found, which showed a daily frequency.

However, also in this second period of monitoring, is confirmed a high level of competitiveness among the ports considered as possible destinations.

Elaborating the real daily data related to the arrivals in the three considered ports of the ships that initially called a port, and subsequently deleted the previous call to reschedule the route, it was found that:

- in 7% of cases the port of Genoa is preferred;
- in 7% of cases the port of Barcelona is preferred;
- in 10% of cases the port of Marseilles is preferred;
- in 17% of cases the percentage of choice of the port of Genoa is equal to that of Marseilles;

- in 37% of cases, the percentage of choice of the port of Genoa is equal to that of Barcelona;
- in 23% of cases the percentage of choice of the port of Barcelona is equal to that of Marseilles;
- in 20% of cases the percentage of choice is the same for all three ports.

The PCM-DAI outputs, even if affected by errors, also reflect the real competitiveness between the destinations examined. In fact, analyzing the values carried out from the model, it results that:

- in 27% of cases the port of Genoa is preferred;
- in 40% of cases the port of Barcelona is preferred;
- in 30% of cases the port of Marseilles is preferred;
- in 3% of cases the percentage of choice of the port of Genoa is equal to that of Barcelona.

However, although it seems that the PCM-DAI model gives good results over a longer period, it remains to be considered the case in which the ship-owners can decide the final destination of the trip between a number of ports greater than three, and the case in which these do not locate along the same coast, but in the same geographical area. According to these hypotheses, it makes sense to include in the set of choice also ports placed on islands.
In this regard, based on these hypotheses, a third numerical application was elaborated, which is discussed in detail in the next paragraph.

5.3 THIRD PCM-DAI NUMERICAL APPLICATION

The third case study aims to test the model's abilities considering a wider set of choices. In particular, it was considered the case in which the ship-owner who must call a destination port, different from the one planned at departure, can decide to reach a port that is not along the same coast of the port initially called.

The need to test the model in this situation arose during the ships' monitoring in the two previous applications, in which several cases were detected; the situation that often presented was of a ship initially headed for port, but at the end of the journey it docked in another port located on the opposite coast, or even on an island.

Receiving notifications in real time by the *MarineTraffic* website, it was possible to have a complete knowledge of the different cases that can happen. For example, the following images show the notifications analyzed by the system in the previous monitoring period.

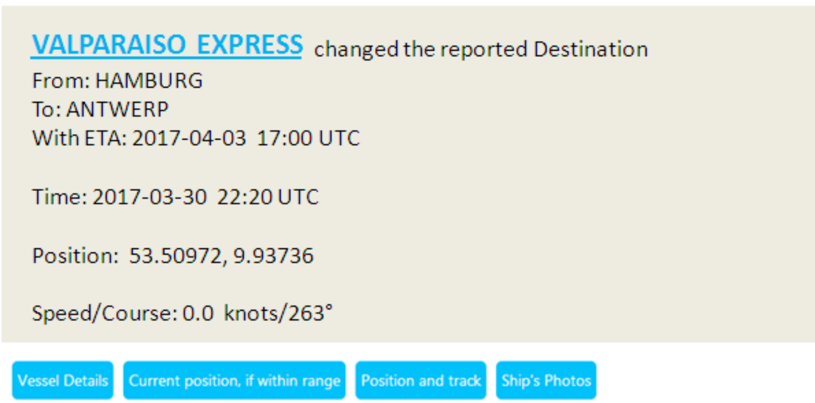


Figure 5.9 - Example of the *MarineTraffic* notification acquired by the model.

In the case shown in figure 5.9 the vessel VALPARAISO EXPRESS initially planned its arrival at the port of Hamburg (Germany), but on March 30th 2017, at 22:20 it deletes this call and changes its itinerary in favor of the Antwerp Port (Belgium) where it foresees arrive on April 3rd 2017 at 5.00pm.

In addition to the estimated time of arrival, the notification (figure 5.9) shows the current coordinates of the vessel at the time of communication, its current navigation speed and the direction. In this case, the ship has modified the destination in favor of another port along the same coast, belonging to a neighboring Country.

Figure 5.10 - Geographical location of the ports of Hamburg and Antwerp.

Instead, on April 1st, 2017, at 2:24 am, the ship BRO ALMA (Figure 5.11) cancels the call to the port of Immingham (England) and plans to dock in Antwerp Port (Belgium) at 22:01 of the same day. In this case the ship-owner has chosen to reach a destination port not located along the same coast and belonging to a non-neighboring Country; however, the two ports are located in the same geographical area.

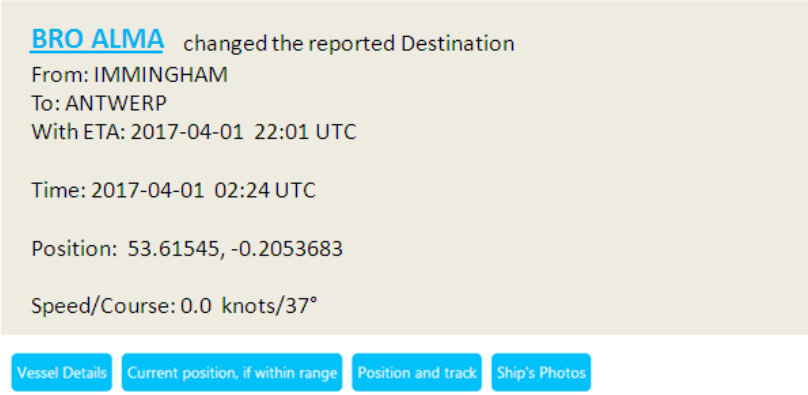


Figure 5.11 - Example of the *MarineTraffic* notification acquired by the model.

Figure 5.12 - Geographical location of the ports of Immingham and Antwerp.

Another example of a notification is shown in Figure 5.13 reporting the route change of the CRUISE SMERALDA, that was due to arrive in Savona (Italy) and call to Barcelona Port (Spain), where it expects to arrive about 15 hours after changing the port call.

Also in this case, the ports interested by the route change do not belong to neighboring Countries, but to the same geographical area, the Mediterranean Sea.

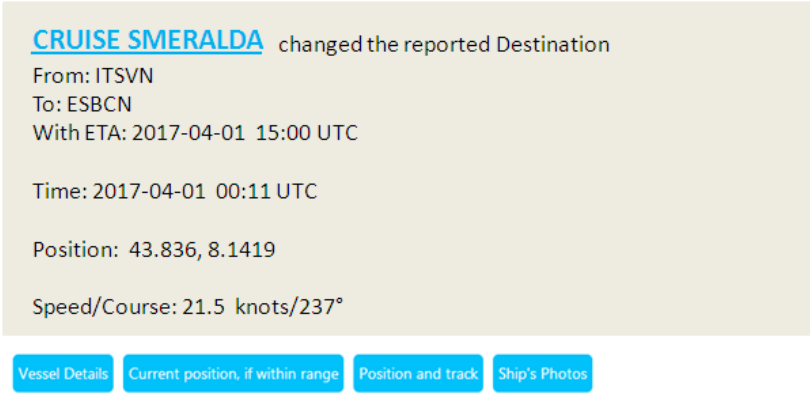


Figure 5.13 - Example of the *MarineTraffic* notification acquired by the model.

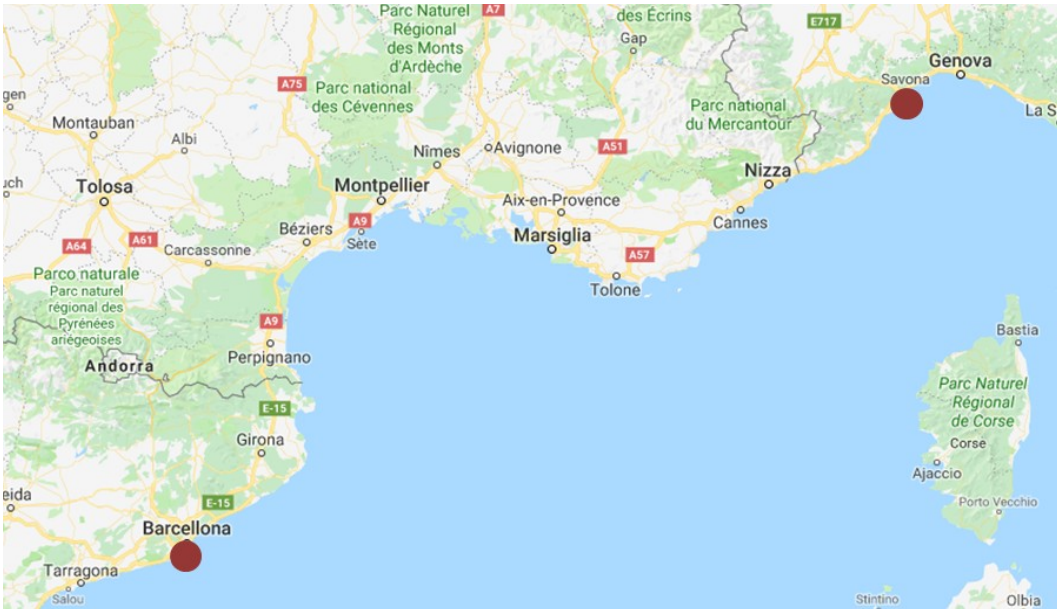


Figure 5.14 - Geographical location of the ports of Savona and Barcelona.

Another similar case occurred on 30th April 2017 at 11:48, when the ship MUSTAFA DAYI (Figure 5.15) that had planned its arrival at the port of Alianga (Smyrna, Turkey), chose the port of Algeciras (Spain) as the final destination of the trip, where will arrive the following day at 17:00.

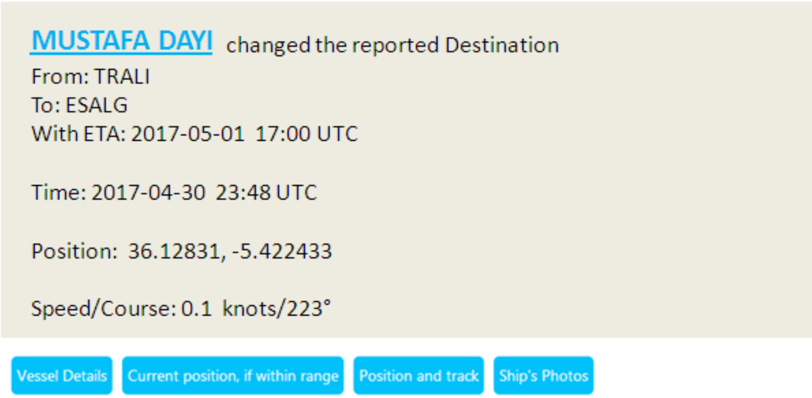


Figure 5.15 - Example of the *MarineTraffic* notification acquired by the model.

Figure 5.16 - Geographical location of the ports of Algeciras and Alianga.

There was also the case in which the ship has changed the route in favor of a port located on the opposite coast, therefore belonging to a different geographical area, as shown in figure 5.17 in which the vessel VIVIEN A, instead of arriving at the port of Algeciras (Spain), has completed the trip to the port of Antwerp (Belgium).

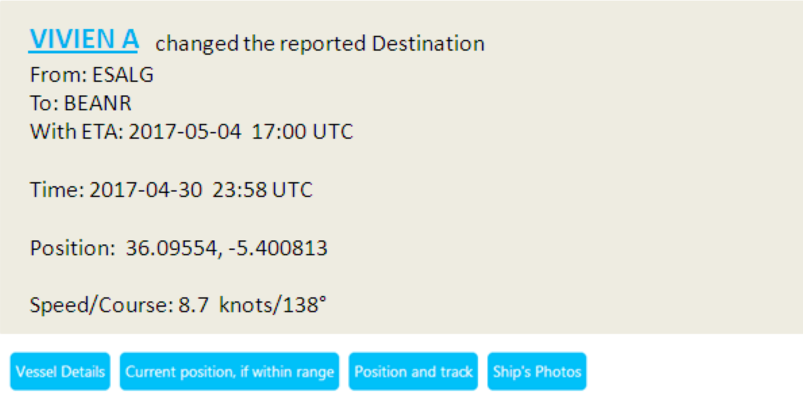


Figure 5.17 - Example of the *MarineTraffic* notification acquired by the model.

Figure 5.18 - Geographical location of the ports of Algeciras and Antwerp.

The last case is that shown in figure 5.19 in which the ports interested by the change of route are carried out belong to the same State, Spain, but one of them is located on an island, Palma de Mallorca.

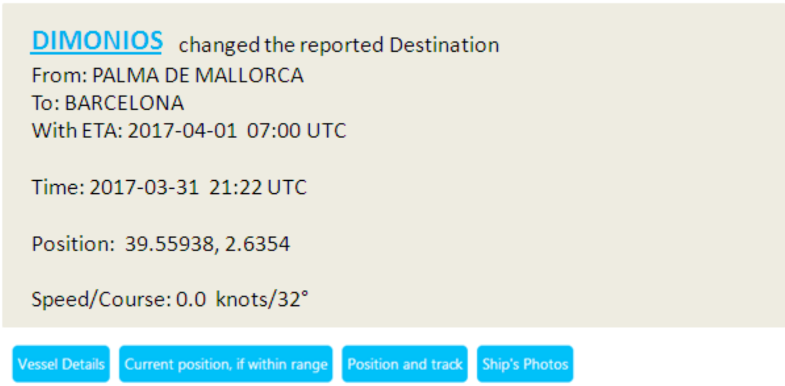


Figure 5.19 - Example of the *MarineTraffic* notification acquired by the model.

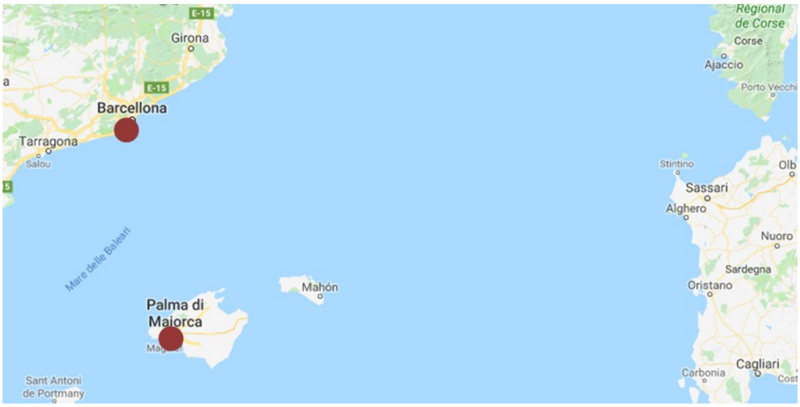


Figure 5.20 - Geographical location of the ports of Barcelona and Palma De Mallorca.

As can observe from the previous examples, the cases could be very diversified. For this reason, unlike the hypotheses respected in the two previous numerical applications, in this third application, the hypotheses have been considered that the maritime company, during the re-planning of the route, can choose the final destination between:

• Ports belonging to the same country or not;
• Ports belonging to neighboring countries;
• Ports belonging to countries not neighboring but belonging to the same geographical area;
• Ports located along the same coast and not;
• Ports located on islands.

Instead, the possibility that a ship leaving from a port can reach another one in the same Country, was neglected.
In light of this, it was decided to analyze the major European freight ports. In order to understand which of these are the main actors in the European scenario of container trade, the volume of containerized ware handled by each of them in 2016 was analyzed.
In this regard, the data sources consulted are the websites of the Port Authorities.
Through a *Cumulative Function* of a handled containers volume indicator in 2016 in each European port (Figure 5.21), it was verified that 90% of the container volume is managed by 15 European ports; these ports are shown in table 5.11.

1	Rotterdam (Nederlands)
2	Antwerp (Belgium)
3	Hamburg (Germany)
4	Marseilles(France)
5	Bremerhaven (Germany)
6	Le Havre (France)
7	Algeciras (Spain)
8	Felixtowe (UK)
9	Valencia (Spain)
10	Marsaxlokk (Malta)

11	Genoa (Italy)
12	Barcelona (Spain)
13	Gothenburg (Sweden)
14	Piraeus (Greece)
15	Bilbao (Spain)

Table 5.11 – Ports that manage 90% of containerized ware in Europe.

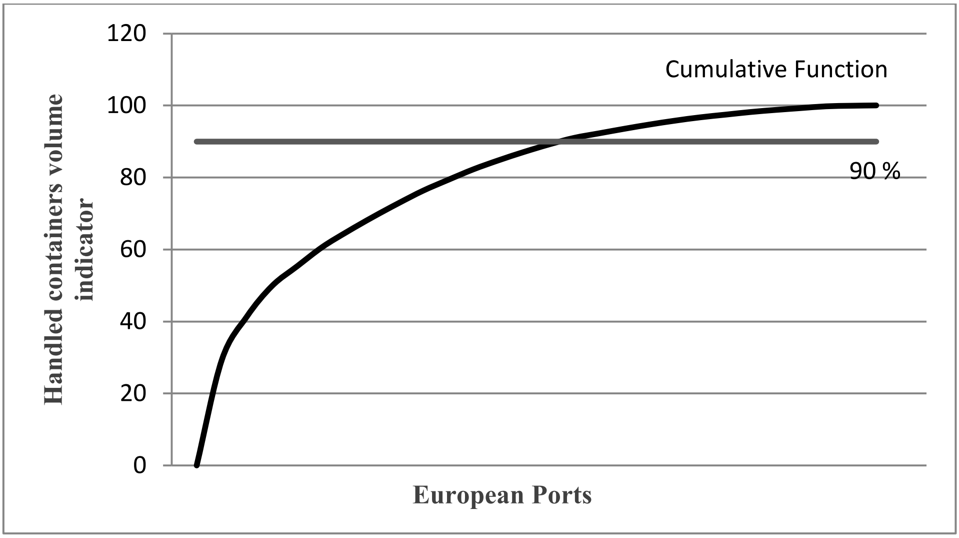


Figure 5.21 – Cumulative Function of a handled containers volume indicator in 2016

Then, the maps in Figures 5.22 and 5.23 show the geographical location of the ports considered in this third numerical application.

Figure 5.22 – Geographical location of the ports of Gothenburg (Sweden) considered in the third numerical application.

Figure 5.23 - Geographical location of the European ports considered in the third numerical application.

In the map (Figure 5.23) an imaginary line separating two geographical areas is clearly distinguishable: that of the North Sea and that of the Mediterranean Sea.
Following careful analysis of the maritime traffic of containers in these two areas, it was decided to separate two sets of choices, one for each identified geographical area.
Therefore, in the third numerical application, fifteen ports were considered as possible destinations, divided into two sets of choice depending on the geographical area of location, as shown in Tables 5.12 and 5.13.
In particular, it was assumed that the shipping companies may choose to complete the trip between eight ports, if they intend to navigate the waters of the North Sea; while seven if they sail in the Mediterranean Sea. Moreover, each port of each geographical area can be considered both as origin and destination. In other words, a ship departing from a port located in one of the two geographic areas analyzed and initially calling a port in the same area, can subsequently modify its itinerary and choose a second port belonging to the same area to finish the journey.

	North Sea
i_1/j_1	Antwerp (Belgium)
i_2/j_2	Bilbao (Spain)
i_3/j_3	Bremerhaven (Germany)
i_4/j_4	Felixtowe (UK)
i_5/j_5	Gothenburg (Sweden)
i_6/j_6	Hamburg (Germany)
i_7/j_7	Le Havre (France)
i_8/j_8	Rotterdam (Nederlands)

Table 5.12 – Choice set in the North Sea area

	Mediterranean Sea
i_1/j_1	Algeciras (Spain)
i_2/j_2	Barcelona (Spain)
i_3/j_3	Genoa (Italy)
i_4/j_4	Marsaxlokk (Malta)
i_5/j_5	Marseilles (France)
i_6/j_6	Piraeus (Greece)
i_7/j_7	Valencia (Spain)

Table 5.13 – Choice set in the Mediterranean Sea area

Table 5.14, 5.15 shows the distances expressed in nautical miles between origin/destination pairs of ports in the North Sea area and in the Mediterranean Sea area.

i_n/j_n	***Antwerp***	***Bilbao***	***Bremerhaven***	***Felixtowe***	***Gothenburg***	***Hamburg***	***Le Havre***	***Rotterdam***
Antwerp	0	564,15	207,33	126	470,27	247,41	195,43	47,45
Bilbao	564,15	0	766,41	547,96	1031,73	801,02	391,93	593,88
Bremerhaven	207,33	766,41	0	279,19	275,67	50,12	399,4	188,06
Felixtowe	126	547,96	279,19	0	503,15	327,7	156,25	101,66
Gothenburg	470,27	1031,73	275,67	503,15	0	259,23	648,64	438,22
Hamburg	247,41	801,02	50,12	327,7	259,23	0	442,17	233,44
Le Havre	195,43	391,93	399,4	156,25	648,64	442,17	0	231,55
Rotterdam	47,45	593,88	188,06	101,66	438,22	233,44	231,55	0

Table 5.14 – Distance between origin/destination pair of ports in the North Sea area, expressed in nautical miles.

Source: https://www.nauticando.net/servizi-per-la-navigazione/navigazione-waypoint/

i_n/j_n	***Algeciras***	***Barcelona***	***Genoa***	***Malta***	***Marseilles***	***Piraeus***	***Valencia***
Algeciras	0	476,17	822,05	971,25	657,36	1392,84	314,3
Barcelona	476,17	0	348,17	664,76	182,5	1009	161,81
Genoa	822,05	348,17	0	571,36	168,3	767,6	507,88
Marsaxlokk	971,25	664,76	571,36	0	613,77	453,18	736,11
Marseilles	657,36	182,5	168,3	613,77	0	890,34	344,12
Piraeus	1392,84	1009	767,6	453,18	890,34	0	1122,1
Valencia	314,3	161,81	507,88	736,11	344,12	1122,1	0

Table 5.15 – Distance between origin/destination pair of ports in the Mediterranean Sea area, expressed in nautical miles.
Source: https://www.nauticando.net/servizi-per-la-navigazione/navigazione-waypoint/

The application of the PCM-DAI model in this third numerical application essentially follows the same procedure explained in the previous applications, but taking into account two wider choice sets and the new hypotheses formulated after the previous monitoring period and explained above.

The PCM-DAI model has been applied to the first 30 days of May 2017.

Once the port of origin *i* and the sailing area are known, the system has acquired the informations necessary for the application of the PCM-DAI algorithm, in the mentioned time interval, using the databases described in the previous paragraphs.

At First, the system extrapolated data about the volumes of containers traded by sea between the countries examinated for each set of choice, expressed in millions of dollars, were assessed; the data are shown in Appendix A, in tables A2 and A3. Then, applying the formula (2) the index Lc_{ij} is obtained for each possible origin/destination port pair.

Moreover, in this case, the linear vector $[r_{ij}]$ is extracted from the Incidence Matrices represented in Table 5.16 for the North Sea area, and in Table 5.17 for the Mediterranean Sea area. Then, this vector contains eight and seven elements respectively, and not 4 as in the previous numerical application.

i_n/j_n	Antwerp	Bilbao	Bremerhaven	Felixtowe	Gothenburg	Hamburg	Le Havre	Rotterdam
Antwerp	0	1	1	1	1	1	1	1
Bilbao	1	0	1	1	1	1	1	1
Bremerhaven	1	1	0	1	1	0	1	1
Felixtowe	1	1	1	0	1	1	1	1
Gothenburg	1	1	1	1	0	1	1	1
Hamburg	1	1	0	1	1	0	1	1
Le Havre	1	1	1	1	1	1	0	1
Rotterdam	1	1	1	1	1	1	1	0

Table 5.16 – Incidence Matrices for the North Sea area.

i_n/j_n	Algeciras	Barcelona	Genoa	Malta	Marseilles	Piraeus	Valencia
Algeciras	0	0	1	1	1	1	0
Barcelona	0	0	1	1	1	1	0
Genoa	1	1	0	1	1	1	1
Marsaxlokk	1	1	1	0	1	1	1
Marseilles	1	1	1	1	0	1	1
Piraeus	1	1	1	1	1	0	1
Valencia	0	0	1	1	1	1	0

Table 5.17 – Incidence Matrices for the Mediterranean Sea area.

The generic linear vector $[r_{ij}]$ corresponds to a row of Incidence Matrix and contains all the values equal to 1, except the elements representing the origin and destination locating in the same Country, or coincident.

Subsequently, the PCM-DAI model elaborates the first data extrapolation from the websites of the Port Authorities; the data concern the technical characteristics of the ports contend in the set of choice, referred to the previous year (2016) respect to the monitoring period.

North Sea area									
	j-th Port	FHc_j ***(ton)***	AHc_j ***(TEU/mq)***	Cc_j	Bc_j	Tc_j	SAc_j ***(ha)***	Lc_j	DTc_j ***(h)***
j_1	***Antwerp***	184.136.000	15,3	145	88	117	13000	2190	0,6
j_2	***Bilbao***	31.604.448	17,6	86	43	38	313	545	1,9
j_3	***Bremerhaven***	83.979.000	16	50	33	50	2113	1100	1,2
j_4	***Felixtowe***	60.565.444	22	26	20	13	3383	2500	0,6
j_5	***Gothenburg***	38.700.000	25,3	50	15	22	220	800	1,4
j_6	***Hamburg***	130.938.000	25	100	38	80	7399	1168	1,7
j_7	***Le Havre***	68.500.000	18,7	47	26	18	13500	1300	2,4
j_8	***Rotterdam***	441.528.000	29,4	334	171	149	10570	981	1,7

Table 5.18 – Technical characteristic of ports considered in the North Sea area, in the 2016. Source: The Port Authorities.

The data indicated in Tables 5.18 and 5.19, dimensionless according the formula (6) are the input for the linear regression (5) of the technical static characteristic of the ports for each area of survey. Moreover, the results obtained applying (5) were converted in Fuzzy numbers, to take into account the uncertainty of some considered parameters.

Mediterranean Sea area									
***j-th* Port**	FHc_j ***(ton)***	AHc_j ***(TEU/mq)***	Cc_j	Bc_j	Tc_j	SAc_j ***(ha)***	Lc_j	DTc_j ***(h)***
j_1 **Algeciras**	64.159.706	18,2	83	39	30	7500	1250	4,2
j_2 **Barcelona**	41.793.734	22,2	126	40	42	828	820	0,8
j_3 **Genoa**	47.880.945	20,6	62	60	35	700	3200	0,7
j_4 **Marsaxlokk**	49.560.000	24	161	50	25	1350	890	0,6
j_5 **Marseilles**	86.000.000	20	10	33	16	262	1500	3,7
j_6 **Piraeus**	35.799.000	14,4	9	4	35	724	1500	0,7
j_7 **Valencia**	57.502.319	16,1	30	18	25	810	850	2,2

Table 5.19 – Technical characteristic of ports considered in the Mediterranean Sea area, in the 2016. Source: The Port Authorities.

Then the PCM-DAI model proceeds with the acquisition of the dynamic variables related to each port, using data coming from the *MarineTraffic* website for each day of the monitoring week, 24 hours per day.

This data, dimensionless according the (5) are other input parameters for the PCM-DAI model application. For example in tables 5.20 and 5.21 are shown the data obtained at 12 a.m. of the 1st May 2017, for the port overlooking on the North Sea and Mediterranean Sea respectively.

			fCc_j	fBc_j	fTc_j	SDc_j
j_1	***Antwerp***	Belgium	0	0	11	250
j_2	***Bilbao***	Spain	63	6	7	14
j_3	***Bremerhaven***	Germany	0	0	0	26
j_4	***Felixtowe***	UK	18	4	5	8
j_5	***Gothenburg***	Sweden	38	0	4	10
j_6	***Hamburg***	Germany	11	0	2	52
j_7	***Le Havre***	France	28	0	15	16
j_8	***Rotterdam***	Nederlands	261	38	89	60

Table 5.20 – Dynamic parameters of the considered port in the North Sea area, obtained at 12 a.m.

of the 1st May 2017.
Source: Elaboration of data coming from MarineTraffiche website.

			$\boldsymbol{fCc_j}$	$\boldsymbol{fBc_j}$	$\boldsymbol{fTc_j}$	$\boldsymbol{SDc_j}$
j_1	***Algeciras***	Spain	61	0	1	48
j_2	***Barcelona***	Spain	113	16	17	11
j_3	***Genoa***	Italy	44	35	13	7
j_4	***Marsaxlokk***	Malta	153	36	5	6
j_5	***Marseilles***	France	7	28	15	2
j_6	***Piraeus***	Greece	0	0	3	30
j_7	***Valencia***	Spain	12	0	4	6

Table 5.21 - Dynamic parameters of the considered port in the North Sea area, obtained at 12 a.m. of the 1st May 2017.
Source: Elaboration of data coming from MarineTraffiche website.

For the whole monitoring period, hour-by-hour the PCM-DAI model calculated the $\tilde{\alpha}_j$ values as linear regression of dynamic variables (7), after having dimensionless all variables according to the formula (6). Due to the uncertainty of the values, also $\tilde{\alpha}_j$ was fuzzified using triangular membership functions.

Then, the $\tilde{\gamma}_{\mathrm{j}}$ value is obtained through the fuzzy product according to (8).

Also in this case, the parameter concerning the travel time $\tilde{T}_{i_1 j}$ is assumed that estimated and communicated by the maritime company both before and during the travel, according to the chosen route; the travel time has been obtained using the GPS and radar signals sent by ships during the travel, acquired by the *MarineTraffic* website and available on its database. The travel time parameter is converted in a triangular Fuzzy number to take into account the variability in the ship-owners perception of travel time, the change of the weather conditions, or possible errors in data communication.

In this third numerical application normal traffic conditions are assumed. For this reason the exponential time parameter λ indicating the variability of travel time according to the traffic conditions is set equal to 2, as in the previous case.

Then, acquired all input data, both having low and high dynamicity, the PCM-DAI model returns the values of the dynamic accessibility indicator (DAI), for each destination port according to equation (9); the results are expressed in term of triangular fuzzy numbers. In particular, in this third case study, the PCM-DAI model recognizing the GPS position is able to associate in which geographic area the ship is sailing and processes only the inputs coming from that area.

For example, a ship that left the port of Antwerp, during the journey changes its itinerary, expecting to end its journey in a northern European port at 12 a.m. 1st May, 2017. The PCM-DAI identifies the area in which operating and after extracting the necessary data from the different databases mentioned, it processes them returns the result in terms of DAI for each port located in that area.

The graphical representation of this latter case is shown in Figure 5.24 and the numerical value of the DAI calculated are annotated in Table 5.22 as the ranking of the fuzzy value.

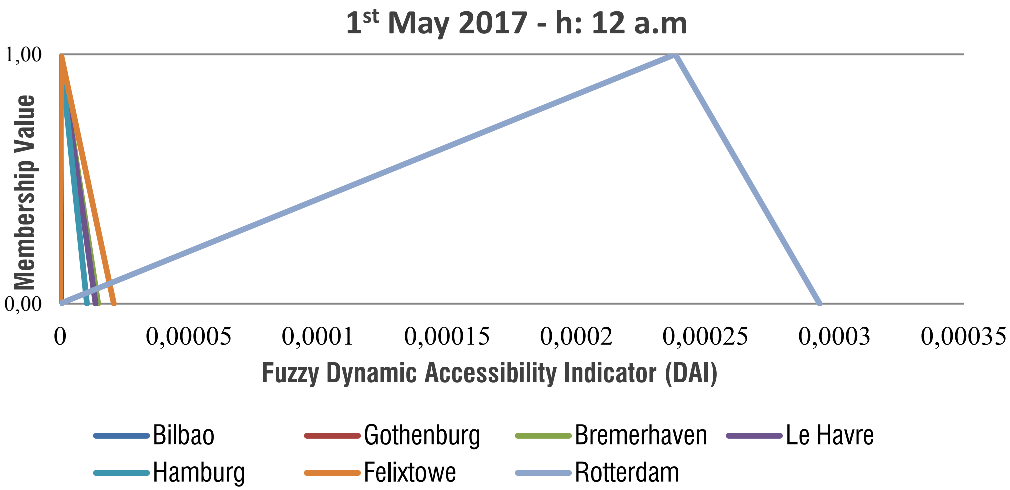


Figure 5.24 - DAIs of the destination ports in the North Sea area, on 1st May 2017 at 12 a.m., considering a vessel left from Antwerp.

Origin Port	Destination Ports		$A_{j\,min}$	A_j	$A_{j\,max}$
Antwerp (Belgium)	j_1	***Antwerp*** *(Belgium)*	0	0	**0**
	j_2	***Bilbao*** *(Spain)*	6,33E-12	5,41318E-11	3,82912E-07
	j_3	***Bremerhaven*** *(Germany)*	7,19E-12	2,24946E-09	4,3498E-07
	j_4	***Felixtowe*** *(UK)*	2,45E-10	3,7885E-08	1,48107E-05
	j_5	***Gothenburg*** *(Sweden)*	2,27E-10	1,77098E-07	1,3742E-05
	j_6	***Hamburg*** *(Germany)*	1,72E-10	2,46606E-07	1,04008E-05
	j_7	***Le Havre*** *(France)*	3,44E-10	4,07468E-07	2,08371E-05
	j_8	***Rotterdam*** *(Nederlands)*	4,86E-09	0,000238182	0,000294052

Table 5.22 - Values of DAIs as fuzzy numbers of the destination ports in the North Sea area, on 1st May 2017 at 12 a.m., considering a vessel left from Antwerp.

Then, the system calculated the intersection between Fuzzy triangles, to evaluate the possibility that the perceived accessibility of a port is higher/lower than the other.

Observing figure 5.22 is clear that the accessibility indicator of the port of Rotterdam is considerably greater than all the others in the same area. However, it is also noted that the Rotterdam triangle intersects the others in a point very close to the zero axes. This means that even if a very high accessibility indicator is attributed to Rotterdam Port, in reality, the possibility that it is perceived as such is very low.

To pass from the measure of possibility to the probability measure, the intersection values thus obtained are further processed by the model, applying the Geer and Klir's method.

Table 5.23 shows the graphical interface about the status of the model at the time of this mathematical transformation for the same case mentioned in Figure 5.24 and Table 5.22.

		Rotterdam	Felixtowe	Hamburg	Le Havre	Bremerhaven	Gothenburg	Bilbao	Antwerp	γ	U	H	P_{min}	P_{max}
Antwerp	p													
	P													
Bilbao	p	0	0,4842742	0,60820	0,68369	0,9100332	0,9942993			4,5443144	1,678314	1,67884	9,700E-14	0,5009520
	P	9,700E-14	0,0190561	0,053672	0,091338	0,3349826	0,5009520							
Gothenburg	p	0,0018026	0,5175133	0,640211	0,713176	0,9242395		0,99429		4,6381747	1,747081	1,747465	9,134E-14	0,4751017
	P	9,133E-14	0,0229837	0,061659	0,10172	0,3385362		0,47510						
Bremerhaven	p	0,0585326	0,9756531	0,986103	0,713176		0,9242395	0,91003		0,9758565	2,38539	2,385923	0,0136790	0,2152625
	P	0,0136790	0,2130361	0,215263	0,156906		0,2020737	0,19904						
Le Havre	p	0,0545681	0,9835119	0,994967		0,7131764	0,7131764	0,68369		1,7582218	2,270953	2,271114	0,0016780	0,2764997
	P	0,0016780	0,2709270	0,2765		0,1539696	0,1539696	0,14295						
Hamburg	p	0,0418630	0,9847686		0,994967	0,9861031	0,6402107	0,60820		1,0151431	2,342138	2,342481	0,0093995	0,2343804
	P	0,0093995	0,2319417		0,23438	0,2322608	0,1498082	0,14220						
Felixtowe	p	0,0805555		0,984769	0,983512	0,9756531	0,5175133	0,48427		1,3519259	2,259002	2,259231	0,0088688	0,2616577
	P	0,0088688		0,261658	0,261206	0,2583887	0,1096448	0,10023						
Rotterdam	p		0,0805555	0,041863	0,054568	0,0585326	0,0018026	0,00158		14,922723	0,099074	0,100061	3,425E-26	0,9885679
	P		0,9885679	5,66E-05	0,002956	0,0084191	2,342E-25	3,4E-26						

Table 5.23 – Application of the Geer and Klir method on 1st May 2017 at 12 a.m., North Sea area, considering a vessel left from Antwerp.

The variables P, U, and H are expressed by Geer and Klir as (11), (12), (13).
Moreover, the minimum probability that the accessibility of the *j-th* port is perceived superior to that of all other ports contained in the set of choices is calculated with the (14).
Then, the final output of the PCM-DAI model proposed, applied in midday of the 1st May 2017, considering a ship left from the Antwerp Port can would like to reach a port within the North Sea area, is the ranking according to the obtained Probabilities for each considered destination port *j-th* about the perceived accessibility; for the specific hour and day the final output, expressed in term of minimum percentage probability that the accessibility of a port is perceived superior than all others by the ship-owners, is shown in the following Table 5.25.

	$P_{j\,min}^{PCM-DAI}$
Bilbao	0,00%
Bremerhaven	40,68%
Felixtowe	26,38%
Gothenburg	0,00%
Hamburg	27,95%
Le Havre	4,99%
Rotterdam	0,00%

Table 5.24 – PCM-DAI model output on 1st May 2017 at 12 a.m., North Sea area, considering vessels left from Antwerp.

As in the previous study cases, to verify the reliability of the model choice prediction, also the real ship-owners' choice ware valued. In Table 5.28, in the first column are reported the PCM-DAI outputs, while the last column indicates the real choice percentage come from the elaboration of the *MarineTraffic* database for the specific case analyzed in Figure 5.22 and Table 5.23.

			PCM-DAI output Probability $(P_{j\,min}^{PCM-DAI})$	Real choice data
j_1	**Bilbao**	Spain	0,00%	0,00%
j_2	**Bremerhaven**	Germany	40,68%	50,00%
j_3	**Felixtowe**	UK	26,38%	16,67%
j_4	**Gothenburg**	Sweden	0,00%	0,00%
j_5	**Hamburg**	Germany	27,95%	16,67%
j_6	**Le Havre**	France	4,99%	16,67%
j_7	**Rotterdam**	Netherlands	0,00%	0,00%

Table 5.25 - PCM-DAI output 1st May 2017 at 12 a.m., North Sea area, compared with real choice data, considering vessels left from Antwerp.

The PCM-DAI model has ran for the two geographical area considered, at every hour of the monitoring period, obtaining 2.712 outputs per day and 81.360 in 30 days of application; for each hour, a comparison with the real data was processed.

For the same reason explained in the previous paragraph, both the model's outputs and the real daily choice percentage were expressed as the average of the daily values carried out hour-by-hour. Thus, 1.534 outputs were obtained, 162 daily values for each port.

As an example, in the following Table 5.29 the model outputs are compared with the real choice percentage day-by-day for the first day of monitoring.

Origin Port *i*	Country	Destination Port *j*	PCM-DAI output Probability	Real choice data
Antwerp	Belgium	Antwerp	0,00%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	40,68%	50,00%
		Felixtowe	26,38%	16,67%
		Gothenburg	0,00%	0,00%
		Hamburg	27,95%	16,67%
		Le Havre	4,99%	16,67%
		Rotterdam	0,00%	0,00%
Bilbao	Spain	Antwerp	4,14%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	24,48%	25,00%
		Felixtowe	32,85%	50,00%
		Gothenburg	0,01%	0,00%
		Hamburg	29,72%	25,00%
		Le Havre	8,81%	0,00%
		Rotterdam	0,00%	0,00%
Bremerhaven	Germany	Antwerp	2,14%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	0,00%	0,00%
		Felixtowe	46,70%	50,00%
		Gothenburg	42,13%	37,50%
		Hamburg	0,00%	0,00%
		Le Havre	9,03%	12,50%
		Rotterdam	0,00%	0,00%
Felixtowe	UK	Antwerp	0,05%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	11,32%	20,00%
		Felixtowe	0,00%	0,00%
		Gothenburg	0,00%	0,00%
		Hamburg	4,01%	10,00%
		Le Havre	84,62%	70,00%
		Rotterdam	0,00%	0,00%

Gothenburg	Sweden	Antwerp	14,30%	14,29%
		Bilbao	0,00%	0,00%
		Bremerhaven	73,97%	57,14%
		Felixtowe	9,67%	14,29%
		Gothenburg	0,00%	0,00%
		Hamburg	1,21%	14,29%
		Le Havre	0,85%	0,00%
		Rotterdam	0,00%	0,00%
Hamburg	Germany	Antwerp	6,30%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	0,00%	0,00%
		Felixtowe	35,29%	50,00%
		Gothenburg	48,29%	50,00%
		Hamburg	0,00%	0,00%
		Le Havre	10,13%	0,00%
		Rotterdam	0,00%	0,00%
Le Havre	France	Antwerp	0,00%	0,00%
		Bilbao	3,36%	0,00%
		Bremerhaven	33,17%	33,33%
		Felixtowe	0,93%	0,00%
		Gothenburg	0,00%	0,00%
		Hamburg	62,53%	66,67%
		Le Havre	0,00%	0,00%
		Rotterdam	0,00%	0,00%
Rotterdam	Netherlands	Antwerp	0,00%	0,00%
		Bilbao	0,00%	0,00%
		Bremerhaven	38,21%	40,00%
		Felixtowe	35,13%	40,00%
		Gothenburg	0,00%	0,00%
		Hamburg	26,64%	20,00%
		Le Havre	0,02%	0,00%
		Rotterdam	0,00%	0,00%

Table 5.26 - PCM-DAI output 1st May 2017 at 12 a.m., North Sea area, compared with real choice data.

Not being possible to report, here, 162 charts for each port, in the following Figure shows the graphical representation of the daily output of the model compared with real choice data for the Port of Marsaxlokk (Malta) as destination, considering the Algeciras Port (Spain) as origin of the journey; The graphic refers to the whole period of monitoring.
The choice to represent the data obtained for the port of Marsaxlokk as an example is not accidental.
During this third monitoring period, a further phenomenon was revealed. In 90% of real cases, the port of Marsaxlokk is the dock favored by ships that change itinerary after their departure, choosing as a possible destination a port located in the Mediterranean area. This means that every day, at least one ship decides to cancel the previous port call and formulate a new one to the port of Marsaxlokk. This confirms that the centrality in the Mediterranean Sea and the excellent performance in handling operations ($\boldsymbol{DTc_j} = 0.6$ h - Table 5.19) make the Malta Island the most favored network node by shipping companies.
However, in the same period, a similar situation was found for the port of Felixtowe,UK. So this suggests that Felixtowe is a major competitor in the hub and spoke network in northern Europe.
Also the outputs of the PCM-DAI model reflect this phenomenon, as can be observe in the Figure 5.25.

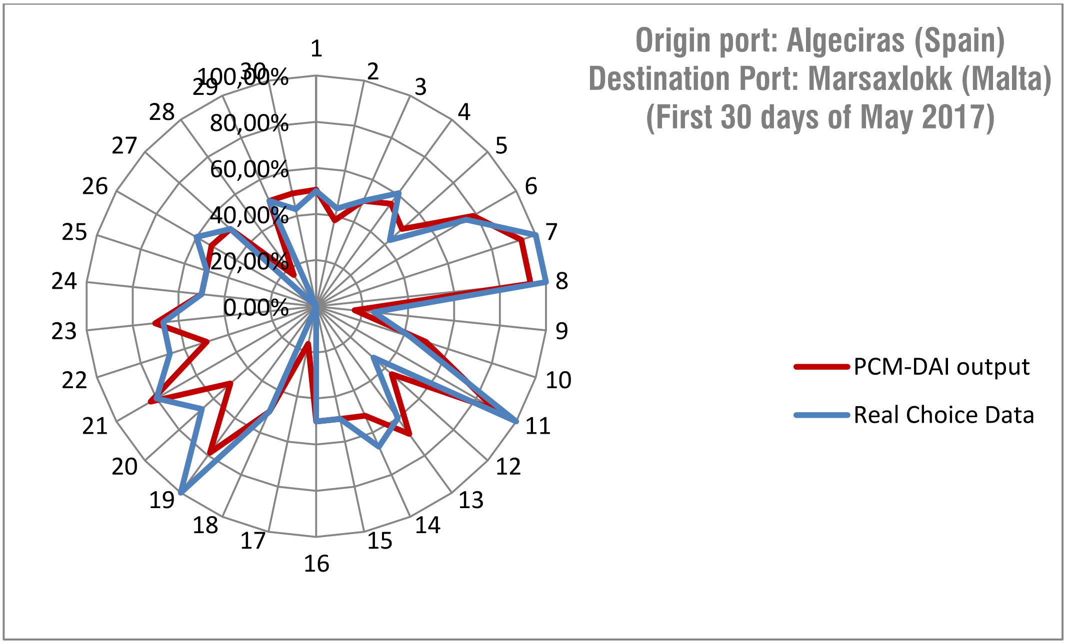


Figure 5.25- Comparison between PCM-DAI daily output and the daily real choice data, in the month of May 2017, considering ships departing from Algeciras and arriving in Marsaxlokk port after changing the route.

CHAPTER 6
RESULTS

Using the *MarineTraffic* website, during an initial period of monitoring, lasting some months, the maritime traffic in the European contest was observed and some anomalous behavior of feeder ships emerged.

Often, feeder ships, engaged in the transport of ware on medium-short routes, during the journey cancel the call to the destination port initially planned and change the route, choosing another port as the final destination.

It was verified that the ports affected by this daily phenomenon are very well connected with the European intermodal transport network, but above all, they have good performances in the services offered.

Underlying this behavior there are several reasons very difficult to understand, such as of economic, political and commercial nature, but certainly, there are reasons relating to the logistics systems.

The present research aimed to formulate a model to support the shipping companies in the decision-making process about the hub port of destination, even en-route, merging the demand with the main characteristics of the transport system and some characteristics of the port, both structural and service-related.

In this research a Port Choice Model based on a Dynamic Accessibility Indicator (PCM-DAI) is proposed.

To verify the applicability of the model three test was elaborated, varying the origin and destination ports, the period of application and the geographical area of survey.

The first test of the model dates back to the third week of March 2017. In this case only three ports overlooking the Mediterranean Sea and located along the same coast and in different Country are considered as possible destinations achievable by feeder ship departed from only one port as origin located in the same area. In particular, the ports of Genoa, Barcelona and Marseilles as possible destinations and the port of Marsaxlokk as origin are considered.

In the second test, the same origin and destination ports are treated, but the time interval of the model application was extended to the entire month of April 2017.

At the end, the third test was realized during the first thirty days of May, considering two different area with different characteristics and trade of freight: the Mediterranean Sea area and the North Sea area.

Whereas in the first and second tests only the possibility that the destinations are located along the same coast and in different Countries was considered, in the third case this restriction was overcome; therefore, in the third test, the ports that can be chosen by the shipping companies as destinations can belong to the same State and can be placed on different coasts, even islands; in this case, the only condition to respect is that the possible destinations belong to the same geographical area.

Following some evaluations explained in paragraph 5.3, eight possible destinations in the North Sea, while seven in the Mediterranean Sea were evaluated.

Therefore, compared to the two previous tests, in this case, the set of choice is wider and includes a denser maritime transport network in both survey areas.

Moreover, in this last test the calculation system has been enhanced; acquired the current GPS position of the feeder ship at the moment of request, the system recognizes in which of the two areas it is sailing and processes only the data relating to the ports belonging to that area.

During all the tests, in each period considered, the model ran every hour for each port, obtaining 504 outputs in the first test, 2.160 in the second, and 81.360 in the third.

To validate the results of the model, during the three periods of application, also the real-time monitoring of the maritime traffic was perform. Thus, for each monitoring

period, the real choice percentages of each selected port for each hour was calculated.
Since in the maritime transport both the travel time and the time spent in port for handling operations are quite long, often the results relating to the following hours have shown the same value. For this reason, as explained in chapter 5, the daily average value was calculated both for outputs coming from the model, and for real choice data extrapolated from the arrivals plan in the analyzed ports.
Then, the daily results obtained from the PCM-DAI with real data coming from GPS sources, were compared.
In order to evaluate the quality of the obtained results, for each test has been considered the following performance indicators:

- *Mean Error*;
- *Mean Absolute Deviation*;
- *Mean Absolute Percentage Error*;
- *Mean Squared Error;*

In statistics, the Mean Error (ME) is a common measure of forecast error in time series analysis. It is given by (16) and represents an average measure of the difference between two variables, x and y, expressing the same phenomenon. In our case, the variables x_i and y_i represent, respectively, the real choice probability coming from GPS sources and the output obtained by the PCM-DAI model, in the same day *i* of the period considered for the model test. Obviously, the quantity difference exists when the x_i value does not equal the y_i value.
Often, many researchers use the Mean Absolute Error (MAE) that allows a clear interpretation of the model accuracy as the average absolute difference between x_i and y_i, thus without any information about the overestimate or underestimate operated by the model in the results elaboration. Instead, in the present study, the ME was considered just to understand if the PCM-DAI model returns values overestimated or not if com-

pared with the real data; the negative sign indicates that the model returns on average higher values than the real data, while the positive sign indicates the reverse case.
The Mean Absolute Deviation (MAD) of a data set is the average of the absolute distance from a central point, the mean. The MAD is given by (17) and represent a simpler measure of variability than the standard deviation.
Here, the MAD indicates the absolute value of the distance between the daily value forecast coming from the PCM-DAI model and the average of the daily real choice data.
While, the Mean Absolute Percentage Error (MAPE) is one of the most popular measures for forecasting error, used by many researchers. The MAPE, is a measure of prediction accuracy of a forecasting method and is defined by (18); it allows to know the percentage of error committed in PCM-DAI model application.
At the end, the Mean Square Error (MSE) is the mean of the squares of the errors, given by (19). The MSE suggests the quality of an estimator, which, in this research, is the PCM-DAI model; a low value of the MSE, indicates that the outputs of the PCM-DAI model, representing the probabilities that a port is chosen because its accessibility is perceived as low, they approach the real values of choice.

$$ME = \frac{\sum_{i=1}^{n} y_i - x_i}{n} \tag{16}$$

$$MAD = \frac{1}{n} \sum_{i=1}^{n} |x_i - m(Y)| \tag{17}$$

$$MAPE = \frac{100\,\%}{n} \sum_{i=1}^{n} \left|\frac{y_i - x_i}{y_i}\right| \tag{18}$$

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (y_i - x_i)^2 \tag{19}$$

Where:
x_i is the output forecast by the PCM-DAI model;
y_i is the real choice data;

i is the i-th day considered;
n is the number of day of the period monitoring;
$m(Y)$ is the mean of the real choice data for each period of monitoring.

In the following Tables the values of the performance indicators calculated for each test are shown.

Indicator	**Value**
ME	-4,7619E-06
MAD	0,010985714
MAPE	22,85 %
MSE	0,0003372

Table 6.1 - Performance indicator – First numerical application.

Indicator	**Value**
ME	-0,00051
MAD	0,017284
MAPE	11,04 %
MSE	0,002666

Table 6.2 - Performance indicator – Second numerical application.

Indicator	**Value**
ME	0,125
MAD	0,061619
MAPE	7,88 %
MSE	0,026087

Table 6.3 - Performance indicator – Third numerical application in the North Sea area.

Indicator	Value
ME	0,142857
MAD	0,056822
MAPE	6,99 %
MSE	0,019569

Table 6.4 - Performance indicator – Third numerical application in the Mediterranean Sea area.

As can be observed from the above tables the performance indicator assume low values in each case of study.

To have a more immediate view of the comparison of the indicators obtained in the different cases, these are represented below on the histograms.

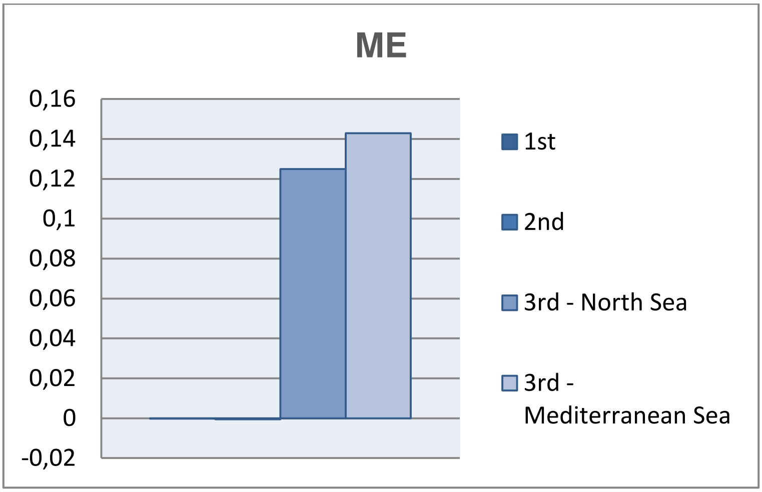


Figure 6.1 – Comparison of ME values obtained for the three PCM-DAI numerical application.

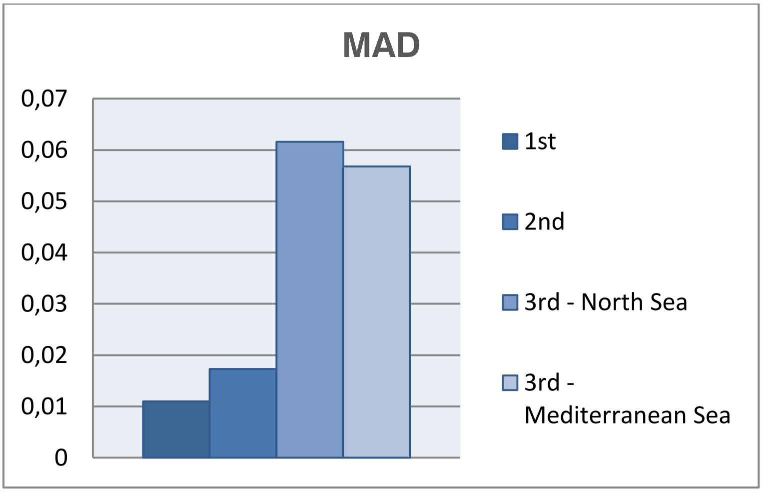


Figure 6.2 – Comparison of MAD values obtained for the three PCM-DAI numerical applications.

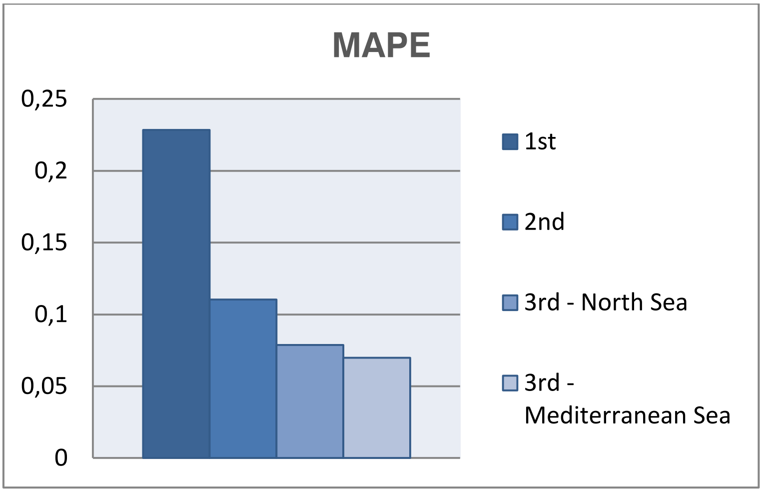


Figure 6.3 – Comparison of MAPE values obtained for the three PCM-DAI numerical applications.

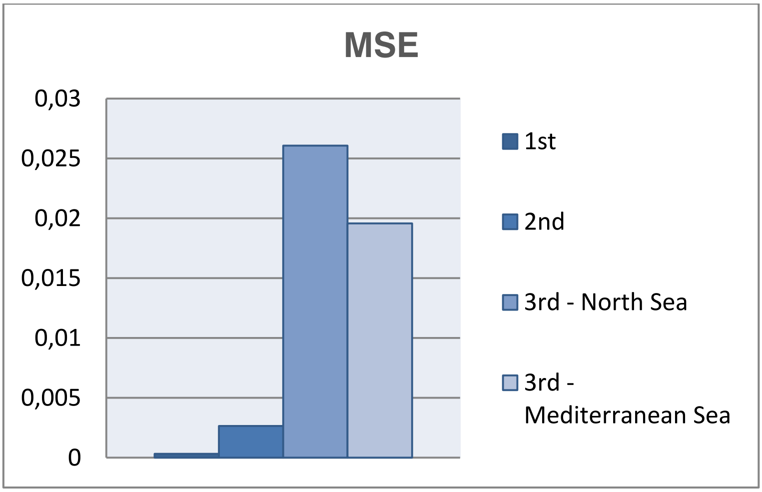


Figure 6.4 – Comparison of MSE values obtained for the three PCM-DAI numerical applications.

Therefore, we can conclude that the results of the proposed model reflect very well what the real choices of operators in the sector are.
Moreover, it can be noted how the model responds well in all the situations that may arise, both in the case where the ship-owner proposes as possible destination ports those located along the same coast and if he considers a generic docking possible in a wider geographical area.
However, the lower MAPE value that measures the prediction accuracy of the forecasting model proposed was obtained in the third case of study, both for the North Sea and Mediterranean Sea areas; it assumed value around the 7-8%.

CONCLUSIONS

In the last decades, both the international maritime trade, the automation of every port's activity, and the handling operations techniques have attracted more and more interest from researchers. The monitoring and planning of port handling activities prove a useful tool for optimizing terminal operations, but it is also essential for shipping companies managing the cargo from point to point.

The companies, before leaving, have to choose the route and the port of destination for calling, in accordance with the final destination of the cargo shift, reducing the transportation costs. These latter include the travel time and the delay time, understood as perceived additional cost.

In the route planning, the choice can differ on the basis of different aspects such as the ports position, the connection between port and inland transport network, the ports' on-time performance in handling operations.

Many researchers have studied this phenomenon in detail, producing studies related to stochastic and probabilistic choice models, according to which the decision-maker chooses the alternative that maximizes the utility perceived.

In literature, the topic of the choice of the destination port was widely studied; particular attention is placed both on the decision-maker, who is and how he interacts with the entire supply chain, and on the competitiveness between ports and how it influences the choice of the decision-maker. On this regard, some authors have found strictly relations between the choice of the destination port and the service characteristics of the ports considered as possible destination to reach.

In addition, they found that the port's accessibility in comparison with those of the other ports belong to the same area, may provide a possible parameter to evaluate in the container port competitiveness; in fact, according to them, during the decision process, the *Accessibility* of a port is one of the most important factors considered by the companies. Due its nature, this process is affected from uncertain or it is characterized by incomplete data related to different quantitative and qualitative determinants.

An important contribution is provided by the Fuzzy theory useful to describe the human judgments or preference expressed by a linguistic variable, in a fuzzy number.

Recently some authors (Chou, 203b; Yeo, 2015) proposed a new conceptual port choice method Fuzzy-Logic based. In these studies, the real data collected to evaluate the port performance was converted into fuzzy numbers, to produce a port choice preference score.

Some researchers (Cullinane, 2009; Dong, 2006) proposed activity-based accessibility models described by logsum function, to provide a measure of individual container ports' accessibility, not considering the uncertainty which affects this measure.

Tange (2011) developed a model integrating the network characteristics of the port industry into the multinomial logit model (MNL) through an accessibility index.

During a period prior to the present study, for several months, the maritime traffic in the Mediterranean area was monitored and some anomalous behaviors were found, especially of feeder ships. Sometimes, during the journey, the ship modifies its route, to plan a new one and select a port of destination, different from the one initially planned. Then, in the final port of destination the subsequent handling operations will take place. This exchange is due to reasons not well known, probably relating to issues of political, commercial and logistics nature.

Until this moment, previous studies analyzed the port's accessibility as a constant over the time, like an own port's characteristic.

However, during the monitoring period prior to the present study, the idea has been advanced that the accessibility of a port is not a static parameter, but may vary over time, being influenced by variables strictly connected to the services offered by the port. Another aspect to underline is that the port's accessibility is not always perceived in the same measures by the maritime operators just because it is affected by parameters more or less variable over time, or even by hour-by-hour dynamic variables.

Following the knowledge proposed in literature, this research the objective was to formulate a choice model of the destination port, based on a dynamic accessibility indicator, able to express it from human perception point of view.

Merging the main maritime transport system characteristics and some port service-related parameters, the PCM-DAI model proposed represents an attempt to foresee the accessibility of the port as it could be perceived by the shipping companies, regardless of the phenomena that may influence the choice but which are not easily identifiable. Furthermore, the model can be used on-line, even en-route.

Starting from the inputs communicated by the shipping company (or the ship-owner) about the GPS current position and the estimated travel time to reach the ports candidate to be the possible destination, the PCM-DAI model recognize in which geographical area the ship is sailing and extrapolates the necessary information from the different databases, distinguishing low dynamic parameters to high. The model is based on the Fuzzy-Logic methodology, carrying out the ranking of destination ports "closer" to the ship-owner requirements, on the basis of their dynamic accessibility indicator, as dependent on a human judgment.

In this study, a calculation system has been created; it processes all input data and converts some of them in Fuzzy numbers, taking into account the uncertainty, or possible errors made by companies in data communication.

After processing the inputs, the system returns the value of the dynamic accessibility indicator (DAI) for each port selected as a possible destination by the decision-maker. The calculated DAIs are represented graphically by means of Fuzzy triangles, representing the accessibility of the port selected as perceived by the decision-maker. The intersections between them represent the possibility that the accessibility of a port can be perceived as superior to that of another. Subsequently, the system operates a

mathematical transformation, according to the method of Geer and Klir (1992), converting the measures of possibility into measures of probability.
Once received the PCM-DAI output in terms of the probability of perceiving the accessibility, it can be assumed as a suggestion of choice.
Consequently, the maritime company can plane the trip, call the preferred port of destination, which, in turn, can organize all handing activities, optimizing the operational times.
In order to validate the PCM-DAI model, it was applied in three cases.
The geographical area, the set choice and the monitoring period were modified. All daily outputs were compared with the real docking data, acquired hour-by-hour by the system. In addition, the data elaborated coming from different sources, such as GPS and Radar signals, Port Authorities websites, and traffic data from *MarineTraffic* website were elaborated.
For each test ran in the present study, some performance indicator were evaluated. Analyzing this latter it is possible to observe a good accuracy of the model in elaborate the ship-owner input and carry out the result close to his wishes.
The proposed model, designed to support the decisions of the shipping companies both in the planning phase of the journey preceding the departure, and also during the trip, could have a dual use.
In fact, the model could also be used in container terminals in order to predict the choices of ships in navigation and to better plan the handling activities.

REFERENCES

Anderson, C.M., Opaluch, J.J. and Grigalunas, T.A. (2009). *The demand for import services at US container ports*. Maritime Economics and Logistics, Vol. 11, No. 2, pp.156–185.

An-Shuen Nir et. al (2003). *Port choice behaviour-from the perspective of the shipper*. Maritime Policy & Management: The flagship journal of international shipping and port research – Vol. 30

Arrow, K.J. (1951). *Social Choice and Individual Values*. John Wiley and Sons, New York. Edizione rivista 1963.

Aversa, R., Botter, R.C., Haralambides, H., Yoshizaki, (2005). *A mixed integer programming model on the location of a hub port in the East coast of South America*. Maritime Economics and Logistics 7, 1–18.

Ben-Akiva, M. e Lerman, S. (1985), *Discrete Choice Analysis*. MIT Press, Cambridge, Mass.

Bierlaire, M. (1997), *Discrete choice models,* in N. Institute, ed., Operations research and decision aid methodologies in traffic and transportation management. Hotel UNI, Balatonfured, Hungary.

Block, H. e Marschak, J. (1960), *Random orderings and stochastic theories of responses*, in I. Olkin, S. Ghurye e W. H. et al, eds, Contributions to Probability and Statistics, Stanford University Press, Stanford, pp. 97– 132.

Brooks, M. R., & Pallis, A. A. (2008). *Assessing port governance models: process and performance components*. Maritime Policy & Management, 35(4), 411-432.

Brooks, M., (2009). *Liberalization in Maritime Transport*. International Transport Forum, OECD, Paris, 31 p.

Bruinsma et. al, (1998). *The accessibility of European cities: theoretical framework and comparison of approaches*. Environment and Planning A, 30, 499–521.

Campos V.B.G., Santos A.C., Zandonade E. (2013). *A model for the analysis of regional Accessibility for freight transportation*, Advanced OR and AI Methods in Transportation.

Chang, W. H. (1974). *Forecasting the imported/export cargoes demand split and the throughput of Taichung port*. Master thesis, National Taiwan University, Taiwan.

Chang, Y.-T., S.-Y. Lee, and J. L. Tongzon. (2008). *Port Selection Factors by Shipping Lines: Different Perspectives Between Trunk Liners and Feeder Service Providers*. Marine Policy 32 (6): 877 – 885.

CHOU C.C. (2005). *A COMPARATIVE STUDY OF MODELS FOR PORT CHOICE*. Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 608 – 616

Chou, C. C. (2010). *AHP model for the container port choice in the multiple-ports region*. Journal of Marine Science and Technology, 18(2), 211 – 232.

Chou, C. C., Chu, C. W. and Liang, G. S.(2003a). *Comparison of two models for port choice*. Journal of Maritime Quarterly., Vol. 12, No. 3, pp.45-61

Chou, C. C., Chu, C. W. and Liang, G. S.(2003b). *A transportation demand split model for international ports in Taiwan area*. Journal of Eastern Asia Social Transportation Studies, Vol. 5, pp.625-637.

Collison, F.M. (1984). *Market segments for marine liner service*. Transportation Journal, Vol. 24, No. 2, pp.40–54.

Cullinane Kevin & Wang Yuhong. (2009). *A capacity-based measure of container port accessibility*. International Journal of Logistics Research and Applications, 12:2, 103-117.

Dalvi M.Q. and Martin K.M. (1976). *The measurement of accessibility: some preliminary results*, Transportation 5 (1), pp.17-42.

De Langen, P. (2007). *Port competition and selection in contestable hinterlands; the case of Austria*. European Journal of Transport and Infrastructures Research 7 (1), 1–14.

Dong, X., et al., (2006). *Moving from trip-based to activity-based measures of accessibility*. Transportation Research A, 40 (2), 118–630.

Fechner, G. (1860). *Elements of Psychophysics*. Vol 1, Rinehart & Winston, New York.

Frankel, E.G. (2001). *Economics of transportation in container shipping logistics*. Proceedings of International Conference on Port and Maritime R&D and Technology, Singapore, October. The Maritime and Port Authority of Singapore, Singapore. pp. 29-31,175-182.

Frémont, A., (2005). *Les réseaux maritimes conteneurisés: épine dorsale de la mondialisation*. INRETS, Paris, France.

Geurs et. al (2001). *Accessibility measures: review and applications*. Bilthoven: National Institute of Public Health and the Environment, RIVM Rapport 408505006.

Geurs, K.T. and van Wee, B., (2004). *Accessibility evaluation of land-use and transport strategies: review and research directions*. Journal of Transport Geography, 12 (2), 127–140.

Giannopoulos, G., Aifadopoulou, G., Torok, A., (2007). *A Port Choice Model for the Transhipment of Containers in Eastern Mediterranean*. Hellenic Institute of Transport, Athens.

Gleave, G. R.(1981). *A port traffic allocation model*. The Dock and Harbor Authority, April, pp. 374-376.

Godaliyadde, D., G. Phylip-Jones, Z. Yang, A. Batako, and J. Wang. (2010). *A Subjective Risk-Estimation Approach for Modeling Ship Hull Vibration*. Journal of Ship Research 54 (2): 95 – 108.

Griliches, Z. (1957), *Specification bias in estimates of production functions*. Journal of Farm Economics 39(1), 8–20.

Guy, E and Urli, B. (2006). *Port selection and multicriteria analysis: An application to Montreal-New York alternative*. Maritime Economics and Logistics 8: 169–186.

Handy S.L. and Clifton K.J. (2001). *Evaluating neighborhood accessibility: Possibilities and practicalities*, Journal of Transportation and Statistics 4 (2/3), pp.67-78.

Hansen, W. G. (1959). *How Accessibility Shapes Land-Use*. Journal of the American Institute of Planners 25 (2): 73–76. doi:10.1080/01944365908978307.

Hayuth, Y. (1995). *Container traffic in ocean shipping policy*. International Conference Ports for Europe, Brugge. PIE-Peter Lang Bruxelles, Pieterlen, Switzerland.

Hensher, D. e Puckett, S. (2004), *Freight distribution in urban areas: The role of supply chain alliances in addressing the challenge of traffic congestion for city logistics.* Working Paper 04-15, Institute of Transport Studies.

Imai, A., Nishimura, E., Papadimitriou, S., & Liu, M. (2006). The *economic viability of container mega-ships*. Transportation Research Part E: Logistics and Transportation Review, 42(1), 21-41.

Julián Martínez Moya & María Feo Valero (2016). *Port choice in container market: a literature review*. Transport Reviews, DOI: 10.1080/01441647.2016.1231233

Leachman, R.C. (2006). *Port and Modal Elasticity Study*. University of California at Berkeley.

Lirn, T. C., Thanopoulou, H. A., & Beresford, A. K. (2003). *Transhipment port selection and decisionmaking behaviour: Analysing the Taiwanese case*. International Jounrnal of Logistics: Research and Applications, 6(4), 229 – 244.

Lirn, TC, Thanopoulou, HA, Beynon, MJ and Beresford, AKC. (2004). *An application of AHP on transhipment port selection: A global perspective*. Maritime Economics and Logistics 6: 70–91.

Liu, J., J. B. Yang, J. Wang, and H. S. Sii. (2005). *Engineering System Safety Analysis and Synthesis Using the Fuzzy Rule - Based Evidential Reasoning Approach*. Quality and Reliability Engineering International 21 (4): 387 – 411.

Luce, R. (1959). *Individual Choice Behavior: A Theoretical Analysis*. Wiley, New York.

Magala & A Sammons, (2008). *New Approach to Port Choice Modelling*. Maritime Economics & Logistics, Vol. 10, pag. 9–34.

Malchow, M.B., Kanafani, A., (2004). *A disaggregate analysis of port selection*. Transportation Research E 40, 317–337.

Manski, C. (1977). *The structure of random utility models*. Theory and Decision 8(3), 229–254.

Marschak, J. (1960). *Binary choice constraints and random utility indicators*. in K. Arrow, S. Karlin e P. Suppes, eds, Mathematical Methods in the Social Sciences, 1959, Stanford University Press, Stanford, California, pp. 312–329.

McFadden D. (1974:b). *The measurement of urban travel demand*. Journal of Public Economics 3(4), 303–328.

McFadden, D. (1981). *Econometric models of probabilistic choice*, in C. Manskie D. McFadden, eds, Structural Analysis of Discrete Data with Econometric Applications, MIT Press, Cambridge, MA.

Morris, J. M., P. L. Dumble, and M. R. Wigan. (1979). *Accessibility Indicators for Transport Planning*. Transportation Research Part A: General 13 (2): 91–109. doi:10.1016/0191-2607(79)90012-8.

Ng, A. K. Y. (2006). *Assessing the Attractiveness of Ports in the North European Container Transhipment Market: An Agenda for Future Research in Port Competition*. Maritime Economics & Logistics 8 (3): 234 – 250.

Ng, A. S. F., Sun, D., & Bhattacharjya, J. (2013). *Port choice of shipping lines and shippers in Australia*. Asian Geographer. 30(2), 143 – 168.

Nir, A-S, Lin, K and Liang, G-S. (2003). *Port choice behaviour – from the perspective of the shipper*. Maritime Policy and Management 30: 165–173.

Notteboom, T., Rodrigue, J.-P., (2008). *Containerization, box logistics and global supply chains: the integration of ports and liner shipping networks*. Maritime Economics and Logistics 10 (1-2), 152–174.

Notteboom, T., Winkelmans, W., (2001). *Reassessing public sector involvement in European seaports*. Journal of Maritime Economics and Logistics 3 (2), 242–259.

Paixao Casaca, A., Carvalho, S. and Oliveira, M. (2010). *Port choice in the European short sea shipping market: the view of point of port authorities*. IAME 2010 Annual Conference Proceedings.

Park, B. I., & Min, H. (2011). *The selection of transshipment ports using a hybrid data envelopment analysis/analytic hierarchy process*. Journal of Transportation Management, 22(1), 47 – 64.

Pearson, R. (1980). *Container line performance and service quality*. Marine Transport Center, University of Liverpool: Liverpool.

Pooler J. (1994). *A family of relaxed spatial interaction models*. Prof. Geogr. 46, pp.210–217.

Porter, M.E. (1990). *The Competitive Advantage of Nations*. New York: Free Press.

Quandt, R. (1956). *A probabilistic theory of consumer behavior*. Quarterly Journal of Economics 70(4), 507–536.

Rietveld, et. Al, (1998). *Is transport infrastructure effective? Transport infrastructure and accessibility impacts on the space economy*. Berlin: Springer Press.

Schoner B, Wedley WC (1989). *Ambiguous criteria weights in AHP: consequences and solutions*. Decis Sci 20(3):462 – 475.

Shibasaki R. et al (2016). *Network assignment model of integrating maritime and hinterland container shipping: application to Central America*. Maritime Economics & Logistics. doi:10.1057/s41278-016-0055-3

Simme Veldman et. al (2013). *A port choice model with logit models: a case study for the Spanish container trade*. Int. J. Shipping and Transport Logistics, Vol. 5, Nos. 4/5.

Simon, H. (1978). *Rationality as process and as product of thought*'.American Economic Review 68(2), 1–16.

Sinesi S. et al. (2017). A Multivariate logic Decision Support System for optimization of the maritime routes. IEEE Xplore DOI: 10.1109/MTITS.2017.8005614 – pag. 75-79.

Slack B (1993). *Pawns in the game: ports in a global transportation system*. Growth Change 24:579 – 588.

SLACK, B. (1985). *Containerization, inter-port competition and port selection*. Maritime Policy and Management, 12, 293-303.

Song, D.W., Yeo, K.T., (2004). *A competitive analysis of Chinese container ports using the analytic hierarchy process*. Maritime Economics and Logistics 6, 34–52.

Sternberg, R.W. (2000). *The successful factors of an ocean transshipment center, a case study of one Italian port*. J. Chin. Port. 29(2):13-18.

Steven, A. B., & Corsi, T. M. (2012). *Choosing a port: An analysis of containerized imports into the US*. Transportation Research Part E: Logistics and Transportation Review, 48(4), 881 – 895.

Talley, W. K., & Ng, M. (2013). Maritime transport chain choice by carriers, ports and shippers. International Journal of Production Economics, 142(2), 311 – 316.

Tange L. Ching et al (2011). *Understanding Port Choice Behavior — A Network Perspective*. Netw Spat Econ 11:65 – 82 - DOI 10.1007/s11067-008-9081-8

Tavasszy, L., Minderhoud, M., Perrin, J. F., & Notteboom, T. (2011). *A strategic network choice model for global container flows: specification, estimation and application*. Journal of Transport Geography, 19(6), 1163-1172.

Thomson, B.J. (1998). *Structure changes in the maritime industry's impact on the inter-port competition in container trade*. International Conference in Shipping Development and Port Management. The Port of Kaohsiung, Kaohsiung, Taiwan.

Tiwari, P, Itoh, H and Doi, M. (2003). *Shippers' port and carrier selection behaviour in China: A discrete choice analysis*. Maritime Economics and Logistics 5: 23–39.

Tongzon, J.L., (2009). *Port choice and freight forwarders*. Transportation research Part E 45, 186–195.

Tversky, A. (1969). *Intransitivity of preferences*. Psychological Review 76(1), 31–48.

Tversky, A. (1972,a). *Elimination by aspects: A theory of choice*. Psychological Review 79(4), 281–299.

Ugboma, C., Ugboma, O., Ogwude, I. (2006). *An Analytic Hierarchy Process (AHP) approach to port selection decisions – empirical evidence from Nigerian ports*. Maritime Economics and Logistics, 8, 251 – 266.

Van der Lugt, L.M., De Langen P.W., & Hagdorn, L. (2007). *Value capture and value creation in the ports 'business ecosystem'*. Paper presented at the Annual

Conference of the International association of Maritime Economists (IAME) 2007, July, Athens.

Veldman, S. and Bückmann, E. (2003). *A model on container port competition: an application for the West European container hub-ports*. Maritime Economics and Logistics, Vol. 5, No. 1, pp.3–22.

Veldman, S., Garcia-Alonso, L., & Vallejo-Pinto, J. Á. (2011). *Determinants of container port choice in Spain*. Maritime Policy and Management, 38(5), 509 – 522.

Veldman, S., L. Garcia-Alonso, and J. Á. Vallejo-Pinto (2013). *A Port Choice Model with Logit Models: A Case Study for the Spanish Container Trade*. International Journal of Shipping and Transport Logistics 5 (4/5): 373– 389. doi:10.1504/IJSTL.2013.055277.

Veldman, S., L. Garcia-Alonso, and M. Liu. (2016). *Testing Port Choice Models Using Physical and Monetary Data: A Comparative Case Study for the Spanish Container Trades*. Maritime Policy & Management 43 (4): 495–508. doi:10.1080/03088839.2015.1099754.

Wan, G. C.(1980.) *A transportation demand split model for international port in Taiwan area*. Master thesis, National Chiao-Tung University, Taiwan.

Wang, J. (1997). *A Subjective Methodology for Safety Analysis of Safety Requirements Specifications*. Fuzzy Systems, IEEE Transactions 5 (3): 418 – 430.

Wang, Y and Cullinane, K. (2006). *Inter-port competition and measures of individual container port accessibility*. Magala, M. (ed). Proceedings of the IAME Conference, The University of Melbourne, Melbourne, Australia, 2006.

Wiegmans, B. W., A. V. D. Hoest, and T. E. Notteboom. (2008). *Port and Terminal Selection by Deep-Sea Container Operators*. Maritime Policy & Management 35 (6): 517 – 534.

Willingale, M. (1981). *The Port-Routeing Behaviour of Short-Sea Ship Operators: Theory and Practice*. Maritime Policy & Management 8 (2): 109 – 120.

Woo, S-H. et al. (2011). *Seaport research: a structured literature review on methodological issues since the 1980s*. Transportation Research Part A: Policy and Practice, Vol. 45, No. 7, pp.667–685.

Yang, Z., L. Mastralis, S. Bonsall, and J. Wang. (2009). *Incorporating Uncertainty and Multiple Criteria in Vessel Selection*. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment 223 (2): 177 – 188.

Yang, Z.-L., J. Wang, S. Bonsall, J.-B. Yang, and Q.-G. Fang. (2005). *A Subjective Risk Analysis Approach of Container Supply Chains*. International Journal of Automation and Computing 2 (1): 85 – 92.

YEO et. al (2015). *Modelling port choice in an uncertain environment*. Maritime Policy & Management. - Vol. 41, No. 3, 251 – 267, http://dx.doi.org/10.1080/03088839.2013.839515

Yeo, G. T., Ng, A. K., Lee, P. T. W., & Yang, Z. (2013). *Modelling port choice in an uncertain environment*. Maritime Policy and Management (ahead-of-print), 1 – 17.

Yeo, G. T., Roe, M., & Dinwoodie, J. (2008). *Evaluating the competitiveness of container ports in Korea and China*. Transportation Research Part A: Policy and Practice, 42(6), 910 – 921.

Yuen, C. L. A., Zhang, A., & Cheung, W. (2012). *Port competitiveness from the users ' perspective: An analysis of major container ports in China and its neighboring countries*. Research in Transportation Economics, 35(1), 34 – 40.

Zong-Hwa Consultant Co.(1978). *Forecasting the volumes of cargoes and the ship-berth demand of Keelung port*. Project Report.

APPENDIX A

	Genoa (Italy)		*Barcelona (Spain)*		*Marseilles (France)*	
April 2017	*PCM-DAI output Probability*	*Real choice data*	*PCM-DAI output Probability*	*Real choice data*	*PCM-DAI output Probability*	*Real choice data*
1	36,08 %	40,00%	27,83%	20,00%	36,08%	40,00%
2	39,58 %	42,85%	20,75%	14,29%	39,66%	42,86%
3	41,66 %	42,85%	16,66%	14,29%	41,68%	42,86%
4	41,46 %	40,00%	17,05%	20,00%	41,49%	40,00%
5	27,68 %	33,33 %	36,16%	33,33%	36,15%	33,33%
6	40,33 %	37,5 %	19,37%	25,00%	40,30%	37,50%
7	38,61 %	40,00%	22,73%	20,00%	38,66%	40,00%
8	37,11%	33,33%	25,82%	33,33%	37,06%	33,33%
9	26,75%	25,00%	36,61%	37,50%	36,64%	37,50%
10	34,93%	33,33%	34,93%	33,33%	34,91%	33,33%
11	50,57%	55,56%	24,72%	22,22%	24,71%	22,22%
12	23,35%	20,00%	38,33%	40,00%	38,32%	40,00%
13	34,13%	33,33%	34,13%	33,33%	31,74%	33,33%
14	19,35%	25,00%	40,37%	41,67%	40,28%	33,33%
15	24,45%	27,27%	37,76%	36,36%	37,79%	36,36%
16	22,86%	25,00%	38,60%	37,50%	38,54%	37,50%
17	35,18%	37,50%	29,61%	25,00%	35,22%	37,50%
18	36,25%	33,33%	27,45%	33,33%	36,31%	33,33%
19	34,89%	36,36%	30,20%	27,27%	34,91%	36,36%
20	35,61%	37,50%	35,59%	37,50%	28,80%	25,00%
21	34,14%	37,50%	31,72%	25,00%	34,14%	37,50%
22	38,64%	40,00%	38,63%	40,00%	22,72%	20,00%

23	26,93%	33,33%	36,54%	33,33%	36,53%	33,33%
24	28,37%	28,57%	35,82%	28,57%	35,81%	42,86%
25	35,67%	42,86%	35,61%	28,57%	28,72%	28,57%
26	25,24%	30,00%	37,38%	30,00%	37,38%	40,00%
27	22,56%	20,00%	38,72%	40,00%	38,71%	40,00%
28	32,89%	37,50%	33,79%	25,00%	33,32%	37,50%
29	24,77%	28,57%	37,60%	28,57%	37,63%	42,86%
30	32,78%	30,00%	33,61%	40,00%	33,61%	30,00%

Table A1 - PCM-DAI output for the month of April 2017, compared with real choice data.

North Sea area					
Origin i		**Destination j**			
Port	**Country**	**Port**	**Country**	$Lc_{ij_{imp}}$ (M$)	$Lc_{ij_{exp}}$ (M$)
Antwerp	***Belgium***	***Antwerp***	Belgium	-	-
		Bilbao	Spain	9,525	8,748
		Bremerhaven	Germany	53,34	42,12
		Felixtowe	UK	17,526	32,076
		Gothenburg	Sweden	7,62	6,804
		Hamburg	Germany	53,34	42,12
		Le Havre	France	36,576	42,12
		Rotterdam	Nederlands	57,15	42,12
Bilbao	***Spain***	***Antwerp***	Belgium	2,0387	1,918
		Bilbao	Spain	-	-
		Bremerhaven	Germany	9,842	6,028
		Felixtowe	UK	2,8823	4,2196
		Gothenburg	Sweden	0,58349	0,3836
		Hamburg	Germany	9,842	6,028
		Le Havre	France	8,436	7,672
		Rotterdam	Nederlands	2,9526	1,644
Bremerhaven	***Germany***	***Antwerp***	Belgium	39,4065	52500000
		Bilbao	Spain	29,19	41250000
		Bremerhaven	Germany	-	-
		Felixtowe	UK	35,028	87500000
		Gothenburg	Sweden	14,595	100000000
		Hamburg	Germany	-	-
		Le Havre	France	70,056	100000000
		Rotterdam	Nederlands	79,786	72500000
Felixtowe	***UK***	***Antwerp***	Belgium	32,277	17,578
		Bilbao	Spain	20,706	12,342
		Bremerhaven	Germany	85,26	35,53
		Felixtowe	UK	-	-
		Gothenburg	Sweden	8,526	6,358
		Hamburg	Germany	85,26	35,53
		Le Havre	France	35,322	22,44

		Rotterdam	Holland	44,457	22,44
Gothenburg	***Sweden***	***Antwerp***	Belgium	6,681	7,581
		Bilbao	Spain	1,834	2,527
		Bremerhaven	Germany	24,89	14,63
		Felixtowe	UK	6,55	8,379
		Gothenburg	Sweden	-	-
		Hamburg	Germany	24,89	14,63
		Le Havre	France	5,633	5,985
		Rotterdam	Nederlands	11,004	7,182
Hamburg	***Germany***	***Antwerp***	Belgium	39,4065	52500000
		Bilbao	Spain	29,19	41250000
		Bremerhaven	Germany	-	-
		Felixtowe	UK	35,028	87500000
		Gothenburg	Sweden	14,595	100000000
		Hamburg	Germany	-	-
		Le Havre	France	70,056	100000000
		Rotterdam	Nederlands	79,786	72500000
Le Havre	***France***	***Antwerp***	Belgium	41,8	36,852
		Bilbao	Spain	36,85	34,362
		Bremerhaven	Germany	99	69,72
		Felixtowe	UK	22,55	34,362
		Gothenburg	Sweden	6,05	5,478
		Hamburg	Germany	99	69,72
		Le Havre	France	-	-
		Rotterdam	Nederlands	26,4	16,932
Rotterdam	***Holland***	***Antwerp***	Belgium	42,8	57,82
		Bilbao	Spain	8,132	12,803
		Bremerhaven	Germany	72,76	78,47
		Felixtowe	UK	22,256	45,43
		Gothenburg	Sweden	7,276	11,151
		Hamburg	Germany	72,76	78,47
		Le Havre	France	16,692	26,432
		Rotterdam	Nederlands	-	-

Table A2 - Volume of container imported and exported via sea in the 2016 between countries in the area of North Sea.

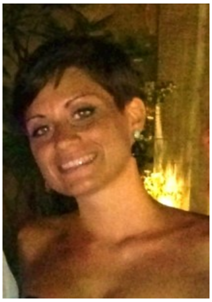
Source: The Observatory of Economic Complexity (OEC).

		Mediterranean Sea area			
Origin i		***Destination j***			
Port	**Country**	**Port**	**Country**	$Lc_{ij_{imp}}$ **(M$)**	$Lc_{ij_{exp}}$ **(M$)**
Algeciras	***Spain***	***Algeciras***	Spain	-	-
		Barcelona	Spain	-	-
		Genoa	Italy	20,4	20,79
		Malta	Malta	0,102	0,243
		Marseilles	France	36	37,8
		Piraeus	Greece	0,63	1,755
		Valencia	Spain	-	-
Barcelona	***Spain***	***Algeciras***	Spain	-	-
		Barcelona	Spain	-	-
		Genoa	Italy	20,4	20,79
		Malta	Malta	0,102	0,243
		Marseilles	France	36	37,8
		Piraeus	Greece	0,63	1,755
		Valencia	Spain	-	-
Genoa	***Italy***	***Algeciras***	Spain	20,644	20,654
		Barcelona	Spain	20,644	20,654
		Genoa	Italy	-	-
		Malta	Malta	0,38509	1,4368
		Marseilles	France	35,333	43,553
		Piraeus	Greece	2,8187	3,9512
		Valencia	Spain	20,644	20,654
Malta	***Malta***	***Algeciras***	Spain	0,2398	0,103338
		Barcelona	Spain	0,2398	0,103338
		Genoa	Italy	1,417	0,384647
		Malta	Malta	-	-
		Marseilles	France	0,3379	0,281309
		Piraeus	Greece	0,1526	0,024112
		Valencia	Spain	0,2398	0,103338
Marseilles	***France***	***Algeciras***	Spain	36,85	34,362
		Barcelona	Spain	36,85	34,362
		Genoa	Italy	43,45	35,358
		Malta	Malta	0,2805	0,33366

		Marseilles	France	-	-
		Piraeus	Greece	0,715	2,0916
		Valencia	Spain	36,85	34,362
Piraeus	***Greece***	***Algeciras***	Spain	1,7612	0,636
		Barcelona	Spain	1,7612	0,636
		Genoa	Italy	3,9508	2,915
		Malta	Malta	0,024276	0,15635
		Marseilles	France	2,0944	0,742
		Piraeus	Greece	-	-
		Valencia	Spain	1,7612	0,636
Valencia	***Spain***	***Algeciras***	Spain	-	-
		Barcelona	Spain	-	-
		Genoa	Italy	20,4	20,79
		Malta	Malta	0,102	0,243
		Marseilles	France	36	37,8
		Piraeus	Greece	0,63	1,755
		Valencia	Spain	-	-

Table A3 - Volume of container imported and exported via sea in the 2016 between countries in the area of Mediterranean Sea.
Source: The Observatory of Economic Complexity (OEC).

C U R R I C U L U M V I T A E



PERSONAL INFORMATION

Name	**SINESI STEFANIA**
Adress	S.C. SPINE ROSSINE, 10 – 70017 – PUTIGNANO (BA)
Mobile Phone	+39 392 5077322
E-mail	stefania.sinesi@poliba.it , sinesistefania@gmail.com
Pec	stefania.sinesi@ingpec.eu
Nazionality	Italian
Date of birth	22/03/1985, Milan
Sex	Female
PROFESSIONAL QUALIFICATION	Civil and Environmental Engineer
PROFESSIONAL REGISTRATION	Ordine degli Ingegneri della Provincia di Bari - Sez. A al n. 11264
DEGREE	Civil Engineer (110 cum Laude) – Title of master thesis: “Study for a general accessibility model related to major European ports” - Technical University of Bari Environmental engineering and land - *Title of master thesis:* “Safety and security in airports”. - Technical University of Bari
ACCADEMIC EXPERIENCE	From A.A. 2015/16 to today Research activity: “Decision Support Systems for the maritime companies based on the optimization of the routes”. – Scientific Tutor Prof. M. Dell’Orco - Technical University of Bari From A.A. 2015/16 to today

Research activity : “Cycling accessibility models and users’ behaviour”. – Scientific Tutor Prof. M. Dell’Orco - Technical University of Bari

From A.A 2015/2016 to A.A 2017/2018

Academic Tutor – DICATECh Department - Technical University of Bari

From A.A 2015/2016 to A.A 2017/2018

Teaching support – “Technical and economics of transport” - Technical University of Bari

From 29/05/2018 to 4/06/2018

Lecturer of the corse: “Ground Accessibility Models” – University of Belgrade, Serbia.

April 2018

Lecturer of the corse: "Integrated transport system".- Istituto Tecnico Superiore (ITS) – Taranto, Italy.

November 2017

Lecturer of the corse: "Transportation Management". - Istituto Tecnico Superiore (ITS) – Taranto, Italy.

October 2017

Lecturer of the corse: "Simulation Laboratory for Warehouse Management and Intermodal Transport Processes".- Istituto Tecnico Superiore (ITS) – Taranto, Italy.

18/05/2017

Seminar Lecturer: “Sustanability of tourist routes: a model of Accessibility for cycle routes. The case of the “Grande Raccordo Anulare in Bici” (Major beltway by bike) in Rome”. – University of Belgrade, Serbia.

22/06/2017

Seminar Lecturer: "Accessibility models for freight ports". – University of Belgrade, Serbia.

A.A 2016/2017

Research activity : "Analysis and processing of data for a general accessibility model applicable to cycle-tourist routes in different territorial contexts". – Scientific Tutor Prof. M. Dell'Orco - Technical University of Bari

From A.A 2010/2011 to A.A.2014/2015

Tutors coordinator of the faculty of Engineering of the province of Bari, Foggia, Matera and Potenza - University Studies e-Campus, Italy.

DEGREE THESIS CORRELATION

"A microsimulation model for the analysis or circulation plans: the case of Carbonara di Bari" – Technical University of Bari

"Demand Model for Electric Car Charging Station. Application to real cases. " - Technical University of Bari

"A Bi-level model of airport choice"- Technical University of Bari

"Innovative systems for railway traction with low environmental impact: the use of hydrogen fueled fuel cells"

WORK EXPERIENCE

From 08/06/2018 to today

Transport modeling service in the context of the 2015-2019 transport plan monitoring. - ASSET - Agenzia regionale Strategica per lo Sviluppo Ecosostenibile del Territorio

From 1/07/2015 to 30/09/2015

Head of logistics - Autotrasporti Perchinelli Gregorio
Trinitapoli (BT), Italy

MOTHER LANGUAGE Italian

OTHER LANGUAGE English (B2), French (A2)

SOFTWARE USED Aimsun, Labview, Matlab, Office suite, Visum.

SCIENTIFIC PUBLICATIONS

"A BI-LEVEL AIRPORT CHOICE MODEL (BACM) IN A MULTI-AIRPORT CONTEXT. THE CASE OF ROME."
S. Sinesi, M. G. Altieri, M. Dell'Orco - ISBN: 978-86-80593-64-7, pag 422-427.

"A DECISION SUPPORT SYSTEM FOR THE MARITIME COMPANIES, BASED ON A DYNAMIC ACCESSIBILITY INDICATOR."
S. Sinesi, M. G. Altieri, M. Dell'Orco, M. Marinelli, M. Ottomanelli - SIET 2017.

"ECO-FRIENDLY TOURIST ROUTE: A MODEL OF ACCESSIBILITY FOR CYCLE ROUTES."
S. Sinesi, M. G. Altieri, M. Dell'Orco, M. Ottomanelli - I-CiTies 2017.

"A MULTIVARIATE LOGIC DECISION SUPPORT SYSTEM FOR OPTIMIZATION OF THE MARITIME ROUTES."
S. Sinesi, M. Marinelli, M. G. Altieri, M. Dell'Orco - IEEE MT-ITS 2017 – IEEE Xplore - DOI: 10.1109/MTITS.2017.8005614 – pag. 75-79.

"EVIDENCE (DEMPSTER – SHAFFER) THEORY – BASED EVALUATION OF DIFFERENT TRANSPORT MODES UNDER UNCERTAINTY. THEORETICAL BASIS AND FIRST FINDINGS."
M. G. Altieri, M. Dell'Orco, M. Marinelli, S. Sinesi - EWGT 2017- DOI: 10.1016/j.trpro.2017.12.117 - pag. 508-5015.