TRANSPORT AND THE ENVIRONMENTAL IMPACTS OF CRUISE SHIPS. APPLICATION TO THE PORT OF BARCELONA

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ELS IMPACTES EN EL TRANSPORT I AMBIENTALS DELS CREUERS. APLICACIÓ AL PORT DE BARCELONA

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Per la meva família i amics
que han cregut en mi
i m'han encoratjat a seguir
endavant amb la tesi

Transport and the environmental impacts of cruise ships. Application to the Port of Barcelona.

Sergi Ros Chaos

Abstract

The rapid evolution of the cruise industry in the last 50 years is evident. In the nineteenth century, cruise ships were simple modes of transport used by immigrants to travel on transoceanic voyages from Europe to North America in search of a better future. Now, they have become authentic floating cities full of amenities and activities to do on board, whose main objective is leisure and pleasure. Passengers no longer go on a cruise ship simply to get from one point to another. Instead, they seek a unique experience on the ship and do not care so much about the final destination. For this reason, many experts consider that cruise ships have become a travel destination in themselves.

This evolution of the concept of cruise ship that occurred in the 1970s has not been easy. It has led to a set of problems that have significantly affected ports and the cities that host them, and to which they have had to adapt.

The main change is associated with the increase in size of the ships to accommodate more passengers and all the on-board activities. To receive this type of ships, ports have had to adapt their berthing line, maritime station, adjacent esplanade and road accesses, among other factors. All this has been undertaken to accommodate the ship and the passengers when they embark or disembark. These ships can carry about 5,400 passengers plus 2,000 crew. Consequently, cruise ships are the mode of transport with the highest capacity. They have been increasing in size every year. In 2009, a ship reached 360 m in length and 222,900 GT of gross tonnage. Since then, no larger ship has been built. Given the apparent gigantism of ships in the cruise industry, this thesis aims to verify and analyse whether an increase in cruise ship capacity and size is justified and supported by economies of scale, as in the case of other types of ship like container ships. The principle of economies of scale states that an increase in the scale of production (in this case the size of the ship) implies a reduction in unit costs. The

conclusions could help to foresee the direction the cruise industry will take in the coming years: towards stagnation in the size of cruise ships or towards cruises of even larger size.

The large passenger capacity of these ships also entails difficulties in managing passenger mobility, especially when more than two cruises concur in the same time slot. In this case, the disembarkation operation becomes very complex, since passengers all leave at once and in a short period of time. Therefore, to manage mobility well, it is essential to have the most detailed knowledge possible of how, when and why disembarking operations are carried out. This is essential to allocate the necessary resources (traffic regulators, sufficient modes of transport, esplanades, enough roads, etc.), give passengers a good service, avoid long waiting times and queues and try to prevent road accesses between the port and the city from collapsing.

This thesis analyses the mobility of passengers on the ground and studies the main variables that explain disembarking operations. These can help to size the various spaces and detect the mobility needs of a cruise terminal.

Another important aspect of great media relevance in recent years is the impact that cruise ships have on the environment. Moving cruise ships at service speed (16–20 knots) requires a large amount of fuel. Consequently, polluting gases, mainly nitrogen oxides, sulfur oxides, suspended particles and greenhouse gases, are emitted in greater amounts into the environment. Due to the enormous growth in the cruise market, many voices have been raised in the civilian population and public administrations that reject cruise tourism completely. For this reason, by 2020, more restrictive environmental regulations had been created through the International Maritime Organization (IMO), mainly limiting the sulfur content in marine fuels to 0.5%. Shipowners have various options to meet these requirements: use scrubbers (that is, filters in ships’ chimneys) together with catalytic reduction devices, use distilled fuels and less pollutants, the cold ironing solution to connect electrically at the docks to obtain energy or use liquefied natural gas (GNL) as an alternative fuel.

The last section of this thesis tries to determine whether LNG could be the most valid option for cruise lines to mitigate emissions to the environment and thus comply with the new environmental restrictions. LNG almost completely eliminates emissions of sulfur oxides and particles. Nitrogen oxides and CO_2 are reduced by 90% and 20% respectively. Furthermore, the price of LNG is almost half that of heavy fuel oil, which makes LNG economically attractive. In contrast, the main negative aspects are the high initial investment that companies must face and the loss of space for cabins to locate LNG tanks. LNG has a density half that of conventional fuels, so it takes almost twice as much volume as conventional fuels to provide the same energy. The idea of adopting

LNG as a cruise fuel is quite new. Very few cruise ships in the world are adapted to this system. Therefore, an analysis and study of its viability is advisable and may help cruise companies to decide whether to adopt LNG as the majority fuel for cruise ships.

Keywords: Cruise shipping; Economies of scale; Cruise gigantism; Cost model; Mobility impacts; Modal distribution; Passenger flow; Environmental impacts; Emissions; Liquefied Natural Gas.

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Els impactes en el transport i ambientals dels creuers. Aplicació al Port de Barcelona

Sergi Ros Chaos

Resum

La ràpida evolució de la indústria dels creuers en els darrers 50 anys és evident. Els creuers que al segle XIX eren simples modes de transport utilitzats pels immigrants en viatges transoceànics des d'Europa a Amèrica del Nord a la recerca d'un futur millor, s'han convertit en autèntiques ciutats flotants plenes de serveis i activitats a bord, en les quals l’objectiu principal ha passat a ser el lleure i el plaer. Els passatgers ja no agafen un creuer pel simple fet de desplaçar-se d’un punt a un altre, sinó que busquen viure una experiència única dins del vaixell i no els importa tant el destí final del seu viatge. Per aquest motiu, molts experts consideren que el creuer ha esdevingut un destí de viatge en si mateix.

Aquesta evolució del concepte del creuer iniciada en la dècada dels anys 70 no ha estat senzilla i ha comportat un conjunt de problemàtiques que han afectat de manera molt significativa als ports i les ciutats que acullen creuers, i pels que s'han hagut d’adaptar.

El principal canvi ha tingut a veure amb l’augment de la mida dels vaixells per encabir més passatgers i totes les activitats que es desenvolupen al seu interior. Per rebre aquest tipus de vaixells, els ports van haver d’adaptar la seva línia d’atracada, l’estació marítima, l’esplanada contigua i els accessos per carretera, etc. Tot això, per donar cabuda tant al vaixell com als passatgers, un cop aquests s’embarquen o desembarquen a terra. No és pot oblidar que aquests vaixells són capaços de transportar prop de 5.400 passatgers més 2.000 tripulants. En aquest sentit, els creuers són el mode de transport de major capacitat. Els creuers han anat augmentat de mida cada any fins a assolir a l’any 2009, els 360 m d’eslora i 222.900 GT d’arqueig brut. Des de llavors no s’ha construït cap vaixell de major tamany. Davant d’aquest aparent gigantisme dels vaixells en la indústria de creuers, la present tesi pretén verificar i analitzar si aquest augment de la

capacitat i mida dels creuers està justificat i es recolza en les economies d'escala, com és el cas d'altres tipus de vaixells com els vaixells portacontenidors. El principi de les economies d'escala estableix que un augment en l'escala de producció (en aquest cas la mida del vaixell) implica una reducció dels costos unitaris. Amb això, es podria preveure la direcció que seguirà la indústria creuerística en els propers anys, si cap a un estancament de la mida dels creuers o, pel contrari, cap a creuers d'inclús major tamany.

La gran capacitat en passatge d'aquests vaixells també comporta dificultats per gestionar la mobilitat dels creueristes, sobretot quan coincideixen més de dos creuers a la mateixa franja horària. Aleshores l'operació de desembarcament esdevé molt complexa, ja que tots els passatgers surten alhora i en un curt període de temps. Per tant, per gestionar bé la mobilitat resulta imprescindible tenir el màxim coneixement possible de com, quan i per què es realitzen les operacions de desembarcament, de manera a assignar els mitjans necessaris (reguladors de trànsit, modes de transport suficients, esplanades, vials suficients, etc.), per donar un bon servei als passatgers, evitant llargs temps d'espera i cues i intentant evitar que els accessos entre el port i la ciutat es col·lapsin.

En aquest sentit, la tesi analitza la mobilitat dels passatgers a terra i estudia les principals variables que expliquen les operacions de desembarcament. Aquestes poden ajudar a dimensionar els diferents espais i detectar les necessitats de mobilitat d'un terminal de creuers.

Un altre aspecte important que no es pot oblidar i de gran rellevància mediàtica en els darrers anys és l'impacte que tenen els creuers sobre el medi ambient. Per desplaçar els creuers a una velocitat de servei (16-20 nusos) es requereix una gran quantitat de combustible. Això comporta l'emissió a l'atmosfera de gasos contaminants, principalment òxids de nitrogen, òxids de sofre, partícules en suspensió i gasos d'efecte hivernacle. Actualment, i a causa de l'enorme creixement del mercat dels creuers, han sorgit moltes veus entre la població civil i les administracions públiques que rebutgen completament el turisme de creuers. Per aquest motiu, per l'any 2020, s'han creat noves normatives mediambientals més restrictives a través de l'OMI, limitant principalment el contingut de sofre en els combustibles marins al 0,5%. Els armadors tenen diverses opcions per complir amb aquests requisits: utilitzar *scrubbers* (això és, filtres a les xemeneies dels vaixells) juntament amb dispositius de reducció catalítica, utilitzar combustibles destil·lats i menys contaminants, la solució del *cold ironing* per connectar-se elèctricament als molls i obtenir energia o utilitzar el gas natural liquat (GNL) com a combustible alternatiu.

En aquest sentit, la present tesi en aquest darrer bloc tracta d'esbrinar si el GNL pot ser l'opció més vàlida per a les companyies de creuers per mitigar les emissions al medi i

complir així amb les noves restriccions mediambientals. El GNL elimina gairebé completament les emissions d'òxids i partícules de sofre. Pel que fa als òxids de nitrogen i el CO_2, aquests es redueixen un 90% i un 20% respectivament. A més, el preu del GNL resulta gairebé la meitat que el fuel pesat, pel que el GNL també és atractiu econòmicament. Per contra, com aspectes negatius més rellevants es troben l'alta inversió inicial que les companyies han d'afrontar i la pèrdua d'espai per a cabines per situar els dipòsits de GNL. Cal recordar que el GNL té una densitat que és la meitat que la dels combustibles convencionals, de manera que es necessita gairebé el doble que els combustibles convencionals per proporcionar la mateixa energia.

La idea d'adoptar el GNL com a combustible per a creuers és força nova. Al món, existeixen molt pocs creuers adaptats a aquest sistema. Per tant, l'anàlisi i estudi de la seva viabilitat resulta molt aconsellable i pot servir a les companyies de creuers per decidir-se finalment en adoptar el GNL com a combustible majoritari per als seus creuers.

Paraules clau: Creuers; Economies d'escala; Gegantisme de creuers; Model de cost; Impactes en la mobilitat; Distribució modal; Flux de passatgers; Impactes ambientals; Emissions; Gas Natural liquat.

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A ship should not ride on a single anchor,
nor life on a single hope.

Epitectus

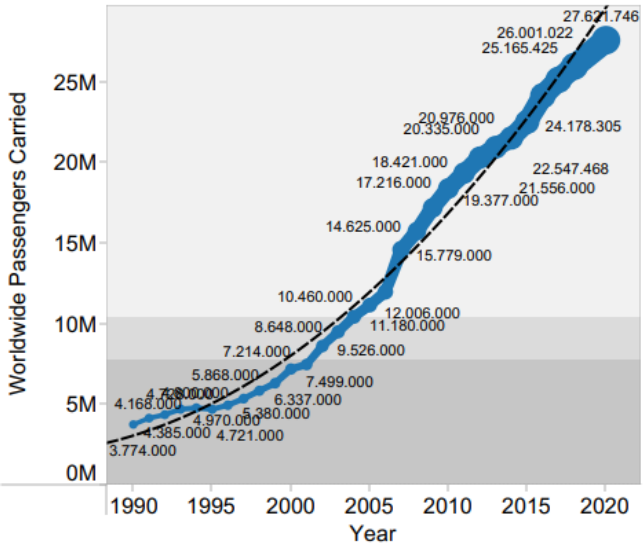
Chapter 1

Introduction

1.1. Background and objectives

Worldwide, cruise tourism represents one of the fastest growing segments of the international tourism market. It has experienced significant growth since the 1990s. By 2020, it had reached 27.6 million passengers and the expectation is that it will continue to grow (**CLIA, 2020**).

Figure 1.1. *Increase in worldwide passengers carried.*



Source: Cruise Market Watch (2020).

The growing evolution of cruise tourism in passenger volume, number of calls, new destinations and size of cruise ships has led to a series of economic, environmental and social impacts on the cities and ports that host the ships. Many of these problems are new, as the concept of cruise ship has changed and they now have much larger dimensions, which pose new challenges and create needs that were never imagined before.

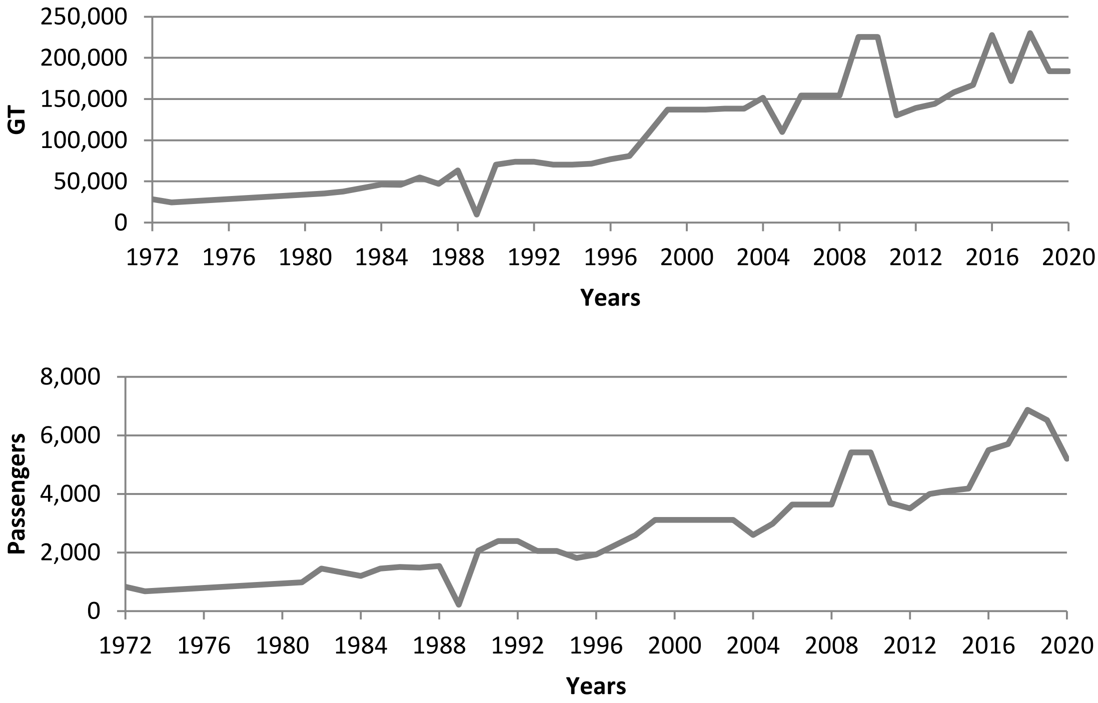
Considering the recent development of the cruise ship, very little research has been done in this field to date. Most existing studies are associated with the economic effects of cruise passengers on the destination, especially in relation to the profile and spending of the cruise passenger, to evaluate whether cruise tourism is beneficial to the community economy (**Henthorne, 2000; Brida et al., 2010; Río and Cruz, 2008, 2008; Pallis, 2015**). These studies conclude that cruise activity is beneficial to the local economy of the city, since in addition to benefits obtained by the activity itself, it involves and encourages other sectors of the tourism industry such as the transport sector, accommodation, the restaurant business and trade (**Brida et al., 2010**).

Cruise tourism also has a social impact. The large daily influx of passengers, especially in the short term, has a negative impact on the local population's quality of life. It can produce uniformity in the city's shops and reduce the passengers' experience with the local culture (**Klein, 2011**). Passengers move through the city en masse, often affecting the local population and interrupting their routines. The port authorities are aware of this situation and make efforts to avoid crowds caused by cruise passengers. They promote measures such as deseasonalizing the arrival of cruise ships throughout the year rather than just in summer, and encouraging the modality of origin-destination cruise ships, whose passengers start or finish the trip at the same port and therefore do not make group excursions to the most emblematic sites in the city.

The third impact of cruise ships is associated with the environment. Despite the fact that the transport of passengers by sea is the most profitable transportation option from an environmental perspective compared to road, rail or air transport, cruise ships also emit polluting gases into the atmosphere that cannot be overlooked (**Butt, 2007**). A cruise ship emits 0.502 kg of CO_2 to the atmosphere per kilometre and per passenger (**Carnival Corporation, 2018**). In global terms, cruise ships were responsible in European territory for 176,817 tons of NO_x, 96,965 tons of SO_2, 7,168,331 tons of CO_2 and 17,283 tons of PM (**European Commission, 2009**). These pollutants cause degradation of the environment and the ecosystems that surround them through acidification of rain or global warming (**Poplawski, 2011**). Given the proximity of ports to urban areas, they also have negative effects on human health that can be translated into premature mortality, allergies, asthma and bronchitis, among others (**IAPH, 2007; Maragkogianni and Papaefthimiou, 2015**).

All these impacts acquire a new dimension and are aggravated by the increase in size of cruise ships. To get an idea of this increase, **Figure 1.2** shows the evolution of cruise ships in terms of size and passenger capacity. From a maximum size of 28,620 GT and 820 passengers in 1972, cruise ships have grown to around 230,000 GT and 6,870 passengers in 2018. This represents an average percentage increase per year of 19% in GT and 25% in passengers.

Figure 1.2. *Evolution of the maximum GT and passenger capacity in a cruise ship.*



Source: Cruise Mapper (2018)

Thus, the main objective of this doctoral thesis is to gain more knowledge about the new phenomenon of cruise ships today and the main problems that are implicit in them. These objectives are:

- Analyze the growth capacity of cruise ships through economies of scale to predict where the cruise industry is heading.
- Evaluate the impact that cruise ship passengers have on mobility.
- Assess the possibility of adopting less polluting cruise fuels such as liquefied natural gas (LNG).

1.2. Research scope of the thesis

The scope of this doctoral thesis is the study and analysis of how the new reality of cruise ships affects the city and the ports that host them.

Of all the new problems that have arisen as a result of the cruise ship phenomenon, two have been chosen for the study: the impact on mobility and the impact on the environment. These are specific problems that have not yet been resolved and studied in depth. Various bodies (shipping companies and port authorities) are currently working to solve them.

- Analysis of the increase in size and capacity of cruise ships

The first aspect that caught our attention when we began to study the phenomenon of cruise ships was the large size and passenger capacity that they have reached, which even exceeds the passenger capacity of airplanes.

Given the increase in cruise ship size, the first thing we considered was to study their feasibility. We aimed to verify from an economic perspective whether this growth was supported by economies of scale and justified further growth of cruise ships in coming years.

To answer this question, a cost model was developed considering capital, operating and voyage costs and taking the number of passengers as the unit of the average cost. The database was comprised of 246 cruises (**Ward, 2015**). Economies of scale were studied in container ships (**Cullinane and Khanna, 2000; Sys et al., 2008; Tran and Haasis, 2015; Van Hassel et al., 2016**), bulk carriers (**Kendall, 1972; Jansson and Shneerson, 1982**) and ferries (**Saurí et al., 2009**) but not cruise ships. Hence, the cost model was designed to determine whether gigantism on cruise ships was supported by economies of scale, in other words, whether increasing the passenger capacity of cruise ships would reduce total unit costs (per passenger unit).

- Assessment of the impact of cruise passengers on mobility

The first question, of growing concern for the port and the city, is the mobility problem caused by the new reality of cruise ships. Cruise ships move large numbers of passengers: each ship carries an average of 2,000 passengers up to a maximum of 5,400 (**Ward, 2015**).

The embarking and especially the disembarking of passengers is very complex and its management is usually a challenge, especially when more than two cruise ships coincide in the same time slot. Cruise ships in transit mode usually aggravate this problem, since in this modality they call at port for a few hours and the passengers use this time to make excursions and visit the city, leaving the ship for a very short period only.

For this reason, a study of this situation is justified to determine how, when and why mobility problems arise and to identify which factors influence the flow of passengers and what modes of transport they choose. The results will help to improve the management and service that is given to passengers.

Therefore, a mobility analysis was carried out by focusing on the Port of Barcelona, for which data are available. The Port of Barcelona is considered a representative cruise port since it has seven cruise terminals where the vast majority of companies in the sector operate, with cruises of various typologies.

The analysis can quantify in time and according to the type of cruise ship (turnaround, transit or mixed) the distribution of passengers in the various modes of transport available (taxis, public buses, shuttle buses, excursion buses or private vehicles). Consequently, the passengers' behaviour once they have disembarked can be predicted. That is, we can determine how, when and for what reasons the flow of passengers occurs in disembarking operations. The mobility analysis also gives us an idea of how the modal choice of passengers occurs. Through these results, we can estimate the volume of vehicles that is generated due to the cruise activity and take pertinent measures to improve mobility in the accesses to the city.

<u>- Assessment of adopting liquefied natural gas (LNG) as an alternative fuel for cruise ships</u>

The second question to analyze is the possibility of cruise companies adopting liquefied natural gas (LNG) as fuel for their ships, to comply with the environmental requirements established by the International Maritime Organization (IMO) for reducing pollution.

Air pollution is a topic of great current interest with considerable media coverage, especially as a result of recent events in the world attributed to climate change, including floods, rising sea levels, droughts and hurricanes. As a consequence, numerous voices have emerged in civil society urging public administrations to act and promote measures to combat climate change. One of these measures is associated with restrictions on emissions of polluting gases from ships. To meet the new standards, ships will need to replace their current heavy fuel oil (HFO) with other less polluting fuel sources.

Among all the possible options (distilled fuels, scrubbers or cold ironing), the use of LNG as a fuel is analysed since it seems to be one of the most competitive options in the long term, especially from an economic point of view. It should be noted that cruise lines have not yet selected any option, since each one has advantages and disadvantages, which make the choice very difficult.

From a technical perspective, LNG poses some challenges. They include avoiding the loss of space for cabins that this technology involves due to the installation of LNG tanks and other extra regasification equipment, increasing the availability of ports that can directly supply LNG to ships and taking the extreme security measures necessary to avoid an accident due to the high flammability and explosiveness of LNG.

The present thesis delves into these questions to study and analyze the feasibility of LNG becoming the main fuel for cruise ships in coming years. For this purpose, an economic analysis was undertaken that included an estimate of the capital investment costs of the LNG system and its operating costs, and a comparison with other systems that are currently adopted to reduce pollution (scrubbers + selective catalytic reduction [SCR]). This analysis made it possible to determine how long it would take to recover the investment. Additionally, a comparison of bunkering operations was carried out: truck-to-ship (TTS), ship-to-ship (STS), and tank-to-ship via pipeline (TPS). The way in which LNG would influence cruise itineraries was also studied, since very few ports have the necessary infrastructure to supply LNG to ships. Finally, a series of recommendations were proposed to encourage the adoption of LNG in cruise ships.

1.3. Main contribution of the thesis

This thesis is a compendium of articles. There are three articles that coincide with chapters 3, 4 and 5 of the thesis. Two of the articles have already been published in international journals (all of them Q1) and the third has been sent and is awaiting acceptance.

A thesis by compendium of articles is justified because the articles explain specific aspects of cruises that are currently believed to be of vital importance and have not been investigated to date. In addition, the articles complement each other. The main contributions of these scientific papers to the literature are described below.

In relation to the cruise industry:

- An analysis of the increase in cruise ship size and verification of whether it is supported by economies of scale, that is, whether an increase in size implies a decrease in average costs.
- Development of a cost model adapted to the case of cruise ships that can quantify the capital, operation and voyage costs.
- Analysis of the sensitivity of these costs to the variables of sailing speed and distance travelled.
- Determination of the optimal size of the ship according to criteria that support economies of scale.
- Assessment of the direction in which the cruise industry is heading.

In relation to the impact on mobility caused by cruise passengers:

- Identification of mobility problems associated with cruise activity: queues and long waiting times to leave the pier when more than two cruise ships coincide at the same time, in which case the mobility of over 15,000 passengers needs to be managed.
- Determination of the distribution of passenger exit flows: departure rates of passengers from terminals in disembarking operations, with differentiation between cruise operations.
- Quantification of the modal distribution of passengers in the disembarking operation according to the cruise operation.
- Estimation of the traffic generated by a cruise ship.
- Tools for port authorities or private operators to improve mobility management in cruise terminals by estimating passenger disembarkation flows and the number of seats required for modal transport.

Regarding the environmental impact of cruises:

- Economic analysis that includes an estimate of capital costs and operating costs to change from conventional fuel to LNG, using a database comprised of 275 cruises.
- Estimate of the time required to recover the investment (payback) of the LNG system installation in a new cruise ship.
- Evaluation of the sensitivity of LNG price on fuel cost.
- Estimate of the economic cost of the LNG system in terms of the loss of passenger cabins on a cruise ship.
- Comparative analysis of the three LNG bunkering methods that are currently available.

- Analysis of the impact of LNG on itineraries.
- Determination of measures to promote the use of LNG on cruise ships.

1.4. Conference contributions and publications from this thesis

The activities carried out during the doctoral programme included:

- Participation in the eighth edition of the Cruise Awards competition at the Seatrade Insider Cruise Awards that took place on 17 September 2014 in Barcelona.
- Participation in the Green Port Congress on the environmental impacts of cruise ships, held in Barcelona 14–17 October 2014.
- Participation in the CAIMANs project (Cruise & Passenger Ship Air Quality Impact Mitigation Actions), which took place at the Spanish National Research Council (CSIC) in Barcelona on 1–2 July 2015. In this project, financed by the European Regional Development Fund, the impacts of air quality by cruise ships in five European ports (Genoa, Venice, Marseille, Thessaloniki and Barcelona) were studied.
- Participation in an academic course organized by the EAE Business School as part of the master's degree in Project Management, held on 21 July 2015 in Barcelona.
- Collaboration in the creation of a guide for dimensioning spaces in cruise terminals published by the PIANC (2016).
- Participation in the sixth national congress of the ATPYC (Technical Association of Ports and Coasts) that took place in Palma de Mallorca on 19–21 October 2016.
- Presentation at the Passenger Ship Sustainability Congress entitled: "Investing in LNG infrastructure to lower air pollution", held on 14 November 2017 in Southampton.

The following articles have been published in scientific journals:

- Ros Chaos, S., Pino Roca, D., Saurí Marchán, S., and Sánchez-Arcilla Conejo, A. (2018). Cruise passenger impacts on mobility within a port area: Case of the Port of Barcelona. International Journal of Tourism Research, 20(2), 147–157.

- Ros Chaos, S., Pallis, A.A., Saurí Marchán, S., Pino Roca, D., and Sánchez-Arcilla Conejo, A., Pallis, A. (2020). Economies of Scale in Cruise Shipping. Maritime Economics and Logistics, 1–23.
- Ros Chaos, S., Saurí Marchán, S., and Sánchez-Arcilla Conejo, A. (2020). Liquefied natural gas in the cruise industry. How far will it go? (Awaiting acceptance.)

1.5. Outline of the thesis

Following the background, objectives, research scope, contributions and publications of the thesis, which are all contained in the Introduction section, the rest of the thesis is structured in the chapters shown in **Figure 1.3**.

Chapter 2 of the thesis describes and defines the concept of the cruise ship and the cruise industry, as well as its development since the end of the nineteenth century, passing through the modern era of the cruise ship (1970s) and arriving at how we know it today. Guidelines are also given on how far the cruise industry is expected to go. In this chapter, cruise activity is contextualized for the specific case of the Port of Barcelona since much of the research has been carried out using data from that port.

The following three chapters (3 to 5) coincide with the three papers published in scientific journals.

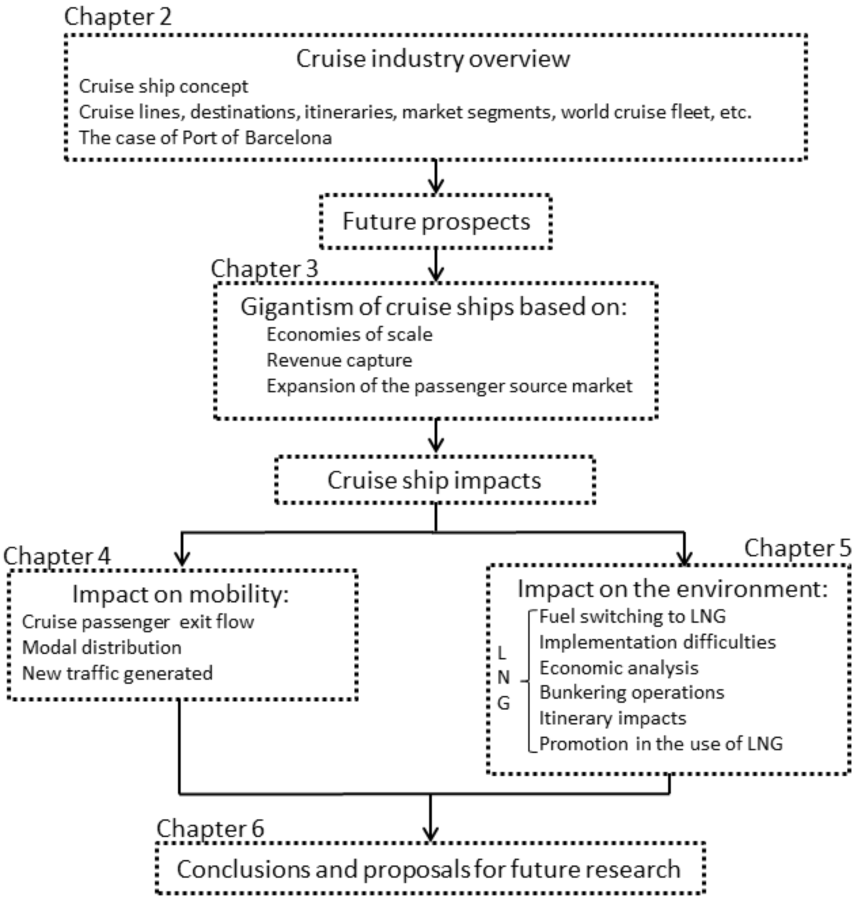
Chapter 3 investigates the trend of larger cruise ships (cruise ship gigantism) observed in the cruise industry. It analyses whether this growth is supported by factors other than revenue capture and capturing a new market, due to economies of scale that have worked so well in other types of ships such as container ships or bulk carriers. The aim is to foresee the path the cruise industry will take in coming years. This chapter coincides with the paper entitled: “Economies of Scale in Cruise Shipping”.

Chapter 4 focuses on aspects of land mobility associated with the cruise ship. The research examines the impacts of cruise passengers in terms of mobility in the Port of Barcelona, for which data are available. This chapter coincides with the paper entitled: “Economies of Scale in Cruise Shipping”.

Chapter 5 proposes as a solution to the environmental impact caused by the burning of cruise ship fuels the replacement of conventional fuels with liquefied natural gas (LNG). Its viability through an economic analysis, a comparison between all available bunkering operations, impacts on itineraries and measures to promote their use are investigated. This chapter coincides with the paper entitled: “Liquefied natural gas in the cruise industry. How far will it go?”

Finally, Chapter 6 presents the main conclusions of the issues investigated and sets out new lines for future research.

Figure 1.3. *Structure of the thesis contents.*



Chapter 2

A general overview of the cruise industry

2.1. An overview of the cruise industry. From its birth to the modern era (1970s)

The concept of cruise ships is complex but the definitions in the literature are similar. According to the **Cambridge Dictionary** (**2020**), a cruise ship is a large ship like a hotel, in which people travel for pleasure. Along the same line, **Cartwright and Baird** (**1999**) define it as a multicentre holiday where you take your hotel with you from centre to centre. For **Polat** (**2015**), cruises are a boat trip made for leisure reasons. A similar definition is given by **Sun et al.** (**2014**), who consider that cruises are intended for leisure travel only. **Pallis** (**2015**) provides a more complete meaning, and states that the cruise profile has a high purchasing power and that ships make one or more calls.

All authors agree that passengers choose to travel on cruise ships for leisure and recreation. However, this has not always been the case. If we go back to the beginnings of the cruise industry, in the late nineteenth century (**Hoseason, 2000**), cruise ships started out as transoceanic travel lines (**Dickinson and Vladimir 1996**) aimed at a population segment with high purchasing power (**Robles et al., 2015**). Their main objective was to travel long distances between continents and particularly between Europe and North America (**Rodrigue and Notteboom, 2012**). Cruise ships were considered a means of transport only (**Robinson et al., 2011**). As trade between Europe and the United States developed in the 1900s, cruises grew each day with increasing numbers of passengers (**Dickinson and Vladimir, 1996**).

The first cruise considered as such by many authors was the S.S. Ceylon (**Robles et al., 2015**). This vessel, owned by the British company P&O (Peninsular & Oriental Steam Navigation Company), travelled between the United Kingdom and the Iberian Peninsula in 1858. Later, in 1881, the company Ocean Yachting Company acquired the ship (**Raluca and Monica, 2008**), refitted it and assigned it to journeys around the world (**Gibson, 2006**), until it was dismantled in 1907 (**Fernández Duménigo, 2008**).

The development of the cruise industry was modest in the early 1900s (**Dehoorne et al., 2008**). Transatlantic travel took new migrants from Europe to the United States and passengers were often segregated by class (**Robinson et al., 2011**). The biggest setbacks in the cruise industry came as a result of the First and Second World War, in which cruise ships such as the Queen Mary or the Queen Victoria were made into troop carriers (**Gibson, 2006**). Laws prohibiting alcohol consumption on board also harmed the cruise industry (**Marquez, 2006**). By the end of the wars, in 1945, many of the reconverted ships had been sunk or seriously damaged (**Fernández Duménigo, 2008**).

In the following years, shipping companies began massively building ships, as Europe's reconstruction stimulated the demand for transatlantic cruises for tourists and business travellers (**Dickinson and Vladimir, 1996**).

However, in the 1960s, the airline industry revolutionized long-distance journeys, causing a rapid decline in cruise passenger numbers (**Hobson, 1993**), with faster and easier travel for passengers by air (**Véronneau and Roy, 2009**). The arrival of the Boeing 747, with a capacity of over 400 passengers (**Fernández Duménigo, 2008**), meant that cruise ships were quickly replaced by fast jet services, with which they could not compete in intercontinental journeys (**Rodrigue and Notteboom, 2012**).

Cruise lines that had made significant investments in the construction of new ships after the Second World War had to get returns on their investments, otherwise they would go bankrupt. Hence, they completely changed the concept of cruising, from a mere mode of transport whose only purpose was to travel from one point to another, to a new modality for tourism whose main objective was pleasure (**Véronneau and Roy, 2009**). A number of measures were taken, such as dedication to shorter distances (e.g., the Caribbean), lower prices, reorganization of itineraries and construction of larger vessels (**Dehoorne et al., 2008; Fernández Duménigo, 2008; London and Lohmann, 2014**).

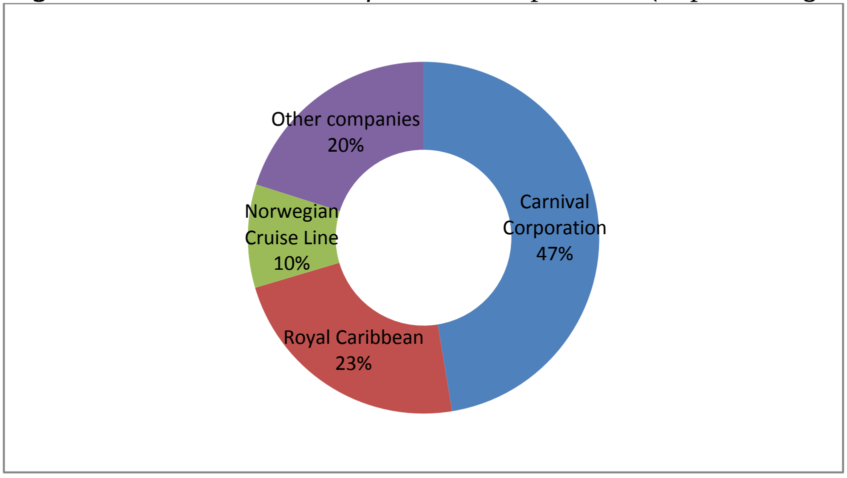
Thus, the cruise industry was relaunched, since all these reforms brought into the market a large new segment that had not yet been exploited: the middle class (**Wood, 2000**). This period in the 1970s is considered by many authors as the beginning of the modern cruise industry (**King, 1999; Terry, 2011; Rodrigue and Notteboom, 2012**).

The most characteristic feature of the modern era of cruising is the concept of "destinization". This is the process by which cruise ships are converted into tourist destinations in themselves (**Weaver, 2005**). Cruise ships have become the core of passenger experiences and the destination is an extension of the same ship (**Stefanidaki and Lekakou, 2014**). For **Page** (**1987**) and **Bull** (**1996**) the nature of cruise ships has changed from floating hotel to floating resort, where ships are a destination in themselves.

2.2. The cruise industry today and future prospects

Today, the cruise industry has become a global phenomenon. It has spread throughout the world and there is no region where cruise tourism does not reach. Of the 52 cruise companies operating worldwide, three monopolize practically 80% of the world market (**Pallis, 2015; Cruise Market Watch, 2020**). These three companies have become consolidated and have ended up absorbing other smaller cruise companies. A clear example is Carnival Corporation, founded in 1972, which is made up of 10 business groups operating cruise ships of different characteristics. This is the company with the largest number of ships in its fleet (104), the highest billing revenue ($20.825 billion) and the highest number of passengers (12.9 million passengers) (**Carnival Corporation, 2019**). It is followed by Royal Caribbean (founded in 1968) with 61 cruises in its fleet, $10.950 billion in revenue and 6.5 million passengers carried (**Royal Caribbean, 2019**). Royal Caribbean also has the highest capacity ships in the world: four ships with 5,400 passengers and forecasts of up to five more with similar characteristics in the next five years (**Cruise Industry News, 2020a**). Finally, Norwegian Cruise Line (founded in 1966) is the smallest of all three companies. In recent years it has grown considerably to reach a fleet of 27 ships. It makes $6.462 billion in revenue and transports 2.7 million passengers per year (**Norwegian Cruise Line, 2019**).

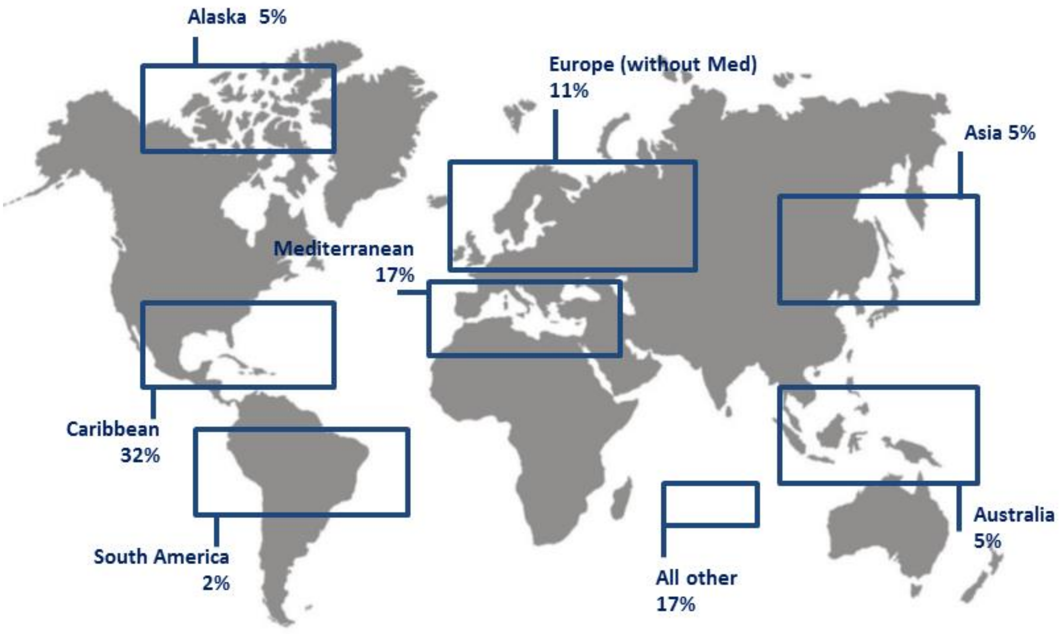
Figure 2.1. *Market shares of the cruise operators (in percentage of passengers).*



Source: Cruise Market Watch (2020)

In relation to markets, the most visited destination is still the Caribbean with a 32% market share. It is followed by the Mediterranean (17%) and Europe without the Mediterranean (11%). Other less popular destinations are Australia, Alaska, South America and Asia, all with 5%, except South America with 2% (**CLIA, 2020**). The first two destinations (the Caribbean and the Mediterranean) have passengers throughout the year, while in the other destinations cruise activity practically disappears outside of the season (**Castillo-Manzano et al., 2014**). For this reason, most cruises in the southern hemisphere only operate during the northern low season.

Figure 2.2. *Cruise line deployment by region.*



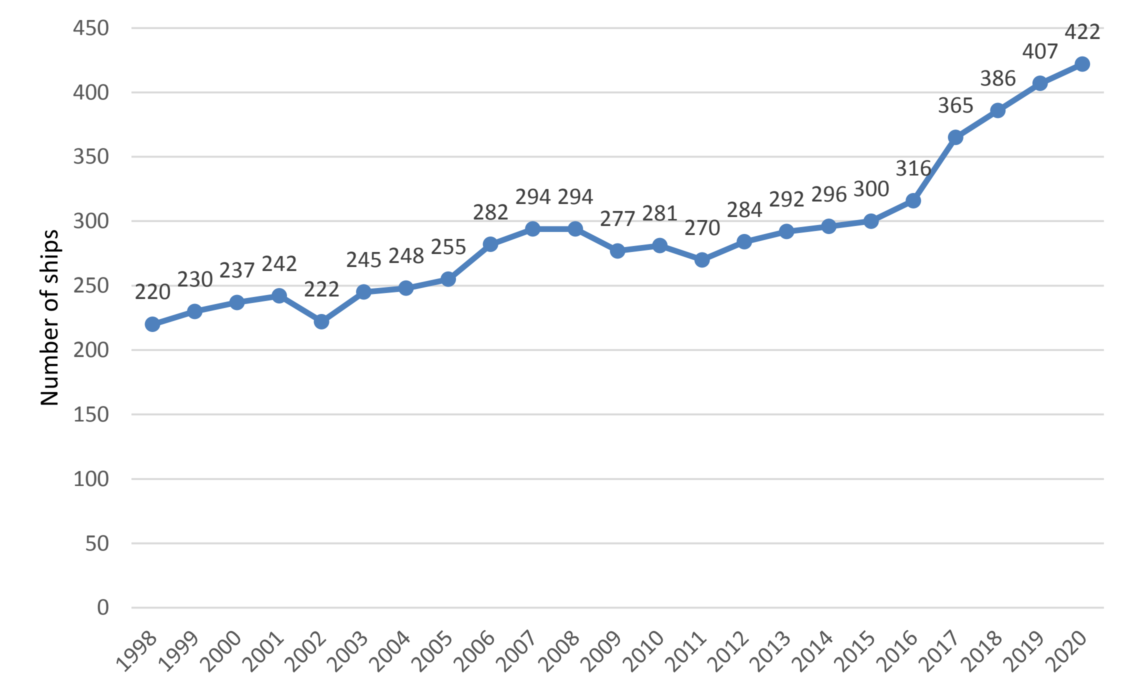
Source: CLIA (2020)

Cruise ship trips tend to last between three and twelve days, with an average duration of 7.2 days (**Pallis, 2015**). Trips usually start and finish at the same port (called the base port) and call between three and five different ports (the ports of call). Longer itineraries are infrequent, although they also exist. For example, the Seven Seas Mariner cruise offers a trip around the world in 119 days.

Most cruise companies focus their development efforts on a certain market segment. Following the classification of the Cruise Lines International Association (CLIA), cruise ships are classified as budget, contemporary, premium, luxury and niche/specialty (**Wood, 2007; Gibson and Parkman, 2018**). For each of these categories, a set of specific characteristics are defined: the duration of the trip, the size and age of the vessel, the level of service, the type of amenities and the type of users. To cover the maximum possible demand, the main companies offer cruise ships in all categories. The contemporary category is the most frequently chosen, with 69.3% of the share (**Cruise Industry News, 2018**). In this category, cruise ships tend to be new, large or very large, and with an average duration of the trip from 3 to 7 days. Passengers who choose these cruise ships cover all ages and incomes and are especially suitable for first-time cruisers (**Robles et al., 2015; Gibson and Parkman, 2018**).

The world fleet of active cruise ships currently stands at around 422 ships (**Cruise Industry News, 2020b**). Despite the sharp increase in cruise ships from the 1990s, when there were only 150 ships available, a certain slowdown in the number of active ships has been observed since 2000, to maintain an average of 260 ships (**Figure 2.3**). This can be explained because old, obsolete ships withdrawn from the market must be subtracted from the count of new ships built. It should be remembered that the useful life of a cruise ship is around 30 years and companies often choose to scrap them because of the high cost of retrofitting. This thesis is reinforced by the fact that new cruise ships are being built larger than previous ones. Hence, the capacity of many of the new cruise ships, especially the largest (mega-cruises), almost doubles the capacity of older ones. The result is that, in the end, fewer cruise ships are built than would initially be expected according to the growth in demand.

Figure 2.3. *World cruise fleet.*



Source: Cruise Industry News (2020b)

This last idea fits with the forecasts and future prospects of the cruise industry. Clearly, the cruise industry is increasingly opting to construct larger ships with greater passenger capacity. This is easily demonstrated by analysing the order books of new ships for each year, and the annual reports and statements made by the main cruise companies. Chapter 3 provides a comprehensive analysis of this topic. In a few words, the trend towards gigantism in cruise ships is mainly explained by economies of scale (**Barron and Greenwood, 2006**), whereby cruise lines can reduce their unit costs by increasing the scale of production (**Papatheodorou, 2006**). This translates into increasing the passenger capacity of the ship. In turn, this makes it possible to offer cheaper trips and thus attract a higher number of passengers (**Robles et al., 2015**).

However, the new reality of the cruise ship has brought problems with it, due to a higher number of calls and passenger capacity. The environmental and social problems take the form of air pollution from fuel combustion and overcrowding of cruise passengers in cities. Consequently, the cruise industry has been strongly criticised by society, which has led to reconsiderations in the search for solutions that minimize these impacts.

The measures that companies will take over the next few years are focused on resolving these aspects. New ships are designed to attempt to minimize polluting emissions. Some solutions improve the design of the ship so that it offers less resistance to movement. Other solutions improve the efficiency of engines. More drastic solutions are also proposed, such as switching to less polluting fuels (liquefied natural gas, the subject of the study in Chapter 5 of this thesis), the use of exhaust gas cleaning systems or electrical connections between the ship and piers.

In relation to the social aspect and to reduce problems of overcrowding of cruise passengers in the city, port authorities are encouraging cruise operators to deseasonalize the arrival of their cruise ships. This means deconcentrating cruise ships in summer and distributing them throughout the year, to reduce the accumulation of cruise passengers in emblematic sites in a city over a short period of time.

Another measure is to encourage cruise companies to use a port as the base port for their cruise ships. For this purpose, the cruise port must have sufficient facilities in the terminal and on the esplanades to accommodate a large volume of passengers. This mode of travel is known as turnaround and means that passengers start or end their journey at the same port. This travel modality generates a greater economic benefit than the transit modality (in which the cruise ship calls in the city for a few hours), due to the spending of cruise passengers in the city. An advantage is that it does not increase the saturation of visitors in the main monuments of the city. Passengers do not go on group excursions, since they start or end their trip in the city. Usually, they stay in a hotel and visit the city for a few days, until they get a plane that returns them to their country of origin.

Lastly, it is important to mention that cruise ships are an evolving concept. In its beginnings, the cruise was only considered a mode of transport to travel from one point to another across the sea. Today, they are something very different: they are a form of tourism that uses the ship as an excuse to visit various cities during the trip.

Due to the changes since the beginning of cruise ship travel, it seems clear that the concept of cruise ship will continue to evolve beyond how we know it today.

Cruise companies, which follow higher-income marketing strategies (**Page, 1987; Weaver, 2005**), offer an increasing number of activities and services on the ship for passengers (**Stefanidaki and Lekakou, 2014**), so that ships must also become bigger. It should be remembered that a considerable part of the income that cruise ship companies obtain comes from additional products and services that are not included in the ticket (**Vogel, 2011**), such as bars and casinos (**Klein, 2006**).

Therefore, the next step for cruise companies to obtain greater profits may be to offer unlimited amenities and activities inside their ships. This would mean that many passengers would stay on the ship when they call at a port, instead of going out to visit the city and spending a significant amount of money there. The spending per passenger per day in the city is up to €130 (**AQR-Lab, 2015**). Statistics show that currently only between 20% and 30% of passengers remain on the ship after each call. The forecast of more amenities on the ship would favour cruise lines, since all the spending that passengers normally do in the city would be carried out on their own cruise ships, which would undoubtedly lead to an increase in profits.

The concept of the cruise ship would have changed again, with the ship now being the destination itself, rather than the destination being the city in the port of call. The cruise ship would then become a floating city, where the passengers would have everything they wanted (shopping areas, swimming pools, entertainment, casinos, theatres, golf courses, etc.). Therefore, they would not need to leave the ship to visit the city and buy things, since they would not care which port or city they were in. They would only care about the ship they were on. Hence, the ship itself would be the main attraction, not the ports of call (**Wood, 2000; Cheong, 2013**).

2.3. The particular case of cruise activity in the Port of Barcelona

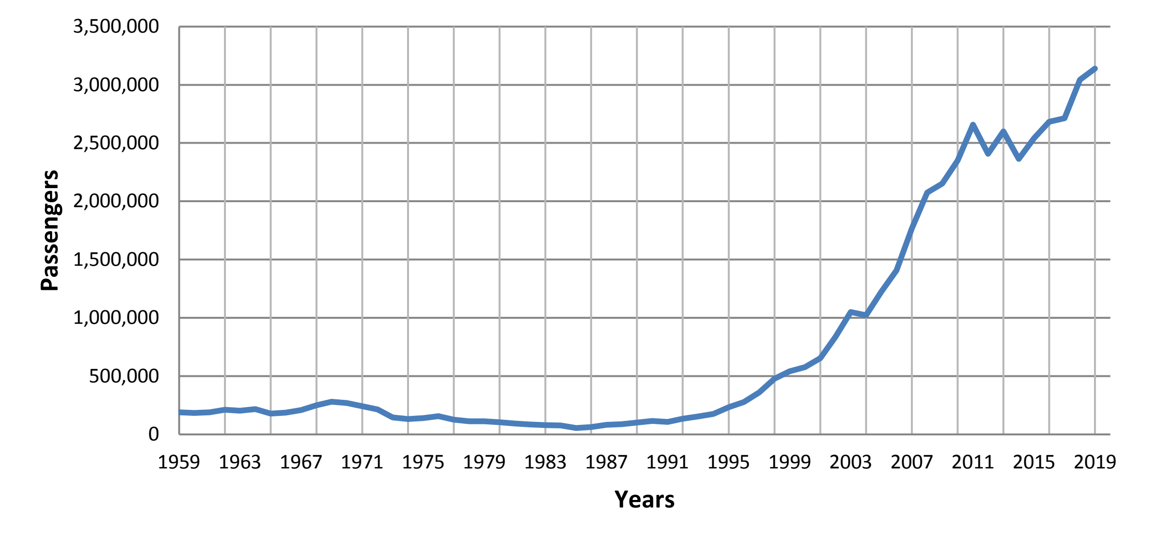
Cruise activity in the Port of Barcelona follows the same pattern as in the rest of the world. The cruise port has been very successful and there is a trend towards increasing passenger numbers.

Hence, the cruise port in Barcelona has experienced rapid growth in the last thirty years. It has become the main European cruise port in passengers and is in fifth place internationally, only behind the Caribbean ports of Miami, Fort Lauderdale, Cañaveral and Cozumel (**Pallis, 2015**).

Before this revolution took place, cruise activity in the port was practically marginal. It was not until 1992, with the Barcelona Olympics, that tourist cruise traffic became highly relevant, gaining calls in a market that had not been introduced or developed until then (**Garay Tamajón, 2015**). Given the insufficient availability of hotel accommodation in the city, the capacity was expanded by 2,500 beds on ten hotel cruise ships moored in the port.

In 1995, Barcelona became the base port for some important cruise lines. By 2011, the record figure of 2.6 million cruise passengers had been reached. In 2012, the number of cruise passengers fell below 2.4 million due to two drawbacks: the difficulties experienced by certain companies in the sector and the weakness of the internal market in southern European countries. Nevertheless, lost traffic recovered in 2013, again reaching 2.6 million cruise passengers. Since 2015, the number of passengers has continued to rise with growths of 7% annually on average, to reach in 2019 the historical maximum of 3.1 million passengers (**Port de Barcelona, 2019**).

Figure 2.4. *Evolution of the number of cruise passengers in the Port of Barcelona.*



Source: Port of Barcelona (2019)

Regarding the supply of facilities, the port currently has seven cruise terminals: two for small ships and the other five for large ships. In recent years, the port has been updating its terminals so that it can compete with other European ports and be able to service large-capacity cruise ships. Until recently, when a mega cruise was calling, it was necessary to occupy two terminals, especially to separate the large volumes of passengers between embarking and disembarking operations.

Thus, the last terminal built in the Port of Barcelona (terminal E) was designed to accommodate cruises of this size. The new terminal E has a 12,500 m^2 maritime station, 1,380 m of berthing line, 12.3 m of draft, 2 gangways and 2 esplanades for embarking and disembarking with the provision of enough parking lots for taxis, buses and private vehicles.

Figure 2.5.*Cruise ship terminal E in the Port of Barcelona.*

Source: https://www.barcelonacruiseterminal.com/

In view of the tremendous success of cruise activity within the port, with increases in cruise passengers each year, the Port of Barcelona has considered the construction and adaptation of new cruise terminals in the coming years, to remain competitive at European level and to be able to continue to offer services to the new ships on the market. These new infrastructures would always be built in consensus with the city, so as to minimize the impact of cruise tourism.

Chapter 3

Economies of Scale in Cruise Shipping

3.1. Introduction

Throughout the last decades, cruise shipping has grown faster than the entire transport and tourism industries (**MacNeill and Wozniak, 2018**). In 1990, only 3.8 million people decided to cruise. In 2004, the number exceeded for the first time the 10 million threshold. The most recent annual review of Cruise Lines International Association (2019) estimated that more than 30 million people cruised worldwide in 2019.

While this increase might be attributed to a number of factors (i.e. the interest of ports and destinations in attracting more cruise calls and visits), the foundations undoubtedly lie on the strategies of cruise lines themselves. Ordering larger cruise ships, to host more passengers, and providing further, upgraded, and differentiated, services on board (**Di Vaio and D' Amore, 2011**) have been core elements of these strategies (**Klein, 2009; Terry, 2011; Cruise Industry News, 2019**). Equally important are the new deployment schemes, seeking the geographical expansion of both port calls and passenger source markets (**cf. Pallis and Arapi, 2016; Karlis and Polemis, 2018**), the increasing involvement of cruise lines in port operations, as well as their involvement in remodelling the governance of cruise ports (**Gui and Russo, 2011; Pallis et al, 2018; 2019**).

The four leading cruise conglomerations (Carnival; Royal Caribbean Cruises Lines (RCCL); MSC Cruises; Norwegian Cruise Line (NCL), which control approximately 88% of the market, have all invested in the ordering and operation of bigger capacity cruise ships. Today, the capacity of each of the 50 biggest vessels in operation exceeds 3,000 passengers, with the biggest of them having a capacity of 6.687 passengers and 228,081 Gross Tonnes (GT). The average dimensions of a cruise ship are 200 meters in length and 26 meters in width (**PIANC, 2016**). Even though the standard deviation of ship dimensions is large, and average numbers need to be treated with caution, these dimensions have little to do with the picture observed in the early 2000s, when cruise ships with a capacity in excess of 2,000 passengers were few, and vessels of around 3,000 passengers were termed 'gigantic'. The order book suggests that, by 2026, a total of 23 cruise ships of over 5,000 passengers will be in operation (**Table 3.1**).

Table 3.1. *Cruise order book for vessels over 5,000 pax (2016-2026).*

Year Built	Company	Name of the ship	Capacity (Pax)	Gross Tonnage (GT)
2016	Royal Caribbean	Harmony of the Seas	5,400	227,700
2018	Royal Caribbean	Symphony of the Seas	5,400	227,700
	Aida Cruises	Aida Nova	5,000	183,900
2019	Costa Cruises	Costa Smeralda	5,000	183,900
2020	P&O Cruises	Unnamed	5,200	183,900
	Carnival	Unnamed	5,000	183,900
	Star Cruises	Unnamed	5,200	204,000
2021	Royal Caribbean	Unnamed	5,400	227,700
	Costa Cruises	Unnamed	5,000	183,900
	Aida Cruises	Unnamed	5,000	183,900
	Star Cruises	Unnamed	5,200	204,000
2022	Royal Caribbean	Unnamed	5,000	200,000
	MSC Cruises	Unnamed	5,400	200,000
	Carnival	Unnamed	5,000	183,900
2023	P&O Cruises	Unnamed	5,200	183,900
	Carnival China	Unnamed	5,000	135,000
2024	Royal Caribbean	Unnamed	5,000	200,000
	MSC Cruises	Unnamed	5,400	200,000
	Carnival China	Unnamed	5,000	135,000
2025	MSC Cruises	Unnamed	5,400	200,000
2026	MSC Cruises	Unnamed	5,400	200,000

Source: Cruise Industry News (2018).

Naturally, the growth in cruise ship size imposes physical restrictions on destination ports. Ports must guarantee sufficient draughts, berthing lengths and cruise terminals capable to handle efficiently large volumes of passengers (**Vogel et al., 2012**). Many ports do not meet these requirements and require major upgrades to host mega cruises (**London and Lohmann, 2014; PIANC, 2016**).

This study investigates whether the continuation of increase of cruise vessel sizes leads to cost savings, i.e. lower average costs, due to economies of scale. Via a model that quantifies three types of costs associated with cruise ships - namely capital costs, operating costs, and voyage costs - we analyse and verify the premises behind economies of scale in the cruise industry. The findings permit an assessment of the direction that the cruise industry is heading, insofar as the size (scale) of cruise vessels is concerned.

A brief discussion of economies of scale in cruise shipping, and the ways existing literature on scale in shipping markets could facilitate our analysis, provide the foundations of our methodology, i.e. the cost model and its components. Subsequently, the study details and quantifies all types of costs in the model. Following the presentation of the integrated results, our study ends by recapping the core findings and their implications, providing some concluding remarks and ideas on further research directions.

This research is of both conceptual and practical importance. As discussed in Section 3.2, the existing literature on optimal ship size, economics of scale and potential diseconomies remains focused on the container market; the cruise case remains noticeably under-researched. A cursory look at the cruise ship order-book shows that the new constructions and the renewal of the global cruise fleet confirm that feeding the ‘seemingly unstoppable globalisation’ of cruising (**Pallis and Vaggelas, 2019**) remains the core strategy of cruise lines. A total of 19 new cruise ships are scheduled to debut in 2020, with the global cruise fleet in operation reaching 278 vessels (**CLIA, 2019**). The 2018 global cruise fleet capacity of nearly 27 million passengers is projected to exceed 39 million by 2027 (**Cruise Industry News, 2018a**). In this vein, the industry needs to know whether future orders should continue seeking economies of scale or diseconomies of scale are starting to set in.

3.2. Economies of scale in (cruise) ships

The pursuit of economies of scale in cruise has been a resounding success, earning record profits for the cruise lines (**Wood, 2000; Paisley 2014**). The main cruise lines almost doubled their net income between 2015 and 2017, when the number of high capacity vessels increased by four per company (**Carnival Corporation, 2017, RCCL, 2017**).

Three are the drivers towards the construction of higher capacity cruise ships. The most highlighted one (**i.e., Wood, 2004; Wie, 2005; Terry 2011; Castillo-Manzano et al. 2014**) is the association of vessel size increases with the creation of 'new' passenger demand. Bigger vessels add a miscellany of on-board activities and services that enable cruise lines to change commercial strategies seeking to expand the social and age groups targeted. It wouldn't be totally inaccurate to say that, for many of the passengers, the ship becomes 'the destination'.

The second driver relates to revenue capture (**Weaver, 2005a; Wie, 2005; Rodrigue and Notteboom, 2013**). In addition to ticket purchases, cruise lines enjoy significant profits from the expansion and variation of the services and activities they offer on vessels (**Klein, 2006; Vogel, 2011; Peisley 2014**). On-board revenues correspond to between 25% and 30% of total income (**Carnival Corporation, 2017; RCCL, 2017; NCL, 2017**). The bigger cruise ships are 'floating resorts' (Wood, 2004) and 'fun ships' (**Dickinson and Vladimir, 1997**), with a range of facilities that are seen as travel destinations in themselves (see: **Bull, 1996; Papathanassis, 2012**). The extent of this transformation is such that leads to the argument (**Bennett, 2016**), and criticism (**Mahoney and Collins, 2019**), that it is the ships themselves the main attraction and the choice of passengers, rather than the ports and/or the destinations these ships call.

The third justification for the tendency towards larger cruise ships is the alleged economies of scale. Increasing passenger capacity on a ship lowers average total costs by spreading fixed costs over (many) more passengers (**Papatheodorou, 2006; Pallis, 2015; Robles et al., 2015**). It is precisely the presence and the potential limitations of such economies that are under examination in the present study.

With the economies of scale concept applying to all types of economic activity, the literature contains also several studies on maritime transport. Recapping these studies though, it was found that none of them has focused on cruise ships (for a recent review, see **Ge et al, 2019**). Research remains heavily engaged with understanding the dynamics of container shipping and, to a lesser degree, other shipping markets.

Kendall (1972) and **Jansson and Shneerson** (**1982**) analysed the optimal size of break bulk ships through economies of scale. **Cullinane and Khanna** (**2000**) quantified economies of scale in containerships. In a study that informed our research, **Stopford** (**2002; 2009**) calculated capital, operating, and bunker costs of containerships, concluding that economies of size diminish very rapidly beyond a certain scale. **Sys et al**. (**2008**) assessed the link between the size of container ships and the operations they perform, while **Saurí et al.** (**2009**) developed a cost model for ro-ro ships. **Tran and Haasis** (**2015**) studied economies of scale in containerships to evaluate possible cost savings. **Van Hassel et al.** (**2016**) generated a model for containerships to assess the effect of economies of scale on total generalised costs. **Haralambides** (**2019**) analysis of *gigantism* in container shipping, noted that above the post-Panamax containership, substantial capacity utilization would be a *sine qua non* in order to achieve the expected economies of scale. **Ge et al** (**2019**) questioned the rationale for further scale increases in containerships, evaluating the economic, operational and environmental conditions and expectations under which liner shipping companies are likely to further the ultra large size.

Evidently, none of these valuable contributions on drivers and impediments of scale increases in vessel sizes have addressed in the specific the economies of scale for cruise ships. In addition, certain variables that affect costs in the container market - such as variation of handling charges and port productivity levels - are, in a way, less important in the cruise world.

Still, the common denominator of these studies, the examination of costs per unit, provides a useful background for studying cruise shipping. Studies dealing with container ships state that unit costs (per TEU slot of carrying capacity) at sea decrease as ship size increases. The opposite occurs in port: the larger the ship, the greater the increase in port unit costs. This phenomenon is known as *diseconomies of scale in port* (**Gilman 1983; Cullinane and Khanna 2000**) and, as **Haralambides** (**2019**) explains, occurs because it takes more time to handle one TEU arriving on a large ship than one unloaded from a smaller one. In the case of cruise ships, the time spent in port does not produce diseconomies, since embarking and disembarking passengers is a much faster process, lasting less than two hours in ports-of-call and three to four hours at home ports; the worst case scenarios of 12 hours (see: **Fogg, 2001**) belong to past century operations.

The time that a ship spends at sea (**Cullinane and Khanna, 2000**), the distance between ports (**Özen and Güler, 2001**), the speed of the ship (**Wong et al. 2007; Notteboom and Vernimmen 2009**) and the efficiency of cranes in loading and unloading the goods in port (**Cullinane and Khanna 2000**) have been seen as factors influencing the total, average and/or marginal costs in container shipping, with the last factor considered to be the most decisive one. In cruise ships, both ship speed and distance between ports influence the reduction in associated costs, despite the fact that speed is often set by the cruise schedule. After a certain point, increasing the speed of a cargo ship also implies an exponential increase in fuel cost. According to **Haralambides (2019)**, an increase in speed of 10% would correspond to an increase of more than 20% in fuel consumption. However, beyond a certain speed (i.e. 5 knots above service speed), this increase in operating costs is not acceptable: the higher cost of fuel could lead to dis-economies (increase of cost per passenger), while itinerary planners demand certain hours at sea to generate income on board.

Our empirical research complements the findings of the studies examining other types of ships, implying that the presence of economies of scale should not be unquestionable: by quantifying the total costs associated with cruise ships, we provide a missing insight on whether there are limits in the relationship between cruise vessel size increases and economies of scale.

3.3. Research methodology: A cost model approach

The analysis of economies of scale in cruise shipping is based on a cost model of a cruise vessel, with the unit to measure average costs being the passenger. In accordance with standard industry practice, the measure of vessel capacity is the *lower berths*[1]. A cruise vessel size is indicated in *gross tonnage (GT)* (**Morgan and Power, 2011**), which measures the volume of all enclosed spaces within the ship and is calculated according to the **IMO** (**1983**) formulation.

Despite the importance of shipping costs when planning the construction of a ship (**Özen and Güler, 2001; Wong et al., 2007**), to date there is no standard cost model. **Foss** (**1969**) analysed the economics of shipping lines in Norway, finding that doubling a ship's capacity would reduce costs per ton-mile by 30%. **Watson** (**2002**) defined economic criteria to evaluate the probability of success of investing in new ships, providing expressions to calculate the different costs: capital cost, crew cost, provisions, maintenance, insurance, etc. **Lois and Wang** (**2016**) provided a generic definition of the capital, running and operating costs of a cruise ship. **Zhou** (**2012**) studied the cost of ships for a container line service, concluding that a good strategy to reduce costs would be to lower speed and acquire more vessels by the carrier. **Erol** (**2016**) calculated unit travel costs for a bulk carrier, concluding that in order to decide on transport operations, in addition to voyage costs, operating- and capital costs must be considered.

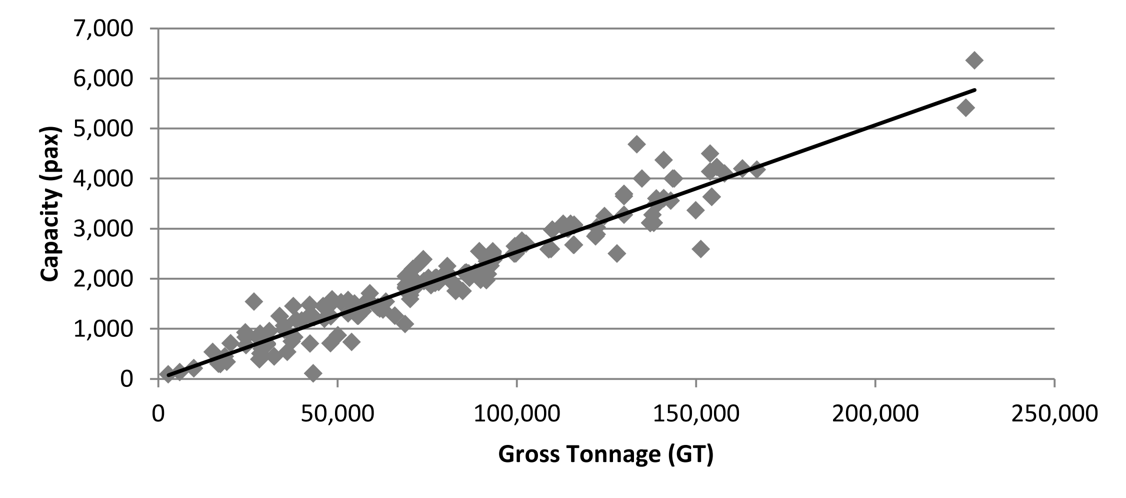
Our own study of cruise ships is based on the **Stopford model** (**2009**). This leads to the calculation of three types of costs:

- **Capital costs:** the costs of building the ship, plus interest.
- **Operating costs:** expenses related to the daily operation of the vessel. Includes crew costs, maintenance and repairs, insurance, and administration costs.
- **Voyage costs:** costs for commercial use of the vessel. Includes fuel costs, provisions, port costs, canal dues, agency expenses, and others.

[1] The number of lower berths (or beds) equals the number of passenger beds on a cruise ship, in turn calculated on the assumption of two passenger beds per cabin (**PIANC, 2016**).

We examined these costs for a sample of 246 cruise ships out of a total population of 350 cruise ships. The list of the global cruise fleet was obtained from **Ward** (**2015**), and excluded were the ships for which construction data were not available. Naturally, passenger capacity is strongly correlated with the size of the ship (**Figure 3.1**). The average ship size in our sample is 81,678 GT and 2,087 passengers capacity. These two parameters have a coefficient of variation of 51 and 52 per cent respectively. This corresponds to an acceptable maximum sampling error of 3.5%.

Figure 3.1. *Cruise passenger capacities in relation to gross tonnage (GT).*



To estimate the various costs included in the model, we also used data related to cruise vessel calls at the port of Barcelona (i.e. when estimating hoteling costs of vessels; port costs etc.), as well as data that are included in the annual reports of major cruise lines (Carnival, RCCL, and Norwegian Cruise Lines-NCL).

3.4. Components of the cost model

3.4.1. Capital costs

The cost of building a cruise ship ranges from €350 million to €1.3 billion (**Cruise Mapper, 2018**); well over other types of ships. According to **Murray (2016)** and to the phase of the business cycle, the construction cost of a containership ranges from €53 million to €200 million at most.

For the calculation of capital costs, we have assumed an interest rate of 3%, 15 years to repay the loan, and 80% of the construction costs financed. We have used construction cost data from the **Cruise Mapper (2018)** database for the 246 vessels - built between

1972 and 2017 - to regress capital costs on the gross tonnage and number of passengers (**Figure 3.2** and **Figure 3.3** respectively).

Figure 3.2. *Capital costs in relation to gross tonnage (GT).*

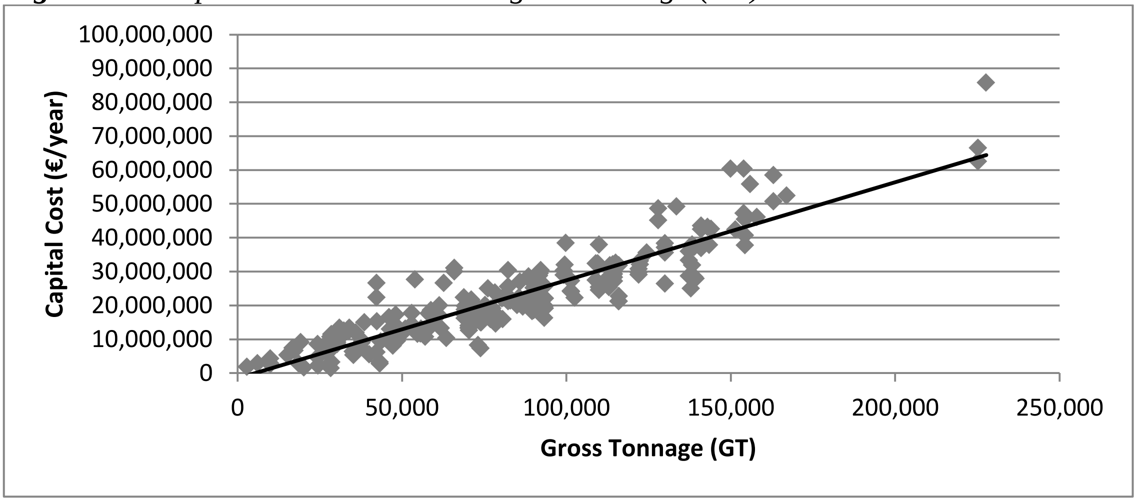
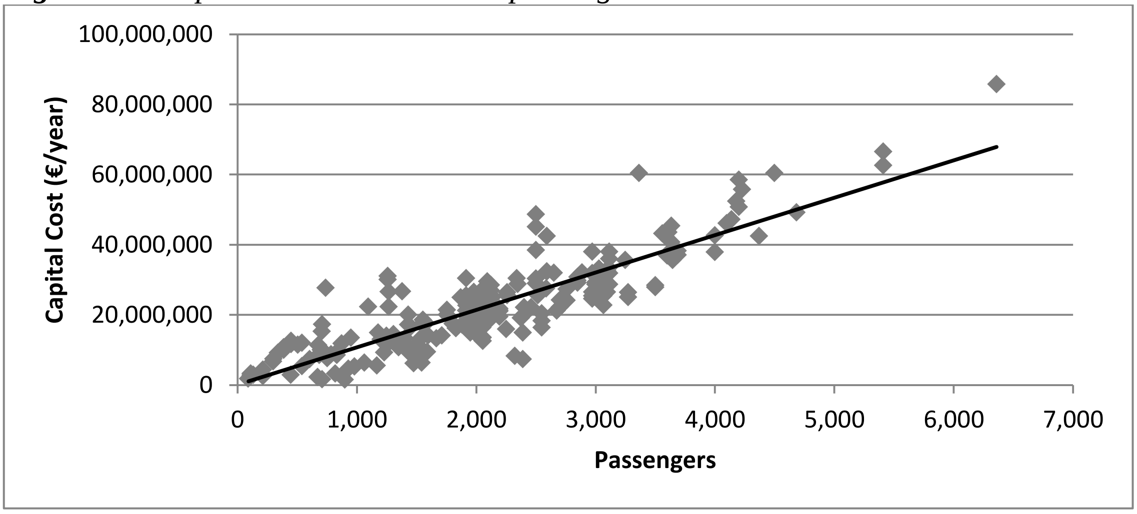


Figure 3.3. *Capital costs in relation to passengers.*



For reasons of consistency and to compare the costs of older vessels with those of newer ones, US dollars were converted to euros, according to the exchange rate during the year of construction of the ships. All the costs of the model are estimated in relation to the GT of the ship, aiming to obtain an overall analytical expression of the costs. The GT, as a measure of the size of the ship, correlates with the passenger capacity of the cruise ship (**Figure 3.1**), while allowing to uniquely identify each ship. The regression gives the following expression with a high coefficient of determination:

$$C_c = 289.91\ GT - 2 \cdot 10^6 \qquad (R^2 = 0.8354) \tag{3.1}$$

3.4.2. Operating costs

3.4.2.1. Crew costs

Crew costs depend mainly on crew numbers, nationality, and employment policies. According to the main cruise companies' annual reports (**Carnival Corporation, 2017; RCCL, 2017; NCL, 2017**), crew costs represent over 40% of total operating costs. These are higher than the respective costs of other types of ships - 32% for bulk carriers (**Stopford, 2009**) and 37% for tankers (**Silos et al., 2012** – because of the additional number of auxiliary personnel (**Morgan and Power, 2011**).

The size of a compliment ranges from 17 members, on smaller cruise ships, to 2,400 on larger ships (**Ward, 2015**). Crew numbers vary according to the ship's size and the level of service (**Gibson, 2008**), with the commonly observed size ranging between 700 to 1,500 (**Terry, 2011**). The structure of crew varies too, although due to flag-state rules the numbers in the highest-ranking posts of captain, officers, and engineers are usually the same regardless of the ship (**Table 3.2**). Most of the crew consists of lower ranks, i.e. cabin stewards, waiters, and cleaners, among other positions.

To determine the personnel assigned to a cruise ship and ensure an adequate sample size, data were taken from the crew lists of 10 cruise ships of different sizes and cruise lines, in an attempt to include most types of vessels. The 10 ships were between 17,000 GT and 156,000 GT and were operated by the main cruise lines[2].

Table 3.2. *Crew size of 10 different cruise ships.*

	SHIP 1	SHIP 2	SHIP 3	SHIP 4	SHIP 5	SHIP 6	SHIP 7	SHIP 8	SHIP 9	SHIP 10
GT	155,873	137,936	135,000	132,500	99,300	90,940	86,273	83,338	42,289	16,927
Captain	1	1	1	1	1	1	1	1	1	1
Chief Officer	2	6	2	1	1	1	1	6	2	0
2nd Officer	3	0	2	2	2	1	3	2	3	2
3rd Officer	0	4	2	3	2	2	4	2	1	1
Radio Officer	0	1		2	1				1	
Chief Engineer	1	1	1	1	1	1	1	1	1	1
1st Ass. Eng.	1	5	2	1	5	1	1	1	1	2
2nd Ass. Eng.	4	4	3	3	5	2	1	4	6	3
3rd Ass. Eng.	5	4	4	4	7	1	5	2	0	1
Deck Seafarer	0	4	1	12	50	8	0	10	17	12
Engine Seafarer	0	0	0	10	43	6	0	44	6	9
Stew	1,699	1,236	1,431	1,190	888	965	830	950	364	192
Total Crew	**1,716**	**1,266**	**1,449**	**1,230**	**1,006**	**989**	**847**	**1,023**	**403**	**224**

Source: Data of various cruise lines collected by authors

[2] Four from Carnival; two from RCCL; one from Star Cruises, one from MSC Cruises, one from Disney Cruise Line, and one from Silversea Cruises.

From **Table 3.2** and through a linear regression we obtain the analytical expression of the low-level crew based on the gross tonnage of the ship. With this expression, the crew cost can be calculated according to gross tonnage.

$$N_{low-ranking\ crew} = 0.0096\ GT + 23.7 \qquad (R^2 = 0.9675) \qquad (3.2)$$

Crew contracts typically range from six to nine months (**Morgan and Power, 2011**). The working schedule is 12 hours a day, seven days a week, with four to eight week interruptions between one contract and the next (**Terry, 2011**). Wages depend to a great extent on position and nationality. There is controversy among cruise lines and crew members about the considerable weight given to nationality in the employee's final salary. In reality, cruise lines mainly hire people from developing countries for low-level positions, with the most common nationalities being: Filipino, Eastern European, Central American, and South Asian (see: **Dauer, 2000; Weaver, 2005b; Wu, 2005; Gibson, 2008**). In addition, when the ship carries a flag such as Liberia, Panama, or the Bahamas that, among others, grant certain flexibilities in personnel recruitment, cruise lines save significantly crew costs (**DeSombre, 2006**).

Given the variability in crew wages, and following consultation with cruise experts, it was decided to proceed to an estimation using the minimum wages established by the International Transport Workers' Federation (ITF), even though these are not accepted universally. The monthly salary is calculated as the sum of the basic salary plus overtime, holidays, and taxes for social security and healthcare. Therefore, and under the hypothesis that the worker is active throughout the year, salaries range from €50,000/year for a captain to €7,000/year for a steward (**ITF, 2017**).

Accordingly, for the sample of the 246 vessels, manning costs per year were calculated as the product of the total crew, times their corresponding wages (**ITF, 2017**). The following expression of manning costs was obtained as a function of gross tonnage:

$$C_w = 111.85\ GT + 1 \cdot 10^6 \qquad (R^2 = 0.9595) \qquad (3.3)$$

These results are in line with the crew costs provided in the annual reports of the main cruise lines, which stand at €19.7 million/year per cruise ship for **Carnival Corporation (2017)** and at €16.7 million/year per cruise ship for **RCCL (2017)**.

3.4.2.2. Maintenance and repairs

The current IMO regulations and the recommendations of the international convention on the Safety of Life at Sea (SOLAS) oblige passenger ships to carry out maintenance and repair operations in a dry dock at least once every three years. These works take place during the off-season and depend on the availability of qualified shipyards. They consist, among other activities, of hull cleaning, superstructure, maintenance of propulsion equipment, electrical installations, safety equipment, ballast tanks, etc.

Maintenance and repairs costs can be estimated from the construction costs of the ship (**Saurí et al., 2009**), with the financial statements of the main cruise companies (**Carnival Corporation, 2017; NCL, 2017**) indicating that annual maintenance and repair costs are around 1.5 to 2.5% of the total construction cost.

Given the absence of sufficient information available on this cost, its sensitivity is analysed. Results show that a variation of 0.5% in construction costs represents only a variation of 4% in maintenance and repair costs with respect to total operation costs, which is considered low. Therefore, in our analysis, it was considered reasonable to assume an amount of 1.5% of construction costs.

3.4.2.3. Insurance

The insurance costs of a cruise ship are distinguished into four types (see: (**Johnson, 1996**): (a) hull and machinery (H&M); (b) protection and indemnity (P&I) insurance; (c) war risk insurance that includes all possible damage caused by acts of war, i.e. terrorism, piracy, and kidnapping (**RCCL, 2017**); and (d) shore-side property insurance. These costs vary according to the age of the ship. In the early 1990s, insurance costs increased greatly because most of the cruise ships were old and needed to be replaced (cf. **Watson, 2002**). In general, insurance costs are related directly to a ship’s construction cost. As neither the literature nor cruise lines provide data about how much insurance costs represent of the construction cost, we have assumed insurance costs at the level of 2% of the construction costs – an amount that corresponds to the case of other types of ships (**Watson, 2002**).

3.4.2.4. Administration costs

Administration costs include office expenses; communications expenses; shore cruises management expenses; and flag costs. These costs depend on the number of ships operated by the cruise company, and tend to increase with the number of ships operated. Based on the 2017 annual reports of Carnival Corporation, RCCL and NCL, these costs were estimated at 12% of operating costs – while it is acknowledged that this estimate might vary depending on the cruise line and the vessel.

3.4.3. Voyage costs

3.4.3.1. Fuel costs

Fuel costs fluctuate according to market characteristics (**Notteboom and Vernimmen, 2009; Ghosh et al., 2015**), with fuel consumption depending mainly on the size and speed of the ship, the power of its engine, and the distance travelled. In general, cruise ships mostly use two types of fuel. When at sea, they use heavy fuel oil (HFO), specifically IFO380 or IFO180. When approaching a port, they switch by law (MARPOL Convention) to less polluting but more expensive fuels such as marine diesel oil (MDO) or marine gas oil (MGO) in order to reduce SO_x emissions (**Corbett and Winebrake, 2008; Tzannatos, 2010**). As of 2019, most cruise ship engines are diesel-electric.

The fuel cost is calculated as the product of the specific fuel consumption (C_e), the total time the ship is at sea and in port (t), the engine power consumed (P) and the fuel price (F_P). Taking values from **Cooper and Gustafsson (2004)** as a reference, the specific consumption for cruise ships is 215 g/KWh (sailing) and 217 g/KWh (in port). The engine power consumed is differentiated into two stages. At sea, the total power is the sum of the propulsion power plus the power needed to meet the on-board electrical demands (lighting and ventilation), plus the boilers. In port the hoteling function is the power required to generate electrical energy in the cruise ship plus the boilers.

Propulsion power has been estimated as a function of the speed and size of the cruise ship according to **Mau's (1969)** formulation. To reveal the essential data, this time we utilised the available database of ships calling at the Port of Barcelona in year 2015, obtaining the following expression with an average relative error of 34%.

$$P_{propulsion}(HP) = 0.0952\, V^{2.39}(1{,}574.5 + 0.0753\, GT)^{0.67} \qquad (3.4)$$

The power of the cruise ship during hoteling depends on many factors such as the degree and type of lighting and ventilation devices, the season, and the time of day. For our research, this has been estimated using data measured *in situ* with a wattmeter in 35 cruise ships that called at the Port of Barcelona in 2015. It has been assumed that the power consumed in hoteling is constant throughout the year.

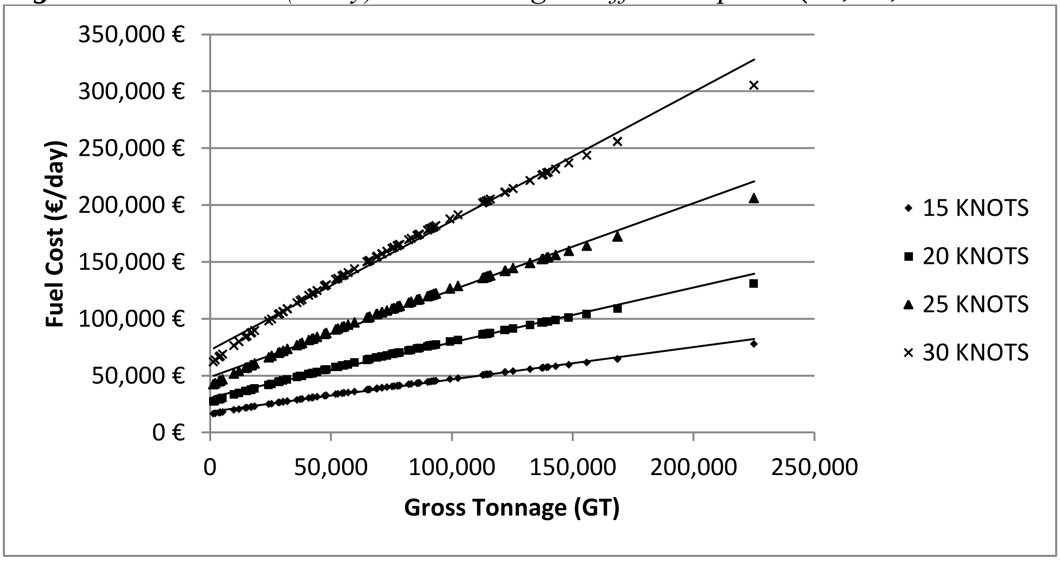
$$P_{hotelling}(HP) = 0.065\ GT + 3{,}000 \qquad (R^2 = 0.599) \qquad (3.5)$$

Electrical power consumption at sea has been taken as the power used in hoteling plus 5%, due to the use of additional safety machinery. For the power of the boilers, an average consumption of 250 kg of fuel per hour has been estimated, determined from data obtained on-board ships.

To estimate the price of marine fuels, we have taken the prices of IFO380 and MGO as $329/mT and $537/mT respectively (**Ship & Bunker, 2017**).[3]

On the basis of this assumption and the available database of cruise ships calling at the Port of Barcelona, the fuel cost was calculated as a function of speed and distance travelled. **Figure 3.4** demonstrates the sensitivity of fuel costs to changes in speed. Considering that the speed of a cruise liner (service speed) is in the order of 20–24 knots and the maximum speed is 2 to 4 knots higher, when the service speed increases from 20 to 25 knots (in cases of emergency, to avoid storms or to make up lost time), the fuel cost increases by an average of €35,000 to a maximum of €75,000 in the largest vessels. This cost increase represents more than half of the daily fuel cost.

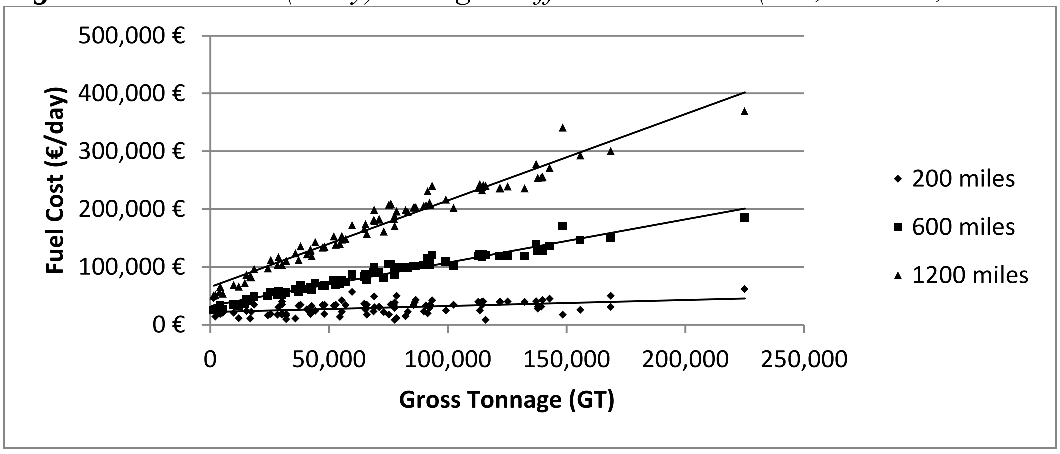
Figure 3.4. *Fuel cost (€/day) when sailing at different speeds (15, 20, 25 & 30 knots).*



[3] Prices were those of the Port of Barcelona at the time when the study was undertaken (2017).

As regards the travel distance parameter, at short distances of, say, 200 miles (i.e. the distance between Barcelona and Marseille), and assuming that all cruise ships sail at their respective service speed, fuel costs are practically the same for any size of cruise vessel. This is not the case when sailing over longer distances (1,200 miles), where consumption differences between sizes can be up to € 200,000 per day (**Figure 3.5**). This is because the larger the cruise size, the greater the power consumed. Over long distances, the difference in fuel costs between ships of different sizes increases further.

Figure 3.5. *Fuel cost (€/day) sailing at different distances (200, 600 & 1,200 miles).*



3.4.3.2. Provisions

The cost of provisions (i.e. food and beverage supplies etc.) depends on the number of passengers and crew. The annual reports of the leading cruise lines (**Carnival, 2017; RCCL, 2017; NCL, 2017),** suggest that these costs are in the order of €10/pax/day. When this cost is linked to the size of the ship, the following expression can be obtained:

$$C_p(€/day) = 0.374\, GT + 2{,}300.5 \qquad (R^2 = 0.926) \qquad (3.6)$$

3.4.3.3. Port costs

Port costs include all the payments cruise lines make at their ports of call, either for infrastructure (occupancy, activity, dockage, wharfage, waste reception fees, etc.) or services (pilotage, towage, mooring etc.). These costs are significant, as evidenced by the pressures cruise lines subject port authorities for pricing concessions, or even reimbursements that would entice them to call at the port or increase their visits (i.e.

Port Houston had paid considerable amounts to cruise lines that after few years decided to stop calling at the port. The latter, however, had already developed terminals, in line with the requirements of bigger vessels. (**Bandara and Nguyen, 2016; Papachristou et al. 2020**).

The type and structure of port costs vary by country and by port (**Chaug-Ing and Hsieh 2005; Erol, 2016**), making it difficult to establish a pattern for all ports. Overall, port costs depend on the gross tonnage of the vessel, the number of passengers, the time spent in port, the area occupied, and the number of calls (**Chaug-Ing and Hsieh, 2005**). The most common dues in cruise ports are dockage and wharfage, which represent the highest percentage of all port revenues from cruise ships. The dockage tax is expressed as a function of the GT, while the wharfage tax depends on the number of passengers (**Port Everglades, 2016; Port Miami, 2016; Port Canaveral, 2016; Port of Barcelona, 2016**) (**Table 3.3**).

Table 3.3. *Dockage and wharfage rates at the main cruise ports of the world.*

	Port Everglades		Port of Miami		Port Canaveral		Port of Barcelona	
Dockage Rates (€)	Single Day	0.12·GT	0.34·GT		LOA: 244-290 m	8.52·LOA·day	0.06·GT (estimated)	
	Multi Day	0.26·GT			LOA: 290-320 m	9.57·LOA·day		
Wharfage Rates (€)	Single Day	2.32·PAX	Single Day	11.09·PAX	Single Day	7.22·PAX	Single Day	2.42·PAX
	Multi Day	9.43·PAX	Multi Day	11.09·PAX	Multi Day	7.22·PAX	Multi Day	2.42·PAX

Source: Port Everglades Tariff No.12 – Port Miami Tariff No.10 – Port Canaveral Tariff No.15 – Port of Barcelona Taxes & Tariffs (2016)

Port authorities do not usually offer pilotage, towage, and mooring services, which are commonly provided by third parties. The role of the port authority might be to set the maximum rates these companies -often concessioners of the port authority- can charge to cruise lines. Using the available data on cruise ships that called at the Port of Barcelona in 2015 (**Port of Barcelona, 2015**), these costs were estimated by the following expressions, with the respective coefficients of determination (R^2 = 0.9953; R^2 = 0.7487 and R^2 = 0.9671):

$$C_{pilotage}(€\ per\ service) = \begin{cases} 222 + 0.01378\ GT & for\ cruise\ ships < 100{,}000\ GT \\ 1{,}600 & for\ cruise\ ships \geq 100{,}000\ GT \end{cases} \quad (3.7)$$

$$C_{towage}(€\ per\ service) = \begin{cases} 302.9 + 0.06648\ GT & for\ cruise\ ships < 70{,}000\ GT \\ 4{,}957 & for\ cruise\ ships \geq 70{,}000\ GT \end{cases} \quad (3.8)$$

$$C_{mooring}(€\ per\ service) = \begin{cases} 92 + 0.012375\ GT & for\ cruise\ ships < 120{,}000\ GT \\ 1{,}577 & for\ cruise\ ships \geq 120{,}000\ GT \end{cases} \quad (3.9)$$

In most ports, the relevant variable is gross tonnage, although the volume of the vessel is also used. The rates are flat and independent of the duration of the service or the number of tugs, necessary to guarantee safety.

3.4.3.4. Agency expenses

This cost consists of travel agency commissions on passenger bookings (either per passenger or as percentage of passenger fares) and payments to shipping agents. According to **Cruise Market Watch (2018)**, agent commissions are estimated at €189 per passenger for an 8-day cruise. This represents approximately 18% of the cost of the ticket.

3.4.3.5. Other costs

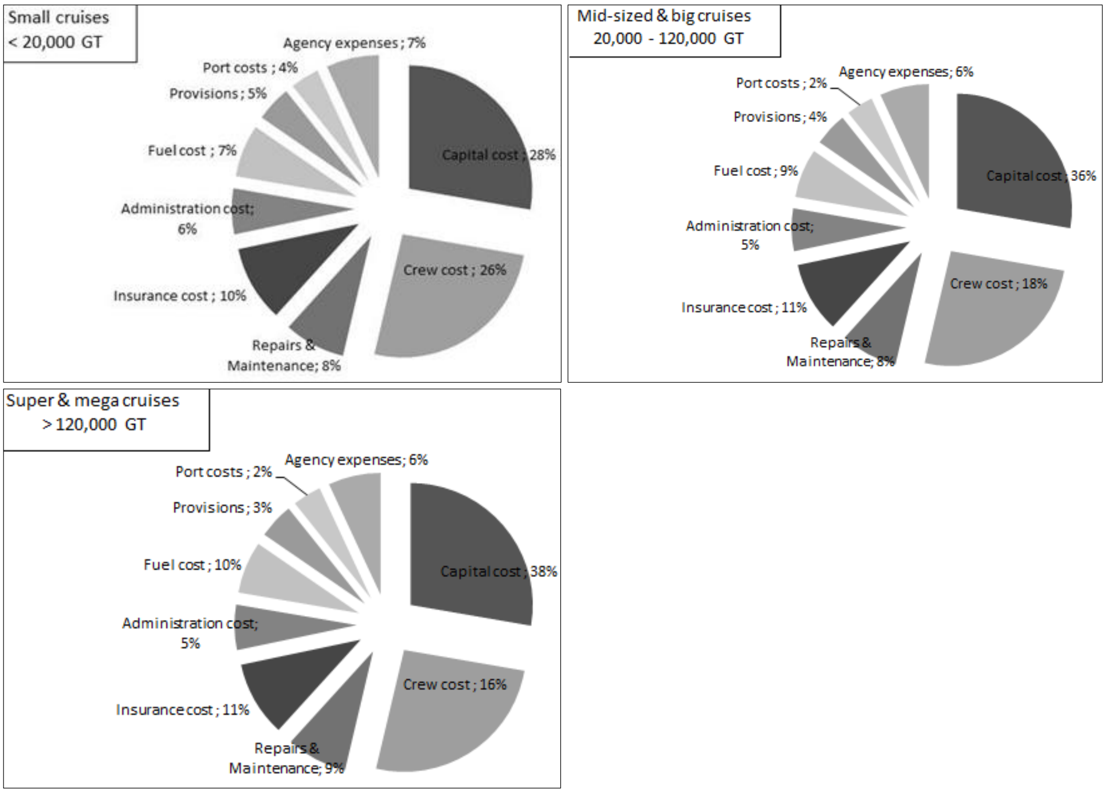
Although less important, it is worth mentioning certain other costs included in a trip that are not described above. These are the expenses for services offered in passenger terminals, payment to consignees, the costs of transporting passengers, crew and luggage, and their medical assistance.

3.5. The overall cost model

Figure 3.6 summarises the results of our cost model, in terms of the weight of each cost element in total annual costs. Costs have been calculated for each of the 246 vessels of our sample, according to the above regressions. These costs have been grouped into different ship sizes, namely small (under 20,000 GT); mid-sized and big (20,000–120,000 GT); and super and mega (over 120,000 GT) ships, with the values shown in **Figure 3.6** being the average values for each size group. It has been assumed that cruise ships are operational the same number of days per year, i.e. 60 days.[4]

[4]According to the available data (Cruise Mapper, 2018), 60% of cruise ships operate 60 days per year.

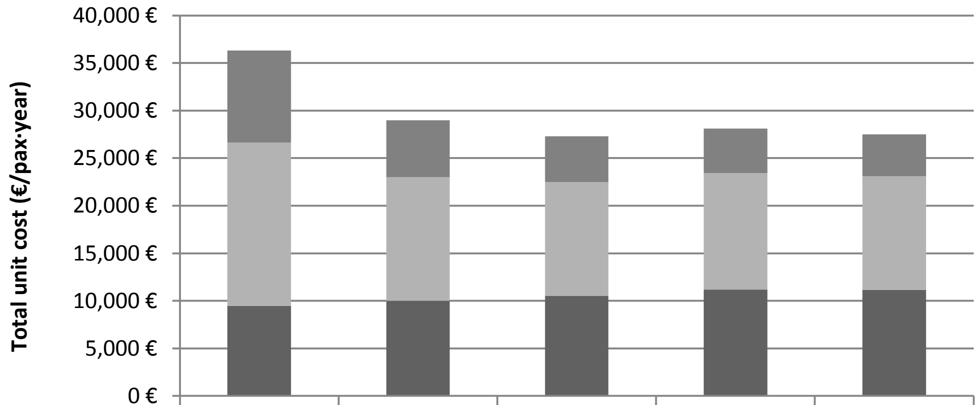
Figure 3.6. *Cruise cost percentages on average.*



Capital costs are the highest cost component (28%-38%). The second highest cost is manning (16%-26%). This is due to the large number of auxiliary personnel required, which increases by a factor of 50 the complement of a general cargo vessel (**Ellis and Sampson, 2003**). The third most costly component is insurance costs, representing 10 – 11% of the total. This figure may seem high, being around 5% in other type of ships, yet it is justified by the substantially higher construction costs of the comparatively newly built cruise vessels. Finally, in contrast to other types of passenger ships (**Saurí et al., 2009**) or cargo vessels, i.e. containerships (**Tran and Haasis, 2015**), tankers (**Watson, 2002**), or bulk carriers (**Stopford, 2009**), operating costs (between 41 and 50%) can be seen to be higher than voyage costs (between 21 and 22%).

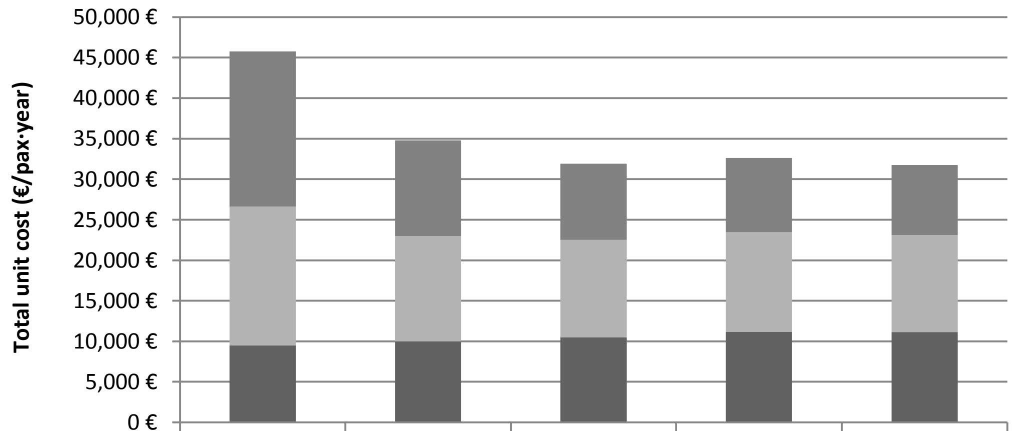
On the basis of these results, we calculate the unit costs per passenger and per year (€/pax·year) under the assumptions of a low operating time (60 days) and full occupancy. As shown in **Figure 3.7**, there is a considerable decline in the sum of the three unit costs (voyage, operating and capital cost), which is estimated at 33% in big cruises compared to small cruises. From this size upwards, average costs remain stable. The explanation lies in the significant weight of capital costs in relation to the other costs: if operating time increases to 120 days, this will only affect voyage costs (**Figure 3.8**). In both cases (60 and 120 days), economies of scale are realized, since average total costs decrease as the size of the ship increases. However, the presence of scale economies is limited to a certain size (60,000-120,000 GT), and from this size upwards average total costs (per passenger) increase again.

Figure 3.7. *Unit costs by sizes of cruise ships (operating time of 60 days).*



	Small cruises (<20,000 GT)	Mid-sized cruises (20,000 GT - 60,000 GT)	Big cruises (60,000 GT - 120,000 GT)	Super cruises (120,000 GT - 200,000 GT)	Mega cruises (>200,000 GT)
Voyage Unit Cost	9,706 €	5,991 €	4,794 €	4,664 €	4,403 €
Operating Unit Cost	17,153 €	13,011 €	11,980 €	12,253 €	11,932 €
Capital Unit Cost	9,468 €	9,990 €	10,517 €	11,195 €	11,154 €

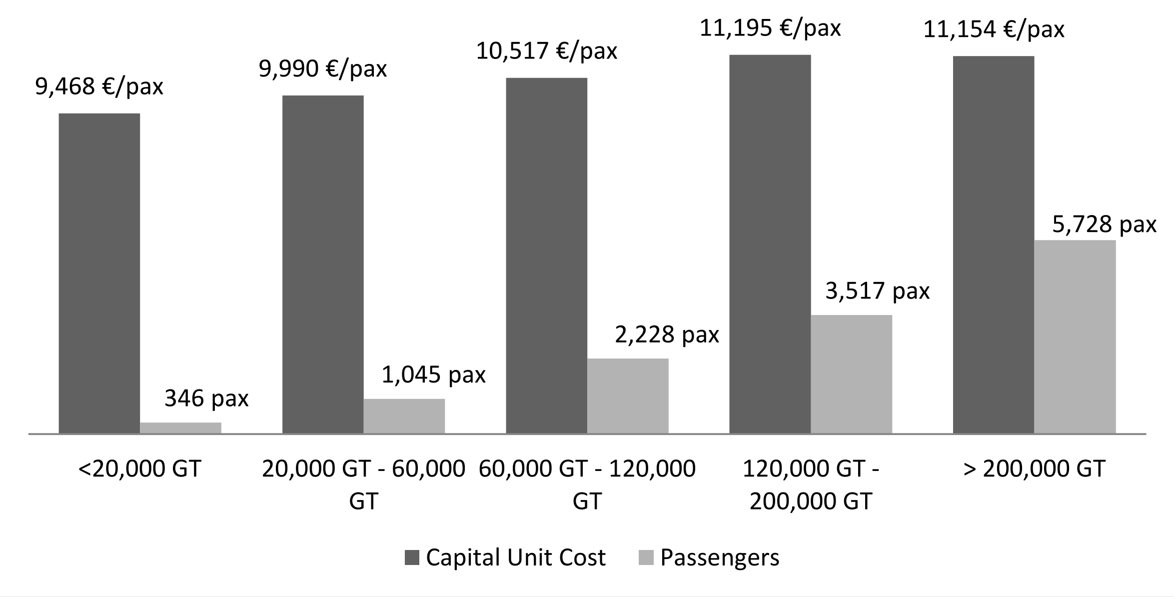
Figure 3.8. *Unit costs by sizes of cruise ships (operating day of 120 days).*



	Small cruises (<20,000 GT)	Mid-sized cruises (20,000 GT - 60,000 GT)	Big cruises (60,000 GT - 120,000 GT)	Super cruises (120,000 GT - 200,000 GT)	Mega cruises (>200,000 GT)
Voyage Unit Cost	19,125 €	11,783 €	9,416 €	9,156 €	8,642 €
Operating Unit Cost	17,153 €	13,011 €	11,980 €	12,253 €	11,932 €
Capital Unit Cost	9,468 €	9,990 €	10,517 €	11,195 €	11,154 €

It is important to highlight that larger cruise ships are more sensitive to passenger occupancy than smaller ones, due to their high capital and operating costs (see **Figure 3.9**).

Figure 3.9. *Average capital cost vs. number of passengers by size of cruise ships.*



The main reason average total costs do not decrease when the ship size increases is the magnitude of capital costs. Although the number of passengers increases significantly with ship size, the capital cost of the biggest vessels (construction and financing cost) is such that the average capital cost per passenger increases instead of decreasing. As shown in **Figure 3.9**, the unitary capital cost of a cruise ship of 2,228 passengers is 10,517 €/passenger. A cruise ship of 3,517 passengers represents an increase in capacity of almost 60%, but its capital cost rises proportionally more the capacity and, as a result, the unitary capital cost rises by 11%.

3.6. Conclusions

Since the beginning of its modern era, the cruise industry has radically transformed itself, via strategies involving, *inter alia*, a continuous increase in the size of ships. This increase has three objectives: to achieve economies of scale, to facilitate revenue capture, and to expand demographically and geographically the passenger source market.

With cruise ship sizes reaching a record of 227,700 GT in 2016, we have attempted here to examine whether larger vessels truly enjoy economies of scale, i.e. whether increasing the size of cruise ships results in the reduction of costs per passenger. Our cost model enabled us to estimate all three types of costs (capital, operating, and voyage costs) for a database of 246 ships. The results advocate the presence of economies of scale up to a certain vessel size, in the range of 60,000–120,000 GT.

These results are consistent with the current state of the cruise market, where 52% of the existing fleet lies within this range. They also suggest that the commissioning of ships larger than 200,000 GT is more part of cruise firms’ commercial strategies and prioritisation of maximising revenues rather than reducing costs.

True, like any study, some limitations are present, and further research is found wanted. Certain assumptions had to be made, as cruise lines are often reluctant to disclose information about their costs, and there is no record of past research on economies of scale and ship size in cruise shipping. Some of the costs discussed here, such as maintenance and repairs, insurance, administration, and agency fees were estimated as percentages of other costs, since that information was not available. However, these costs are given as a range of values and were verified via consultation of cruise lines’ financial statements, so as to advance the validity and the reliability of the research.

Furthermore, our results indicate that by increasing the size of ships, the greatest reduction in average costs is achieved in voyage costs, rather than capital or operating costs. Still, the quantification of voyage costs would benefit from further specification, since such costs depend on many variables like the number of days travelled per year, as well as speed and distances travelled. The same holds with regard to the quantification of fuel costs, especially in light of new regulations such as IMO 2020.

Nonetheless, our findings come in support of indications in the current orderbook, whereby stagnation in the size of very large cruise ships (227,700 GT), is attributable to the exhaustion of economies of scale beyond 120,000 GT.

Yet it is acknowledged that neither the impact of the physical limitations of piers (berth lengths and draughts, which have historically limited cruise development (see Lim, 1998), nor the increased social and environmental impacts associated with cruise growth (**Pallis and Vaggelas, 2018**) should be underestimated. To receive a mega cruise ship, a cruise terminal must guarantee at least 10 meters of draught, 425 meters of berth length and navigation channel 132 metres wide, assuming good weather and other navigational conditions (**Vogel et al., 2012; PIANC, 2016**). Limits might also regard land-side operations, i.e. space for the apron area, the ground transportation area and road communications (**PIANC, 2016**), and not least the carrying capacity of destinations (**Stefanidaki and Lekakou, 2014**) and the social acceptance of further growth of cruising in certain destinations (**Esteve-Perez and Garcia-Sanchez, 2015; 2017; Navarro et al, 2019**).

Even though port and destination limitations were not discussed in the study, in nevertheless provides input to planners and port managers to understand the fundaments and directions of the cruise industry; to better assess the future of cruise ship renewal strategies; and thus to better forecast the terminal adaptations necessary to ensure the efficient and effective accommodation of cruise calls.

Chapter 4

Cruise passenger impacts on mobility within a port area: Case of the Port of Barcelona

4.1. Introduction

Cruise tourism is currently the segment of the international tourism market that has grown most strongly worldwide (**Brida and Zapata, 2009; Sun et al., 2014; Polat, 2015**). Despite the global economic crisis in 2008, cruise tourism has experienced significant growth, reaching a total of 24.2 million passengers in 2016. According to **CLIA (2017)**, this number is expected to reach 25.3 million passengers in 2017. This growth in cruise tourism has been reflected not only by passenger volume but also by the number of calls, the number of new destinations and the size of cruise ships (**London and Lohmann, 2014**). From 2009 to 2013, cruise capacity increased by 18% (**CLIA, 2015**). Furthermore, in the coming years (2017-2026), the leading cruise lines are planning to build up to 17 vessels with capacities of more than 5,000 passengers (**Cruise Industry News, 2017**). Thus, the trend towards giant cruises is expected to continue.

The increasing number of passengers entails a set of economic, environmental and socio-cultural impacts for the cities and ports that attract these cruises (**Brida et al., 2010**).

Many studies have investigated the economic impacts of cruises in various ports around the world: Australia (**Dwyer and Forsyth, 1996**), France (**Torbianelli, 2012**), Malta (**McCArthy, 2003**), Greece (**Lekakou et al., 2011**), the Caribbean (**Brida et al., 2012**), Jamaica (**Kerswill, 2013**), Spain (**AQR-Lab, 2015**) and globally (**Pallis, 2015**).

In terms of environmental impacts, although maritime transportation is considered the most cost-effective mode of transport compared to road, rail or air (**Butt, 2007**), cruise ships produce serious adverse effects on the marine environment and human health that cannot be neglected (**Poplawski et al., 2011; Maragkogianni & Papaefthimiou, 2015**). The main environmental impacts are the emission of harmful gases into the atmosphere and the generation of waste. A typical cruise can generate between 2.5 and 4.0 kg/pax·day of solid waste, 0.16 kg/pax·day of hazardous waste, 40 l/pax·day of black water, 340 l/pax·day of grey water and 10 l/pax·day of bilge water (**European Commission, 2009; Caric, 2015**). In addition, a cruise ship emits an average of 33.6 g/pax·h of NO_x, 29.8 g/pax·h of SO_x and 3.1 g/pax·h of PM_{10} (**CENIT, 2016**). All of these pollutants have significant effects, especially considering the growth forecasts for this industry. Therefore, further measures are needed to mitigate the environmental effects of cruises in order to make cruises a more sustainable mode of transport (**Klein, 2002; Butt, 2007).** These measures may include legislative restrictions and adopting specific procedures for waste management (**Commoy et al., 2005; Dragovic et al., 2015**).

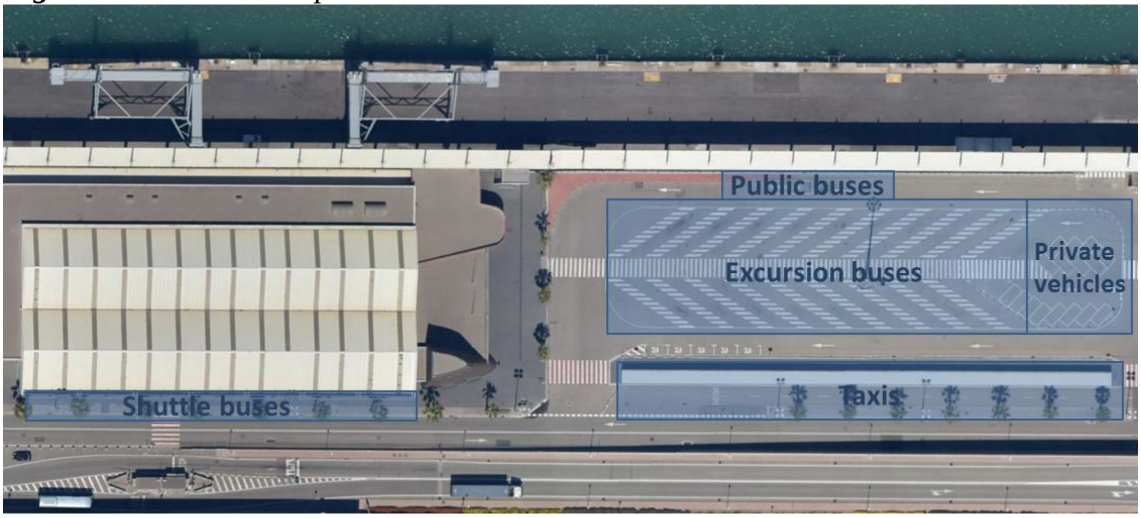
The third category of impacts frequently associated with cruise tourism is socio-cultural. The large daily and, in particular, short-term passenger flows affect the quality of life of the local population. The main problems that have been identified are overcrowding, the homogenization of the port experience and the need to honestly represent cultural and historical sites (**Klein, 2011**).

Inside a port, the impacts associated with cruise activity are essentially related to mobility and are based on providing good service to a high volume of passengers who typically arrive en masse all at the same time (**Klein, 2011**). The port must guarantee sufficient operating space at the piers assigned to cruise activity for all of the transport modes used by passengers (**Fogg, 2001**). Therefore, a sufficiently wide esplanade is required to serve all available transport modes: taxis, public buses, shuttle buses, excursion buses and private vehicles (**PIANC, 2016**). These transportation links should not be underestimated, since transportation to and from the port is the cruise passenger's first and last impression of the port (**Fogg, 2001**) and since the environment is one of the most valued factors for cruise passengers (**Baker, 2015**). It is also essential to have roads with enough entry and exit lanes so that passengers can reach their destination cities quickly, safely and efficiently. However, in most cases, available space on the pier is a scarce resource (**McCarthy, 2003**) because it is land reclaimed from the sea. Therefore, optimizing the free space is very important (**Fogg, 2001**).

A passenger's decision to choose one transport mode over another depends on several factors, such as whether the port is a homeport or a port of call, the length of stay, whether he or she is travelling alone or with family, income level, and age. Many studies have been conducted regarding passenger behaviour, focusing on the motivations that encourage passengers to take a cruise ship (**Andriotis and Agiomirgianakis, 2010; Brida et al., 2012; Sanz-Blas et al., 2015**). However, none of these studies have specifically addressed the passengers' choice of transportation; therefore, this is still a not well understood phenomenon (**Ferrante et al., 2016**).

The Port of Barcelona, which is a cruise port that had 2.6 million passengers in 2016 (**Port de Barcelona, 2017**), is considered one of the largest European turnaround cruise ports and the fourth busiest port internationally (**European Commission, 2015**). At this port, the most common transport option is a taxi. Taxis are often used by passengers travelling to or from the airport, railway stations or hotel, since they are carrying their luggage. Another available transport mode is a public bus, which typically heads to the city centre. These buses are chartered by the Port Authority depending on the number of cruise ships that day. Despite their low cost, however, public buses are still rarely used. On certain cruises, cruise lines operating at the port offer shuttle buses to the city. However, due to their high cost compared with other transport modes, the shuttle buses are not widely used. The cruise lines and the associated travel agencies also organize excursion buses to the main museums and city landmarks. Another travel option is a private vehicle, although this option requires long-term parking at the pier. Finally, as the cruise terminal is located near the city, passengers can travel on foot (see **Figure 4.1**).

Figure 4.1. *Modal transport distribution in a cruise terminal.*



The main mobility problems, queues and waiting times, arise during disembarkation, as passengers usually exit at the same time. Disembarkation is therefore a complex process that requires tremendous logistical effort (**Gibson, 2006**) and, in the worst case, can last up to 12 hours (**Fogg, 2001**). In contrast, embarkation is normally a staggered process that does not cause mobility problems. Cruise ships typically arrive early in the morning (5-10 a.m.) and leave in the afternoon (5-10 p.m.), and only a few ships remain moored at the pier for more than one day. There is, however, a tendency to minimize the time at port to reduce port taxes and to encourage passengers to spend more on board than in the city. The berth allocation problem has been the subject of numerous articles addressing how to determine the best positions of ships on the pier in both time and space (**Cordeau et al., 2005; Wang and Lim, 2007**). For cruise ships, this is not an issue since the cruise terminals have sufficient berthing capacity. Each terminal hosts a maximum of one cruise ship per day, as previously assigned by the Port Authority. Therefore, there are no physical limitations that force cruise ships to wait to dock.

Mobility problems associated with disembarkation often worsen when more than two cruise ships are disembarking passengers at the same time. Traffic management is necessary on days with more than approximately 15,000 passengers, whether they are embarking or disembarking (**Port de Barcelona, 2014**). Ferry operations located on the same pier do not interfere with the mobility of cruise passengers, as their schedules do not coincide. The ferries arrival between 22:00 and 23:00, when the cruise ships have already departed.

The growing importance of the cruise industry is highlighted by its status as one of the tourism industry sectors that generate the highest profit, along with lodging and restaurants; however, there is a lack of literature studying the impacts of passenger mobility (**Stynes, 1997**). As previously explained, the existing literature has generally focused on analysing the economic effects of cruises on the destination, particularly examining cruise passenger expenditure and profiles, to objectively assess whether cruises are beneficial to the global community economy (**Henthorne 2000; Río and Cruz, 2008; Brida et al., 2010**).

This paper uses the terrestrial mobility data of cruise passengers (passenger flows and modal distribution), which have not yet been addressed in the literature. Some studies have discussed the design of cruise terminals (**Fogg, 2001; PIANC, 2016**), but they did not specifically address passenger mobility. The data obtained in this study can serve as the starting point for dimensioning the different spaces in a cruise terminal, which has frequently been demanded by the designers of these terminals.

In this context, the aim of this work is to study the impacts of cruise passenger on mobility in ports using data from the Port of Barcelona. This research studies the main explanatory variables, the flow distribution over time, the modal shift of the passengers and the traffic generated by cruise activity.

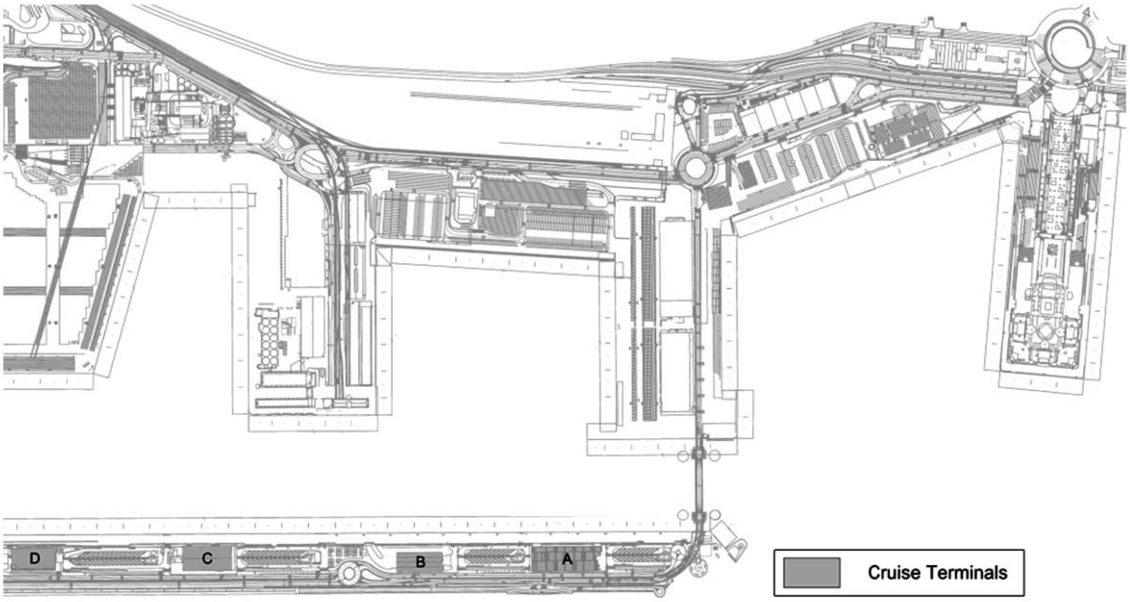
The rest of this paper is structured as follows. In section 4.2, the empirical data source and the methodology are explained. Section 4.3 discusses the empirical results, and section 4.4 is devoted to the concluding remarks.

4.2. Data and methods

4.2.1. Data

The data used in this paper came from a mobility study commissioned by the Barcelona Port Authority in 2011 (most recent data available) for the cruise pier located at *Adossat Pier* (**Figure 4.2**).

Figure 4.2. *Cruise terminals in the Adossat Pier of the Port of Barcelona.*



The study (**Doymo, 2011**) consisted of fieldwork that included data collected from direct observations of passenger transport mode choice for 9 cruise ships using the port. In 2011, there were 881 calls, and 81 of them were from different vessels. Cruise ships of differing types, capacities, cruise lines and arrival times were chosen to cover most of the representative cases. The representativeness of the sample was analysed using the expression given for finite populations of small size, with a confidence level of 95% and a standard deviation of p = 0.05. A sampling error of 13% was obtained, which is acceptable for this analysis. This fieldwork may have the following two limitations: the date the observations were taken and the number of cruise ships taken as a sample.

Although all data were recorded in 2011, these data are considered relevant because no significant changes have occurred since that time. The port infrastructure has remained the same: 4 cruise terminals with the same road access. Since 2011, the volume of passengers at the port has varied each year, but in 2016, the number of passengers was similar to that in 2011 (2,683,584 passengers). Despite the number of passengers remaining stable, the number of calls has decreased because the cruise industry has adopted the economies of scale that have been so successful in other naval sectors (**Kendall, 1972; Papatheodorou, 2006; Tran and Haasis, 2015**). As a result, there are fewer cruise ships with greater capacities. Thus, the total number of passengers is very similar to the one registered in 2011. In addition, the proportion of homeport versus transit calls has barely changed, from 56% of homeport calls in 2011 to 58% in 2016.

The number of samples may not be representative because it is assumed that the same cruise ship results in the same passenger behaviour, which may not always be the case. Depending on the season, the number of passengers and the climatic conditions, passenger behaviour could differ. However, these data should be taken as a first approach to the problem of terrestrial mobility related to cruise ships. Additional studies would be required to extend the results.

The fieldwork was conducted by a team of five people between 13 June and 15 July 2011. One observer at the exit of the pier counted passenger entries and exits in 10-minute periods. In addition, four more observers at the exit of the maritime stations and at the drop-off and pick-up points of the esplanades counted the total number of passengers entering and exiting the terminal in 10-minute periods as well as their selected transport mode: taxi, public bus, shuttle bus, excursion bus or private vehicle. Some other variables were considered such as the number and occupancy of vehicles, queues, efficiency and incidents.

The sampling campaign was performed from the moment that the cruise ship arrived until its departure. Data collection took an average of 11.4 hours per cruise. In these periods, an average of 3,909 passengers entered the terminal, and 3,903 passengers exited the terminal (**Table 4.1**). These data are the starting point for the work described in this paper.

Table 4.1. *Cruise ship data collection.*

Cruise ship	Terminal	Cruise operation	Pax entering	Pax exiting	Cruise line	Arrival day & time
Sovereign of the Seas	A	Turnaround	3,376	2,658	Royal Caribbean	25/06/2011 7:00
Carnival Magic	D	Turnaround	4,241	5,534	Carnival Corporation	10/07/2011 5:00
Brilliance of the Seas	B	Turnaround	2,618	2,625	Royal Caribbean	24/06/2011 5:00
Liberty of the Seas	B	Turnaround	4,772	4,980	Royal Caribbean	02/07/2011 5:00
Norwegian Epic	A	Turnaround	5,039	4,347	Star Cruises	03/07/2011 5:00
Grandeur of the Seas	A	Transit	2,423	2,383	Royal Caribbean	20/06/2011 6:00
Independence of the Seas	B	Transit	4,377	4,456	Royal Caribbean	11/07/2011 7:00
MSC Fantasia	B	Interporting	4,196	4,201	MSC	11/07/2011 7:00
MSC Splendida	B	Interporting	4,139	3,944	MSC	15/07/2011 9:00

Direct observation was selected as the data collection method because it is particularly suited to understanding an on-going behaviour, process or event (**Taylor-Powell and Steele, 1996**). Additionally, data collection is a reliable and widely used method in the existing literature. For instance, **Scherrer et al. (2011)** observed visitor behaviour during guided tours of Kimberley Coast (Australia) to examine the potential environmental impacts. **Jaakson (2004)** observed the space-time behaviour of passengers in 4 cruise ships in the Port of Zihuatanejo (Mexico). Other methods can be used to collect information, and each has its own advantages and weaknesses. **Douglas and Douglas (2004)** gave questionnaires to cruise passengers on 7 Pacific Island ports of call to evaluate their expenditures. **Andriotis and Agiomirgianakis, (2010)** and

Brida et al. (2012) used surveys to determine cruise passenger profiles in the ports of Heraklion (Crete, Greece) and Cartagena (Colombia) respectively. Finally, **De Cantis et al. (2016)** used a more modern method that consisted of monitoring cruise passenger flow using an infrared beam counter and subsequently tracking the passengers using GPS devices.

4.2.2. Methodology

The cumulative curves of the passenger exit flow for the nine studied cruises were plotted. The most relevant variables, such as the periods of maximum demand, variability of the peak hour over time and maximum and average exit rates, were derived from these curves. To obtain greater detail, these variables were studied over shorter periods of time (10 minutes), since the passenger flow fluctuated substantially over time. Subsequently, to determine the passenger exit rates for each cruise, the curves were adjusted using linear regression with $R^2 > 0.9$ (**Figure 4.4**). The curves were grouped by cruise operation type to find repeating patterns that could explain passenger behaviour in terms of leaving the terminal. In addition, to explain the different exit rates, the correlations were analysed using the Pearson correlation coefficient, with the help of the commercial software Minitab, taking a moderate correlation to be $r > 0.4$.

In addition, to quantify the modal distribution of the cruise passengers, the disembarkation data were statistically analysed and validated to obtain the relative percentages of passenger transport mode choice and the average occupancies of the various transport modes.

The ratio of the number of vehicles generated per cruise ship to the number of passengers carried by a cruise was calculated and analysed to determine whether there was any correlation between this ratio and the cruise operation type.

4.3. Results

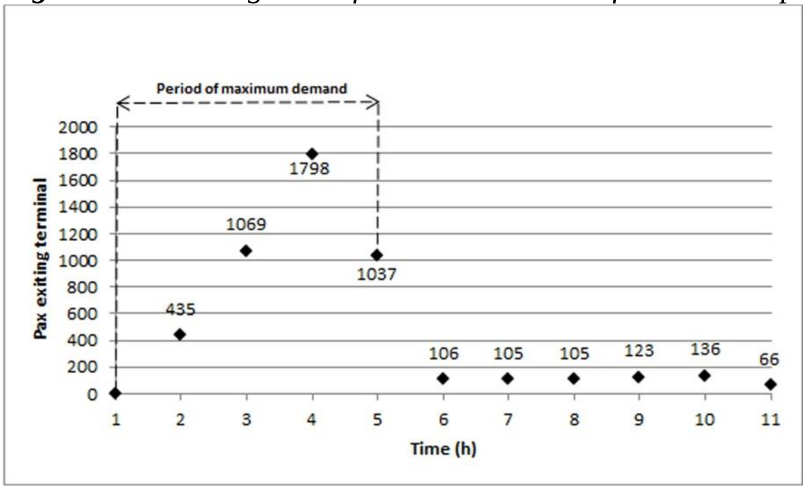
4.3.1. Cruise passenger flow exiting the terminal in a disembarkation operation

The analysis of the passenger exit flow for the nine studied cruises (**Table 4.2 and Figure 4.3**) shows that disembarkation is a lengthy process that can last between 7 and 12 hours. This finding is in agreement with that of **Fogg (2001)**, who established that the disembarkation process for a home port falls within 12 hours. The maximum demand period, which is defined as the time slot in which the largest number of passengers departs, typically begins one hour after the cruise docks at the pier.

Table 4.2. *Variables for passenger exit flow at the terminal.*

Cruise ship	Cruise operation	Period of maximum demand (h)	Peak hour (h)	Max pax per hour (pax/h)	Max pax in 10 minutes (pax/10 min)	Mean pax per hour (pax/h)	Mean pax in 10 min (pax/10 min)
Sovereign of the Seas	Turnaround	1st to 4th	3rd	1,092	329	266	55
Carnival Magic	Turnaround	1st to 5th	4th	1,868	371	503	86
Brilliance of the Seas	Turnaround	1st to 5th	5th	933	264	219	43
Liberty of the Seas	Turnaround	1st to 5th	4th	1,798	486	453	88
Norwegian Epic	Turnaround	1st to 5th	5th	1,611	373	363	65
Grandeur of the Seas	Transit	2nd to 7th	4th	772	136	184	37
Independence of the Seas	Transit	1st to 6th	4th	1,207	254	319	60
MSC Fantasia	Interporting	1st to 3rd	2nd	2,245	575	601	106
MSC Splendida	Interporting	1st to 2nd	1st	1,993	551	439	75

Figure 4.3. *Passenger exit flow at the terminal for cruise ship Liberty of the seas.*



The cruise operation (turnaround, transit or interporting) depends on the passenger flow, which is in accordance with the results from **Di Vaio and D'Amore (2011)**. In turnaround cruises, the period of maximum demand lasts up to four hours, with a peak time between the third and fifth hour depending on the cruise. However, in transit cruises, this period extends over five hours, peaking at the fourth hour (**Table 4.2**). This difference occurs because the exit flow of transit passengers is a more staggered and prolonged process than the exit flow of turnaround passengers. In turnaround cruises, passengers have already booked their return journey by plane or train at a certain time, and therefore exit the terminal within a shorter period of time. In addition, in interporting cruises, which are a mixture of the previous two cruise operation types (**Lekakou et al., 2009**), the maximum demand period is concentrated within approximately two hours. Specifically, the peak demand for MSC Fantasia occurred in the second hour, and that of MSC Splendida occurred in the first hour. These cruises have a later arrival time and more turnaround passengers than transit passengers.

The data suggest that cruise ships arriving at 5 a.m. generally have a four-hour period of maximum demand for the disembarkation process that peaks in the fourth or fifth hour. For cruise ships arriving at 6 a.m., the period of maximum demand lasts five hours, with a peak in the fifth hour. For cruise ships arriving at 7 a.m., the maximum demand period varies from two to five hours with a peak in the second, third or fourth hour depending on the cruise. In addition, for cruise ships arriving at 9 a.m., the maximum demand period only one hour and peaks within that hour. These data show that the later the cruise arrives, the sooner passengers begin to disembark and the earlier the peak hour is.

When designing and managing a cruise terminal, the maximum number of users that the terminal can serve must be determined (**PIANC, 2016**). The results of this analysis show that, at most, over half of all passengers could disembark in one hour (**Table 4.3**). This is the case of the interporting cruises, in which an average of 52% of all passengers disembarked in one hour. On the other hand, transit cruises disembarked 30% of its total passengers in one hour. Turnaround cruises present an intermediate percentage (37%). Considering 10-minute intervals, the maximum passenger flow ranges from 18% in transit cruises (Grandeur of the seas) to 30% in turnaround cruises (Sovereign of the seas). These figures are again in accordance with the previous results. The maximum exit flows in turnaround operations are higher than in the transit operations, since the turnaround passengers end their journey and many of them have already arranged a travel mode to return to their homes.

Table 4.3. *Maximum exit flows in 1-hour periods and 10-minute intervals.*

Cruise ship	Cruise operation	Max pax per hour (pax/h)	%	Max pax in 10 min (pax/10 min)	%
Sovereign of the seas	Turnaround	1,092	41%	329	30%
Carnival Magic	Turnaround	1,868	35%	371	20%
Brillance of the seas	Turnaround	933	36%	264	28%
Liberty of the seas	Turnaround	1,798	36%	486	27%
Norwegian Epic	Turnaround	1,611	37%	373	23%
Grandeur of the seas	Transit	772	32%	136	18%
Independence of the seas	Transit	1,207	27%	254	21%
MSC Fantasia	Interporting	2,245	53%	575	26%
MSC Splendida	Interporting	1,993	51%	551	28%

In most of the cases studied, the flow of passengers exiting the terminal (**Figure 4.4 and Table 4.4**) occurs linearly in three different stages. In the first stage, which roughly occurs between the first and third hour after the cruise ship arrives, the average exit rate (λ_1) is 13 passengers per minute in turnaround cruises and 9 passengers per minute in transit cruises. The second stage, which occurs between three and four and a half hours, is when most passengers leave the terminal. During this time, in turnaround cruises the exit rate (λ_2) doubles compared to that of the first stage, with an average of 27 passengers per minute. In transit cruises, the pace also increases but slower (15 passengers per minute). In interporting cruises, the first two stages show an exit rate of 37 passengers per minute, which is a high rate. In the third stage, which occurs between four and a half hours until the last passenger has disembarked, the exit rate (λ_3) is very low, between 1 and 2 passengers per minute in the three cruise operation types. Comparing these results with those of the few other studies that have investigated the flow of passengers in different transport modes confirms that passenger disembarkation is a linear process. **Molyneaux et al. (2014)** indicated that the flow of passengers disembarking from trains follows a piecewise linear function. In the case of airplanes, this process also behaves linearly (**Horonjeff, 1969**) with an exit rate of between 4 and 39 passengers per minute (**Fricke and Schultz, 2008**), which is within the range of our results (**Table 4.4**).

Figure 4.4. *Passenger exit flow by cruise operation.*

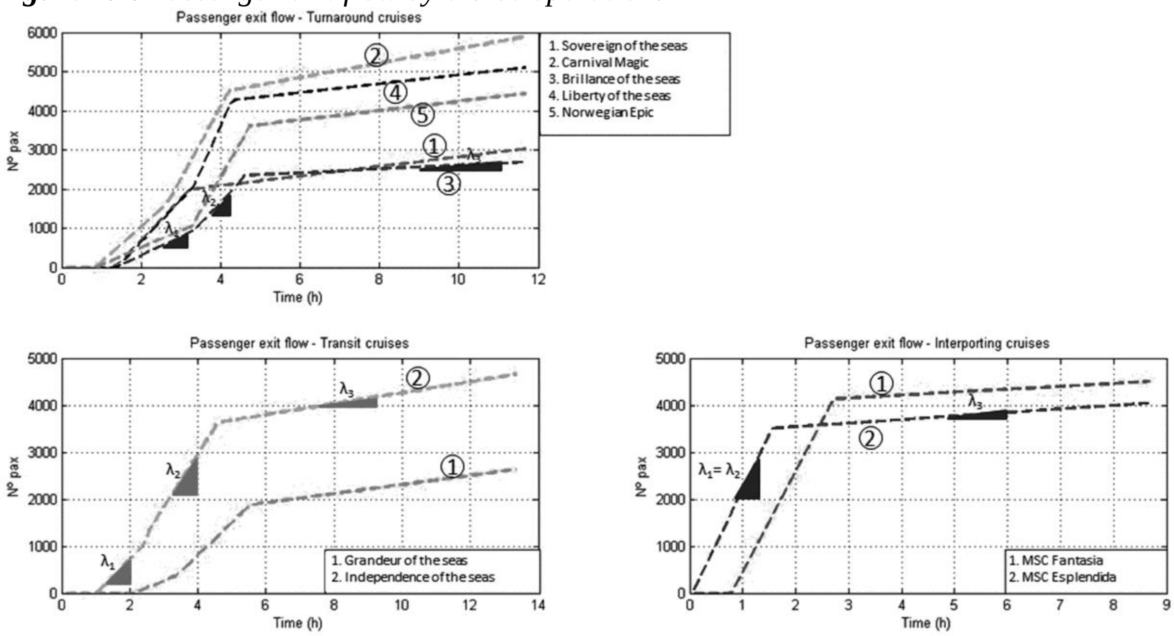


Table 4.4. *Passenger exit rates by cruise.*

Cruise ship	Cruise operation	Arrival time (a.m.)	Pax disembarking	λ_1 (pax/min)	λ_2 (pax/min)	λ_3 (pax/min)
Sovereign of the Seas	Turnaround	7:00	2,658	18	18	2
Carnival Magic	Turnaround	5:00	5,534	15	31	3
Brillance of the Seas	Turnaround	5:00	2,625	8	18	1
Liberty of the Seas	Turnaround	5:00	4,980	18	38	2
Norwegian Epic	Turnaround	5:00	4,347	8	29	2
Grandeur of the Seas	Transit	6:00	2,383	6	12	2
Independence of the Seas	Transit	7:00	4,456	13	19	2
MSC Fantasia	Interporting	7:00	4,201	36	36	1
MSC Splendida	Interporting	9:00	3,944	39	39	1

To explain the different exit rates found, a correlation analysis was conducted. This analysis (**Table 4.5**) confirmed that the passenger exit flow strongly depends on the type of operation and the arrival time of the cruise ship. This correlation exists only during the first period (λ_1), between one and three hours after the cruise ship arrives. After this time (in the second and third periods), the passenger exit flow is independent of the cruise operation and the arrival time of the cruise ship.

Table 4.5. *Correlations between passenger exit rates and the cruise operation, arrival time and number of passengers on cruise ships.*

Passenger exit rate	Cruise operation	Arrival time	Number of pax
λ_1 (pax/min)	0.738	0.737	0.246
λ_2 (pax/min)	0.297	0.180	0.714
λ_3 (pax/min)	-0.547	-0.332	0.501

Future demands for high-capacity cruise ships with disembarkations of approximately 5,000 passengers will not significantly increase the passenger flows from maritime stations during peak periods of 10 minutes. When exiting the ship, the passenger must go through different spaces inside the terminal, such as the gangway, boarding corridor, baggage lay down, customs and exit door (**PIANC, 2016**), which make disembarkation a more staggered process over time. However, a good dimensioning of these spaces, especially the gangway, which is the most critical element of the terminal, will be necessary (**Cox and Long, 2004**). In addition, the results show that an increase in cruise capacity does not necessarily result in an increase in the maximum flows.

4.3.2. Modal distribution of cruise passengers in a disembarkation operation

The results obtained during the disembarkation operation of the studied nine cruises from the fieldwork at *Adossat Pier* of the Port of Barcelona (**Table 4.6**) show that 35% of all cruise passengers use a taxi, making it the most commonly used transport mode. These results are consistent with those of **Hall and Braithwaite (1990)** since the Caribbean ports in their study are mostly homeports, resulting in high taxi use. In contrast, in the Port of Zihuatanejo (Mexico), a port of call between the ports of Miami and Los Angeles, few passengers use taxis, and most opt for excursion buses (**Jaakson, 2004**).

Table 4.6. *Mean modal transport percentages by cruise operations.*

% Pax in transport modes	Turnaround	Transit	Interporting
Taxi	48%	10%	25%
Excursion and transfer bus	25%	13%	24%
Shuttle bus	0%	49%	35%
Public bus	13%	15%	8%
Private vehicle	8%	1%	3%
On foot	6%	12%	5%
Total	100%	100%	100%

Currently, the Port of Barcelona is considered a homeport because more than half of passengers begin or end their journey in this city. If the modal distribution is differentiated by type of cruise operation, then the use of taxis in turnaround operations increase to an average of 48%. These ports occur at the end of the journey, so passengers are carrying their luggage and usually stay in the city overnight. Therefore, the passengers find it quicker and easier to take a taxi to their hotels instead of using other transport modes as taxis offer a direct route without requiring transfers. In addition to taking a taxi, passengers heading for the airport have the option of taking a transfer bus (25%), which some cruise lines charter to take passengers straight to the airport. For transit cruises, the most frequently used transport mode is the shuttle bus (49%). In these cases, passengers stay in the city for a few hours and leave their luggage on the cruise ship. Additionally, passengers may have previously booked a shuttle bus through a travel agency or on board the ship to take them directly to the area they wish to visit. For interporting cruise operation, the most common transport modes are shuttle buses (35%) and taxis (25%). This is a logical outcome since this operation is a mixture of the previous two modes and includes both passengers who are ending their journey and others who are just calling.

Other significant findings include the following:

- The number of passengers choosing excursion or transfer buses is fairly constant regardless of the cruise operation (13-25%). In ports of call, such as the port of Chios (Greece), the percentage of passengers who opt for excursions is much higher (55%) (**Lekakou et al., 2011**).

- No passengers in the turnaround operation chose shuttle buses, since they are ending their journey and heading for hotels, the airport or railway stations.

- For various reasons, few passengers choose public buses (8-15%). The first reason is a lack of knowledge; the passengers have not been informed about the existence of a public bus that can take them to the city, and the signage for the bus stop in insufficient and often not appropriately visible. The second reason is finances; although the cost of bus travel is relatively cheap (€3 one way, €4 return), many passengers think that taking a taxi costs less. In reality, taxi rides from the *Adossat Pier* cost €0.98/km with additional charges for the pick-up fee (€2.05) and pier entry/exit (€4.20). The Port Authority needs to encourage the use of public buses to reduce gas emissions and traffic at the pier.

- The number of passengers travelling in private vehicles is low (1-8%), and these are mostly vans from private companies hired by the passengers themselves. The pier does not have long-term parking, and the closest parking area is over 1 km away. In other ports, especially in America, long-term car parks are one of the main sources of income for port authorities. **Fogg (2001)** estimates that in American ports, between 20 and 30% of the cruise passengers use private parking.

- A significant number of passengers (5-12%) go into the city on foot, which is a key feature of the Port of Barcelona, since the city is located just 1.8 km from the cruise pier. Therefore, in ports close to the destination city, the pavement must be wide, comfortable and safe. In addition, these designs should consider the profiles of cruise passengers: sensitive to long distances and often have difficulties walking (up to 10% of cruise passengers) (**Jaakson, 2004**).

- The use of the various transport modes does not vary greatly with the cruise operation. Taxis have an average occupation of 3 passengers (**Table 4.7**), but despite the need to queue, passengers are increasingly demanding taxis with greater capacity (4+ pax). Although public buses do work at full capacity (40 pax) at certain times, the average number of bus passengers throughout their operating hours is only 10. Chartering large excursion and transfer buses often costs less for cruise lines, even the buses are not used to full capacity (32.4 pax). The average occupancy of private vehicles is over 4 pax as these are often vans hired by the passengers and not their own cars.

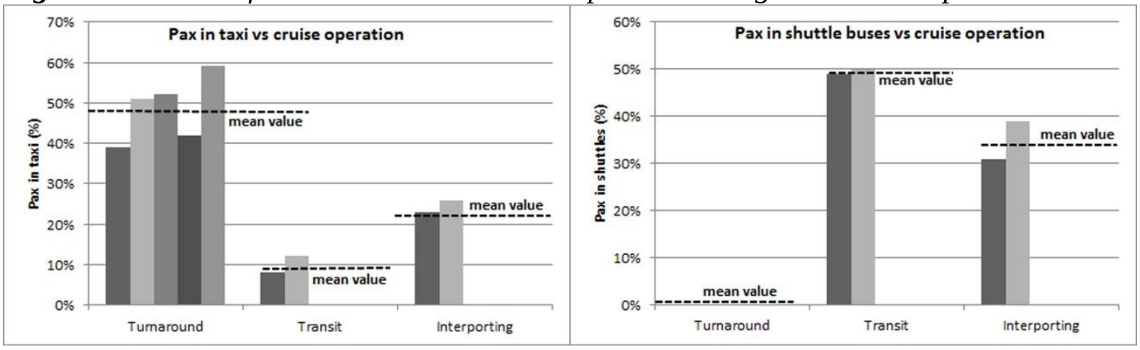
Table 4.7. *Mean occupancy of transport modes.*

Transport mode	Mean occupancy (pax)
Taxi	3.0
Excursion and transfer bus	32.4
Shuttle bus	25.8
Public bus	9.9
Private vehicle	4.8

- The number of passengers who remain on the cruise ship and do not exit during a cruise call can be significant (**Jaakson, 2004**). According to **Stefanidaki and Lekakou (2014)**, these passengers do not interact with the local system or population. In the case of the studied cruises, 30% of the total passengers stayed on the cruise ship. By contrast, in the port of call of Cartagena de Indias (Colombia) this percentage decreased to 10% (**Brida et al., 2010**).

- In terms of the parameters that influence a passenger's transport mode choice, the data show a clear correlation between only the mode choice and the cruise operation. Nevertheless, many other factors such as the distance from the port to destination attractions, the confidence level against the destination, the safety of the destination, and the passenger profile can be considered (**De Cantis et al., 2016**). These last parameters were not included in this analysis due to the lack of adequate data. As shown in **Figure 4.5**, the number of passengers selecting taxis and those using shuttle buses varies greatly depending on the cruise operation type.

Figure 4.5. *Plots of taxi and shuttle bus transport modes against cruise operation.*



The recent arrival of high-capacity cruise ships will require reinforcing the transport modes and managing traffic with a greater number of personnel. Special consideration should be given to taxis, as this port seeks to become a pure homeport, which mostly uses taxis, rather than a port of call. The reason for this desired shift is that homeports produce a higher economic impact for the city (**de la Vina and Ford, 1999; Lekakou et al., 2009; Brida and Zapata, 2009; Pallis, 2015**). The trend towards becoming a homeport has been developing in Barcelona since 2011, and in 2016, 58% of cruises were turnaround operations (**Port of Barcelona, 2017**). As a consequence, the cruise terminals at this port will require a greater number of taxis, since cruise ships that begin or end at the same port (turnaround operations) require more taxis.

4.3.3. Estimating the traffic generated by a cruise

Estimating the traffic generated by a particular cruise ship is quite difficult since the traffic depends on many factors, such as the cruise operation type, arrival time, and cruise line, as noted previously. **Table 4.8** presents the empirical data from the fieldwork, from which some conclusions can be drawn.

Table 4.8. *Ratios between cruise passengers and vehicles generated.*

Cruise Ship	Cruise Operation	Pax disembarking	Total vehicles	Ratios Veh/Pax (%)
Sovereign of the Seas	Turnaround	2,658	410	15%
Carnival Magic	Turnaround	5,534	881	16%
Brillance of the Seas	Turnaround	2,625	583	22%
Liberty of the Seas	Turnaround	4,980	795	16%
Norwegian Epic	Turnaround	4,347	849	20%
Grandeur of the Seas	Transit	2,383	169	7%
Independence of the Seas	Transit	4,456	314	7%
MSC Fantasia	Interporting	4,201	424	10%
MSC Splendida	Interporting	3,944	441	11%

In general, the traffic generated by cruise activity has no direct implications for the city. At most, 881 new vehicles are generated, the process can last for up to 12 hours, and passengers are heading to multiple destinations (airport, train stations, tourist attractions, etc.).

As illustrated in **Table 4.8**, turnaround cruises generate more vehicle traffic (15-22%) since more passengers use taxis, which have a smaller capacity than buses. However, for transit cruises, the percentage of vehicles drops to 7% because more passengers choose shuttle buses, which have a greater capacity than taxis. For interporting cruises, as taxis and shuttle buses have similar demand, the percentage of vehicles generated (10-11%) falls between the two previous cruise operation types.

With the expected future trends of this port becoming a homeport and higher capacity cruise ships, traffic is expected to increase even as the overall number of passengers remains constant. This result will occur because passengers will travel by taxi more than by bus and because taxis have smaller capacity.

4.4. Conclusions

The fundamental contribution of this paper is studying the impact of cruise passengers on mobility within a port area, focusing on the Port of Barcelona. Specifically, this study analyses and predicts the behaviour of cruise passengers on land, that is, understanding how, when and why the flow of passengers occurs, their transport mode choice and the vehicles generated by cruise activity.

The results show that the flow of cruise passengers exiting the terminal greatly depends on the type of cruise operation and the arrival time of the cruise ship. The data show that the later the cruise ship arrives, the sooner passengers disembark, and the less time they take to do so.

Looking more closely at passenger exit flow, this process generally occurs linearly in three different stages. In the first stage (between one hour and three hours after the arrival of the cruise ship), the mean exit rate is 13 and 9 passengers per minute in turnaround and transit cruises respectively.

In the second stage (from three to four and a half hours), the mean exit rate is 27 passengers per minute in turnaround cruises, which is more than twice that in the first stage. In transit cruises, the pace is 15 passengers per minute. In the third stage (from four and a half hours until the last passenger has disembarked), the mean exit rate sharply decreases between 1 to 2 passengers per minute in all cruise operations. These results are in agreement with the conclusions of other studies. For example, in the case of trains, disembarkation is a piecewise linear function (**Molyneaux et al., 2014**). In airplanes (**Horonjeff, 1969**), the disembarkation process is linear, with an exit rate within the range of our results (**Fricke and Schultz, 2008**).

The modal distribution analysis shows that, on average, most passengers choose a taxi (35%), followed by excursion and transfer buses (22%), shuttle buses (19%), public buses (12%) and private vehicles (5%). This distribution is for the particular case of the Port of Barcelona, which is considered a homeport. In addition, a passenger's choice of transport mode strongly depends on the cruise operation type. In a turnaround operation, most passengers (48%) select a taxi. However, in a transit operation, most select shuttle buses (49%). In addition, in an interporting operation, both taxis and shuttles are popular transportation modes, since in this type of operation, some passengers are beginning or ending their journey while others are just calling. Furthermore, 30% of all passengers remain on the cruise ship and do not exit at the Port of Barcelona.

Predicting the road traffic generated by a cruise is very difficult as it depends on many variables. Using the percentages of vehicles with respect to the total number of passengers, the data shows that in turnaround cruises, the percentage of vehicles is between 15% and 22%; in transit cruises, the percentage drops to 7%; and in interporting cruises, the percentage is between 10% and 11%. In terms of mobility, this new traffic has little impact on the overall city traffic. The cruise traffic is small compared with the city traffic and has multiple destinations: airports, railway stations, tourist attractions, etc. However, this traffic does affect the internal mobility of the port, as the traffic is generated at peak hours and on roads with limited capacity.

The future demands of the port entail receiving cruise ships with greater capacity and with turnaround operation. These factors affect port mobility, as the future cruise activity will generate a higher volume of traffic that should be better managed. More turnaround cruises will require a greater number of taxis, which will generate more vehicles on the road and result in queues and long waiting times for passengers. The long-term solutions aim to completely change the current taxi management model, as taxis are responsible for the main mobility problems. One option is a mass transit system, such as a "People Mover" capable of moving a massive number of passengers via tramway or light rail (**Vickerman and Beatley, 2004**). This system has already been implemented in the Port of Venice as an air train connecting the maritime terminal with the car park (**Moretti, 2012**). Port Everglades (Florida) is also considering implementing this system in its cruise port to alleviate vehicular congestion (**Vickerman and Beatley, 2004).** However, this solution requires a substantial infrastructure investment. Another proposed suggestion is the creation of a "Mobility Centre", which is defined as an area far away from the cruise pier where passengers are brought by shuttle buses and can then take a taxi to their destination without a long waiting time.

The results of this research can be applied by port authorities or private operators for the correct dimensioning of a cruise terminal and can thus help to manage port traffic more efficiently. Considering the lack of research on cruise passenger mobility, this article contributes to the body of knowledge by identifying how, when and why mobility problems arise, determining which factors determine the passenger flow, and quantifying the transport modes and the road traffic generated by cruise activity. In addition, this paper considers the future mobility needs of the cruise industry and proposes possible solutions.

Due to the limitations of the data used in this study, the results should be considered a first approach to the problem of terrestrial mobility related to cruise ships. More research is necessary to understand and predict cruise passenger behaviour and to thus improve their mobility within a port.

Chapter 5

Liquefied natural gas in the cruise industry. How far will it go?

5.1. Introduction

Air pollution derived from cruise ships burning of fossil fuels is a topic of growing concern for both private and public stakeholders (**Klein, 2011; Pallis, Rodrigue, and Notteboom, 2014; Carić and Mackelworth, 2014**), particularly in light of the growth of the cruise industry in recent years. Studies have reported that since 2009, the number of passengers has increased by 69%, and up to 30 million passengers are forecast in 2019 (**CLIA, 2019**). Additionally, the economies of scale, which have been applied with marked success for other ship types such as container ships (**Van Hassel, Meersman, Van de Voorde, and Vanelslander, 2016**) or bulk carriers (**Jansson and Shneerson, 1982**), have also begun to be applied to the cruise industry with similar success (**Wood, 2000; Papatheodorou, 2006**). Thus, new cruise ships are larger and therefore have a greater passenger capacity (**Cruise Industry News, 2019**).

However, cruise ships are a significant source of environmental pollution, which has led to criticism and debate. In response, new restrictive policy measures were established in 2008 regarding the use of marine fuels (**Ballini, 2013; Geertsma, Negenborn, Visser,**

and Hopman, 2017; Thomson, Corbett, and Winebrake, 2015). The International Maritime Organization (IMO) under the International Convention for the Prevention of Pollution from Ships (MARPOL Annex VI) reduced the limit for sulfur content in fuel to 0.1% within Emission Control Areas (ECAs), sometimes referred to as Sulfur Emission Control Areas (SECAs). Outside of ECA zones, the limit was set at 3.5% until 2020, when it will be reduced to 0.5%. Also, NO_x emissions were limited to 2–3.4 g/kW·h following the IMO NO_x Tier III limits that took effect in January 2016 (**Tzannatos, Papadimitriou, and Koliousis, 2015; Lepistö, Lappalainen, Sillanpää, and Ahtila, 2016; Chang, Park, Lee, and Kim, 2018**).

In relation to greenhouse gases (GHG), IMO through the Maritime Environment Protection Committee (MEPC) adopted in 2011 a package of GHG reduction measures such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). In this way, all newly built ships with a gross tonnage equal to or greater than 400 GT, since January 2013 have the obligation to meet the minimum performance levels of the EEDI index. In addition, existing vessels must have a SEEMP on board to control and reduce CO_2 emissions (**Deniz and Zincir, 2016**). It is noteworthy that in the 72nd meeting of the MEPC, it was agreed to reduce CO_2 emissions through the implementation of various phases of the EEDI index, reaching a reduction of 40% in 2030 and 70% in 2050 compared to 2008 (**IMO MEPC 72, 2018**).

Despite the harmful effects of GHG emissions on the environment, its effects and implications have not been studied in maritime transport. The reasons are basically justified because maritime transport has always been considered as the most energy efficient means of transport and because SO_x and NO_x have taken center stage as the main pollutant gases in sea transport (**Gilbert and Bows, 2012**).

To comply with the new limits of SO_x and NO_x established by IMO, shipowners have opted for new strategies such as the use more eco-friendly fuels (**Svanberg, Ellis, Lundgren, and Landälv, 2018**). However, the cost of distilled fuels (i.e., marine gasoil or marine diesel oil) is nearly double that of conventional fuel (**Ship and Bunker, 2020**), making their use economically unfeasible (**Molitor, Bakosch, and Forsman, 2012; Armellini, Daniotti, Pinamonti, 2015; Armellini, Daniotti, Pinamonti, and Reini, 2018; Kim and Seo, 2018**).

Another option is the use of conventional fuels in conjunction with scrubbers to retain harmful gases rather than emitting them into the atmosphere. This solution also entails high upfront costs for the acquisition of a scrubber and the related equipment (**Boulougouris and Chrysinas, 2015; Drewry, 2018**). Moreover, substantial environmental impacts could stem from the discharge of contaminated water retained by the scrubber into the environment without prior treatment (**Molitor, Bakosch, and**

Forsman, 2012; Boer and Hoen, 2015). Nonetheless, this approach has been the most widely adopted and consider the most feasible by cruise companies; Carnival has installed scrubbers in more than 60% of its fleet, with Royal Caribbean and MSC following suit (**Ports and Harbors, 2018**).

This second solution must be accompanied by a system that reduces NO_x emissions, since scrubbers have no effect on NO_x (**Zincir and Deniz, 2014**). To this end, there are several emission abatement systems: exhaust gas recirculation (EGR), selective catalytic reduction (SCR), scavenge air humidification method (SAM), water injection and Miller Cycle (**Zincir and Deniz, 2014**). Of all these, SCR is the most popular since it is the method that reduces NO_x the most, between 90 and 95% (**Cofala et al., 2007; Elgohary, Seddiek and Salem, 2015**). SCR works by combining ammonia (NH3) with a catalyst mounted on a ceramic monolith. The result is a reduction of NO_x, forming nitrogen and water (**Azzara, Rutherford, and Wang, 2014**).

The cruise industry has also evaluated cold ironing, an approach whereby shore-to-ship electric power is provided to the cruise ship while it is docked at a port, an approach often used for ferries (**Ericsson and Fazlagic, 2008**). Although this system removes all pollutant gases, it has only been implemented in a few ports, mainly in North America and Northern Europe (**Ericsson and Fazlagic, 2008; Ballini, 2013; Kruse, DeSantis, Eaton, and Billings, 2018**).This is due to the high power demands of cruise ships, and this approach would require the development of important and expensive electrical infrastructure on land with low margins of economic return (**PIANC WG 152, 2016**).

For these reasons, liquified natural gas (LNG) may be a more economically viable economic fuel option that will allow the industry to comply with the new environmental regulations (**IMO, 2016b; Armellini, Daniotti, Pinamonti, and Reini, 2018; Green Cruise Port, 2018; Kruse, DeSantis, Eaton, and Billings, 2018**). LNG results from the liquefaction of natural gas, in which it is converted to a liquid state at −162 ºC and at atmospheric pressure (**Burel, Taccani, and Zuliani, 2013**), reducing its volume 600-fold and thus facilitating its transport and storage (**Bittante, Jokinen, Pettersson, and Saxén, 2015**). Furthermore, LNG is one of the most environmentally friendly fossil fuels, and its adopted could result in an almost complete elimination of sulfur oxide emissions, a 90% reduction in NO_x emissions, a 20-30% of CO_2 emissions and almost all particle emissions (**Burel, Taccani, and Zuliani, 2013; Ballini and Bozzo, 2015; Palmer-Huggins and Foss, 2016**). These emission reductions would facilitate compliance with even the most restrictive limitations of the MARPOL VI guidelines. Moreover, the price of LNG per t is less than half that of heavy fuel oil (HFO) (**Klein, 2015**), which makes it economically attractive.

The present study investigates the use of LNG as a future fuel for cruise ships and analyzes the prospective economic development associated with the use of this fuel through capital and operational costs as well as economic indicators. Additionally, this study provides useful information that may encourage stakeholders to invest in LNG-fueled ships and explores policy measures and incentives that may be enacted by port authorities to promote LNG adoption.

The notion of LNG implementation is quite novel, given that LNG technology has only just begun to be developed within the cruise industry. Few LNG-fueled cruise ships exist worldwide, although this fuel type has been adopted by some other ship types, including ferries and tankers. Therefore, little research on this topic exists. Some notable examples include **Burel, Taccani, and Zuliani (2013)**, who studied the potential benefits of LNG in different ship types and observed up to 35% reductions in operating costs as a result. **Klein (2015)** determined that the most suitable LNG systems for the cruise industry would be dual-fuel four-stroke engines coupled with gas turbines. Furthermore, **Molitor, Bakosch, and Forsman (2012)** examined the feasibility of introducing LNG in any vessel, suggesting that newly built cruise ships could feasibly apply this technology. **Le Fevre (2018)** evaluated the most promising sectors for LNG in maritime transport and found that newly built ships such as ro-ro ferries, cruise ships, bulk carriers, large container vessels, and LNG tankers were promising candidates. **Boulougouris and Chrysinas (2015)** analyzed the technical and economic requirements necessary to establish LNG as a fuel for cruise ships and concluded that reconversion was feasible in ships of a certain size. **Rivarolo, Rattazzi, and Magistri (2018)** investigated a cruise ship case study with different fuel alternatives and determined that the LNG engine was the most economically competitive. **Deniz and Zincir (2016)** compare the different alternative fuels in marine navigation, through eleven environmental and economic criteria, obtaining that LNG is the most suitable alternative fuel. **Elgohary, Seddiek and Salem (2015)** also evaluate alternative fuels but with different criteria such as availability, safety or performance, concluding that LNG is the future replacement of current marine fuel. **Taljegard et al. (2014)** develop a model to analyze the different fuel options, also considering CO_2 restrictions. Through an analysis of Monte Carlo, they obtain that LNG is the optimal alternative fuel in most cases. Finally, **Baresic et al. (2018)** analyze the general costs of LNG under different demand scenarios, obtaining that the profitability of LNG will depend on the price difference with diesel-based alternatives and the availability of LNG supply infrastructure.

This study fills the literature gap by assessing the development level of LNG technology in the cruise industry and the difficulties that may be encountered while implementing LNG technology, such as cost, lack of infrastructure, and safety. Next, an economic analysis of LNG is presented, followed by an analysis of bunkering operations. Next, the impact of LNG adoption on itineraries is addressed, and measures to encourage the use of LNG in cruise ships are discussed. Finally, conclusions drawn from the previous analyses and discussion are presented.

5.1.1. Implementation difficulties

Although the worldwide fleet of LNG-powered vessels is very extensive and comprised of 31 ferries in operation and 11 under construction, as well as 12 tankers in operation and seven under construction (**DNV GL, 2017**), this technology is yet to be widely implemented in the cruise sector due to the hesitancy of cruise companies to retrofit their ships to use LNG fuel.

Currently, among the > 350 operational cruise ships worldwide (**Ward, 2015**) only four are LNG-operated: the AIDAsol, AIDAprima, AIDAperla, and AIDAnova (**Cruise Industry News, 2019; Wang, Li, and Xiao, 2019**). Of these, only the first three are capable of operating on LNG when moored in a port. This feature is important given that cruise ships need to keep auxiliary engines in operation to produce the electricity needed to provide minimum services while moored, which further contributes to air pollution (**European Commission, 2009; Tovar, Tichavska, Gritsenko, Johansson, and Jalkanen, 2019**). Additionally, compared to cargo ships, the energy demand of cruise ships is greater due to the continuous use of auxiliary engines while docked (**Tovar, Tichavska, Gritsenko, Johansson, and Jalkanen, 2019**).

The forecast for the next eight years is very promising, as up to 19 LNG-operated cruise ships are planned to be built in this period (**Table 5.1**). By 2025, cruise ships will account for the majority of all LNG-fueled vessels (10.9%), followed by oil tankers (7.4%) and containerships (5.8%; **Lloyd's Register, 2012**).

Table 5.1. *Forecast of LNG cruise ships (2019-2027).*

Year	Cruise Line	Ship Name	Gross Tonnage (GT)	Lower Berths
2019	Costa Cruises	Costa Smeralda	183,900	5,224
2020	Carnival Cruise Line	Mardi Gras	183,900	5,200
2020	P&O Cruises	Iona	180,000	5,200
2021	Disney Cruise Line	Unnamed	140,000	2,500
2021	Costa Cruises	Unnamed	183,900	5,224
2021	Viking Ocean	Unnamed	-	-
2021	Ponant	Le Commandant Charcot	30,000	270
2022	MSC Cruises	World class	200,000	5,400
2022	Royal Caribbean International	Iron class 1	200,000	5,000
2022	P&O Cruises	Unnamed	183,900	5,200

2022	Carnival Cruise Line	Unnamed	183,900	5,200
2022	Disney Cruise Line	Unnamed	140,000	2,500
2023	Disney Cruise Line	Unnamed	140,000	2,500
2023	AIDA Cruises	Unnamed	183,900	5,400
2023	MSC Cruises	Meraviglia 5	177,100	4,888
2023	Princess	Unnamed	175,000	4,300
2024	MSC Cruises	World class 2	205,700	5,264
2024	TUI Cruises	Unnamed	161,000	4,000
2025	Princess	Unnamed	175,000	4,300
2025	MSC Cruises	Unnamed	200,000	5,400
2026	TUI Cruises	Unnamed	161,000	4,500
2026	MSC Cruises	Unnamed	200,000	5,400

Source: Cruise Industry News (2019).

Cruise companies' decisions to invest in LNG conversion are not trivial. First, the high initial investment cost is among the main challenges of LNG adoption (**Ballini, 2013; Burel, Taccani, and Zuliani, 2013**). Shipping lines must ensure the recovery of their investment, also accounting for the loss of cabin space to accommodate LNG tanks and other additional regasification equipment.

Second, both critical infrastructure and the necessary crew are lacking. There are relatively few ports with LNG refueling facilities with the capacity to supply LNG directly to vessels (**Klein, 2015; International Transport Forum, 2018**). Although there are numerous terminals planned or under construction, the supply remains low (**Kruse, DeSantis, Eaton, and Billings, 2018**).

Finally, safety concerns must also be considered. In the event of a collision, the gas tank could catch fire and cause an explosion. Also, a perforation in the tanks could lead to passenger suffocation (**Jeong, Lee, and Zhou, 2017; Raof, Lim, Suharto, and Rahim, 2018; Armellini, Daniotti, Pinamonti, and Reini, 2018**). Moreover, the technology to supply LNG to ships has developed only recently, and regulations for this technology have not yet been consolidated (**SSPA Sweden AB, 2013a**).

In 2017, the IGF code applicable to LNG ships and other vessels consuming low flashpoint fuels entered into force. This code contains a specific part for LNG, which includes a set of particular requirements related to fuel tanks, pipes, instructions on how to do bunkering, fire safety, prevention of explosions, ventilation, control and surveillance, etc. (**IMO, 2016a**). Other requirements not covered in the IGF code are included in the standard ISO 20519:2017, which deals with the machinery, operating procedures and training of the personnel involved, among others. (**ISO, 2017**).

5.2. Methods

This study analyzed the feasibility of implementing LNG fuel in cruise ships, accounting for the economic, operational, planning, and regulatory requirements to establish LNG as the predominant fuel for cruise ships. Analysis of these four aspects was conducted using the database published by **Ward (2015)**, integrating data from 275 cruise ships.

Economic analyses included the estimation of capital and operational costs, as well as the economic payback period. Moreover, investment costs were quantified for each vessel through formulations established by the **Danish Maritime Authority (2012)**, which estimate the associated additional costs as a function of a ship's power.

Regarding operating costs, firstly, a sensitivity analysis of the LNG price variable has been performed following a Monte Carlo simulation with 10,000 iterations.

And secondly, the current fuel costs of LNG and HFO have been compared. In addition, two future cost scenarios were considered (i.e., 500 USD/t and 600 USD/t). These scenarios correspond to the upward pricing trend of LNG projected for coming years (2020–2030) in "worst-case scenario" conditions (**Raof, Lim, Suharto, and Rahim, 2018; Steuer, 2019**).

Once capital expenditures (CAPEX) and operating expenditures (OPEX) were calculated, the economic payback period was calculated to determine the years needed to recover the investment versus the alternative of continuing to consume HFO and use scrubbers plus SCR to reduce emissions.

The LNG propulsion system also influences the design of the vessel due to the space required for fuel tanks. For each vessel, the size of the tanks was calculated for a minimum seven-day autonomy. The volume of the tanks was then converted to the number of lost cabins. The economic cost of the cabins was determined with the assumption that two passengers would have occupied each cabin at a cost per cabin of 0.0215 million USD/m^2 (**Klein, 2015**), considering the number of days on which cruise ships will be operational in 2020 (**Cruise Mapper, 2019**). The year 2020 was chosen because it will be the earliest period for which an entire year dataset will be available (i.e., earlier years only have partial datasets).

Regarding bunkering operations, three available methods were compared: truck-to-ship (TTS), ship-to-ship (STS), and tank-to-ship via pipeline (TPS). The flow rate and time spent refueling determines the viability of these methods. Also, the bunkering time must be less than the time that the ship is moored at a pier to avoid operational delays.

For the itinerary impact analysis, cruise ports in Europe that currently have the capacity to carry out LNG bunkering operations were identified. Through analysis of these ports and the **Cruise Mapper (2019)** database (i.e., where the 2020 itineraries are outlined), the percentage of itineraries that would be affected if a cruise does not already refuel at one of these ports were determined.

Finally, different measures to promote the use of LNG as a fuel for cruise ships were examined. Current incentives offered by port authorities were analyzed from the perspective of potential LNG system investors.

5.3. Results and discussion

5.3.1. Economic analysis of LNG

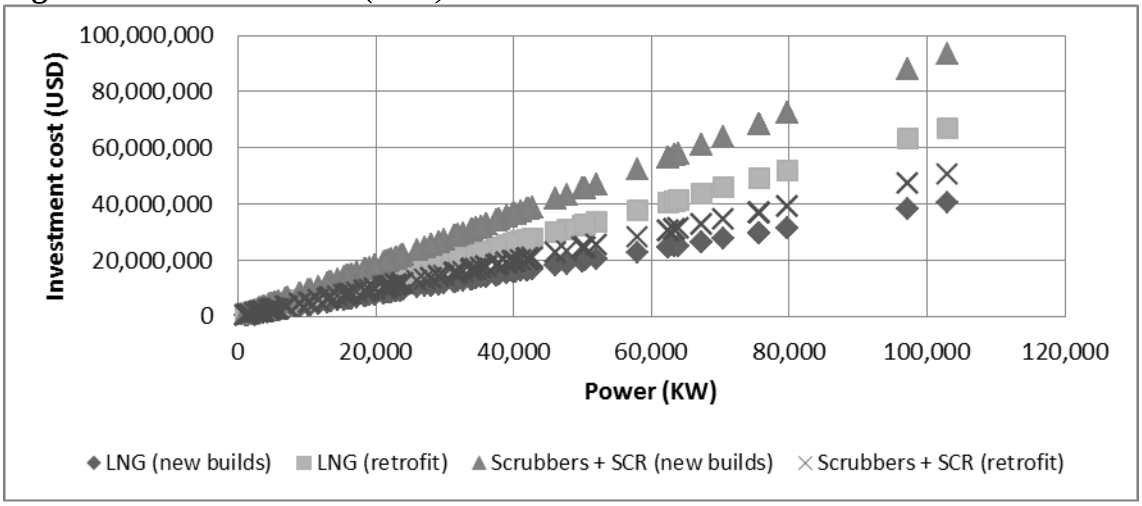
To study the economic feasibility of LNG as a fuel for cruise ships, the CAPEX and OPEX were estimated and compared with the currently adopted system to reduce pollution (i.e., scrubbers plus SCR). Then, with the economic payback, it is possible to estimate the number of years that would be necessary to recover the investment compared to the current alternative of consuming HFO.

5.3.2. Capital costs

The extra investment costs of implementing an LNG system versus a conventional fuel system include the gas engine itself, LNG tanks, vaporization equipment, gas valves, LNG pipes, and auxiliary systems. These costs are considered high capital expenditures, and according to **Kim and Seo (2019)**, the investment cost of an LNG system is 30% that of the construction cost of a ship. Furthermore, **Verbeek et al. (2011)** estimated this cost to be 1.5 to 2 times higher than the associated costs of an oil-fueled engine. Other authors consider the investment cost in terms of the installed power of the ship (**Molitor, Bakosch, and Forsman, 2012; Tzannatos, Papadimitriou, and Koliousis, 2015**).

This study estimated investment costs following the formulation of the **Danish Maritime Authority (2012)**, as this data comes from MAN Diesel & Turbo and Wärtsilä, the main suppliers of LNG engines. **Figure 5.1** shows the investment cost for newly built and retrofitted vessels as a function of their power. According to this formulation, the LNG investment cost of a 4-stroke dual-fuel in retrofitted vessels is 570 €/kW and in a new ship is 345 €/kW. In relation to scrubbers for retrofitted vessels, the cost reaches 384 €/kW, to which the cost of installing the SCR system (45 €/kW) must be added, reaching a total of 429 €/kW. In the case of new vessels, the cost of scrubbers (750 €/kW) plus SCR (45 €/kW) amounts to 795 €/kW.

Figure 5.1. *Investment cost (USD).*



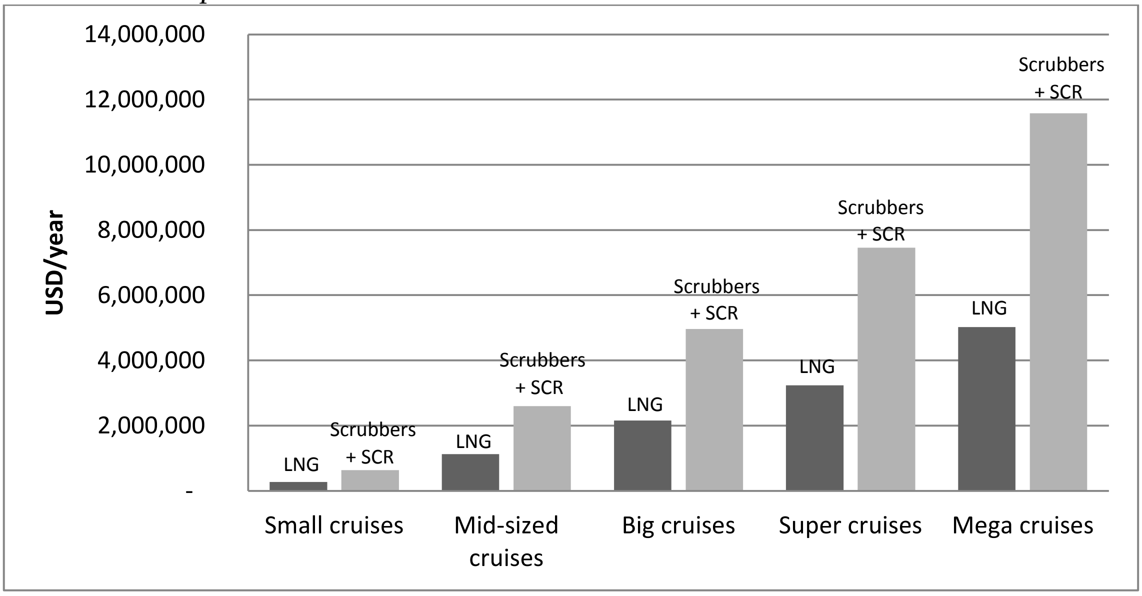
Source: Danish Maritime Authority (2012)

Figure 5.1 explains one of the main reasons why no cruise ship has yet been retrofitted to use LNG. The extra cost of converting an average 40,000 kW power vessel is approximately 26 million USD. However, new ships with an LNG engine would cost 16 million USD, almost half of the cost of retrofitting. This greatly deters shipowners from adapting their existing ships to LNG propulsion (**Sharples, 2019**). Therefore, most of owners opt for scrubbers plus SCR in retrofitted ships, which can be much more cheaply adapted to existing cruise ships (429 €/kW; **Danish Maritime Authority, 2012**).

Another notable aspect is that propulsion by LNG is more economical than scrubbers plus SCR in newly built vessels, mainly due to the additional costs that scrubbers entail with SCRs, engine adaptation, adding generators, electric and propulsion systems (**Danish Maritime Authority, 2012**). However, since the costs vary according to the size of the vessel and its installed power, these comparisons should only be considered a rough generalization (i.e., installing an LNG system on a new vessel is typically cheaper than installing scrubbers plus SCR).

CAPEX as a constant annual fee was calculated as the product of the initial investment (IC) distributed equally over the useful life of the investment (n) and under a given discount rate (R). Taking n=15 years and R=10%, which are values regarded by **Livanos, Theotokatos, and Pagonis (2014)** to be reasonable for the maritime industry, we determined the LNG-associated CAPEX (**Figure 5.2**). These values ranged between 275,000 and 5 million USD per year, depending on the size of the vessel. Regarding scrubbers plus SCR implementation, the related cost was between 633,000 and 11.6 million USD, which represents a 130% greater investment than that need for LNG adoption.

Figure 5.2. *CAPEX (USD/year) comparison between LNG and scrubbers + SCR in new build cruise ships.*



5.3.3. Operational cost

5.3.3.1. Maintenance and repair costs

Many authors agree that the maintenance and repair costs are practically the same for conventional fuel and LNG-powered vessels (**Verbeek et al., 2011; Tzannatos et al., 2015**). LNG is a clean fuel, which means that the associated engines and equipment will require less maintenance and will therefore last longer. In contrast, oil-fueled engines and equipment endure greater wear and require more maintenance, but the overall cost of each repair is lower (**Le Fevre, 2018; Raof, Lim, Suharto, and Rahim, 2018**).

5.3.3.2. Fuel cost

The cost of LNG is a variable that fluctuates according to the time of year and geographical region (**Molitor, Bakosch, and Forsman, 2012; Klein, 2015**). Compared to other marine fuels, LNG has historically been more expensive than HFO, but cheaper than distilled fuels. However, the recent growth in gas production in 2009 and the increase in crude oil prices have reversed this trend, making LNG the most cost-effective among marine fuels (**Tzannatos, Papadimitriou, and Koliousis, 2015**).

Taking the daily LNG prices from the first year in which data are available (1997) until today, it is observed that the data series of **Energy Information Administration (2020)** approximates a log-normal distribution of average 295.33 USD/t and standard deviation 139.31. This gives an idea of its high variability.

The cost of LNG and HFO can be calculated from the respective specific fuel consumption, the total operating time of the cruise ship, and the power consumed as indicated below:

$$Fuel\ cost = C_{esp} \cdot [t_{sea} \cdot (P_{main\ engine} + P_{aux\ engine}) + t_{port} \cdot P_{hotelling}] \cdot F_p \qquad (5.1)$$

where C_{esp} is the specific fuel consumption, t_{sea} and t_{port} are the time of the cruise ship spent in the sea and moored in port respectively; $P_{main\ engine}$, $P_{aux\ engine}$ and $P_{hotelling}$ are the power of the main engine, the power of the auxiliary engine and the power in the hotelling operation respectively. Finally F_p is the fuel price expressed in USD per ton.

assuming that:

- The operating times of the cruises are as indicated by the established 2020 itineraries (**Cruise Mapper, 2019**);
- Cruise ships operate 60% of the time in the open sea and spend 40% of the time moored in a port (**Cruise Mapper, 2019**);
- The power required while the ship is sailing is equivalent to the power of the main engine plus the power of the auxiliary equipment, while the power when the ship is moored is equivalent to the power of the auxiliary equipment (**Lloyd's Register, 2012**) (the power required by the boilers was not considered);
- The cruise sails at typical service speed;
- The specific fuel consumptions are 215 g/kW·h for HFO (**Cooper and Gustafsson, 2004**) and 167 g/kW·h for LNG (**MAN Diesel & Turbo, 2012**).

In order to evaluate the sensitivity level of the LNG price on fuel cost, a Monte Carlo analysis is carried out using the LNG price as a random variable.

Table 5.2. *Results of the sensitivity analysis by the Monte Carlo method (fuel costs for different cruise sizes).*

Category	Min (USD/year)	Mean (USD/year)	Max (USD/year)	5% (USD/year)	95% (USD/year)
Small cruise	733,110	4,750,237	23,649,880	2,054,850	8,979,924
Mid-sized cruise	1,198,998	7,768,991	38,679,280	3,360,698	14,686,630
Big cruise	2,337,908	15,148,640	75,420,150	6,552,974	28,637,230
Super cruise	3,183,259	20,626,150	102,690,900	8,922,426	38,992,010
Mega cruise	4,254,522	27,567,470	137,249,500	11,925,090	52,114,000

As one might assume a priori, there is a great variability in the fuel cost (**Table 5.2**), so the fuel cost is very sensitive to the fuel price variable. For example, in the case of a vessel of more than 200,000 GT (mega cruise), the fuel cost ranges between 11.9 and 52.1 million USD per year depending on the LNG price.

For our analysis, the last value to date (i.e., as of June 2019) was considered for LNG (213 USD/t; **Energy Information Administration, 2020**) and for HFO – IFO380 (395 USD/t; Ship & Bunker, 2020). Forecasts indicate an increase in production costs for LNG in the coming years (**Raof, Lim, Suharto, and Rahim, 2018; Steuer, 2019**); consequently two additional cost scenarios of 500 and 600 USD/t have been considered.

Figure 5.3. *Fuel cost (USD/year) comparison between HFO and LNG in different scenarios.*

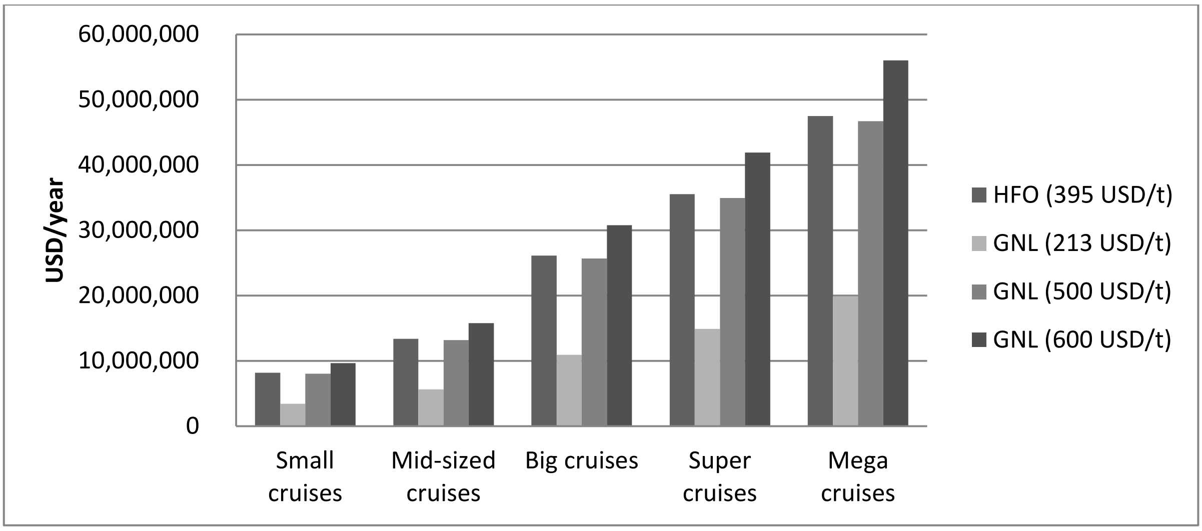


Figure 5.3 presents the fuel costs for the different price scenarios considered for HFO and LNG, grouped according to representative cruise ships of different sizes. Based on these results, LNG fuel is no longer competitive compared to HFO when it exceeds 105 USD/t in cost at a 500 USD/t cost, corresponding to the first of the proposed scenarios.

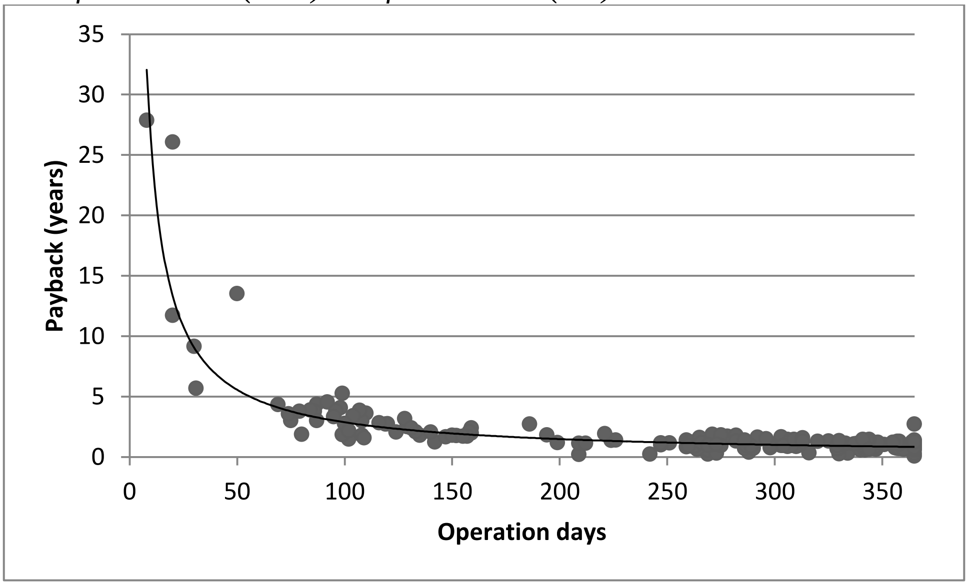
Additionally, the annual LNG fuel cost for large ships ranged between 11 and 20 million USD, depending on the size of the vessel. These results exceed the fuel costs for other types of ships. For example, this cost is between 6 and 10 million USD for container ships (**Notteboom and Vernimmen, 2009**).

5.3.4. Payback

The payback period was estimated as the quotient between the investment cost for LNG implementation and the savings produced by switching from HFO to LNG (**Equation 5.2**). The fuel costs considered to correspond to the scenarios described in Section 5.3.3. In order to update fuel prices, the following annual interest rates have been assumed: 12% for HFO and 6% for LNG, following the upward trends of bunker prices in recent years (**Ship & Bunker, 2020; Energy Information Administration, 2020**).

$$Payback = \frac{Investment\ cost}{(Cost\ HFO - Cost\ GNL)} \quad (5.2)$$

Figure 5.4. *Years to recover the investment vs. operation days assuming annual interest rates for the HFO (12%) and for the LNG (6%).*



Considering the annual interest rates above, the results in **Figure 5.4** demonstrate that payback is recoverable in less than four years for more than 90% of the analyzed cruise ships. This diverges from the observations of **Zhou, Shen, Liu, Li, and Yang (2013)**, whereby the payback for small bulk carriers was recovered in just slightly over a year. Moreover, according to a study conducted by **DNV GL (2016)**, the average payback period for all types of vessels ranged from 3.7 and 6.5 years. In summary, the payback period achieved by new cruise ships powered by LNG differs little from that found for other types of LNG-powered ships. Therefore, the incorporation of LNG technology in new cruise ships is considered feasible from the economic standpoint discussed above.

5.3.5. Additional costs

Additional costs may arise due to the need to provide additional space for the LNG tanks. In this context, the loss of space inside of the ship is a subject of great concern for cruise companies (**Molitor, Bakosch, and Forsman, 2012**), as the installation of the LNG system requires a considerable amount of space that could otherwise be allocated to cabins. Eliminating cabins decreases the value of the ship, as it consequently generates lower income (**Klein, 2015**). It should also be noted that the main source of income for cruise ships is ticket sales, followed by on-board service revenue (**Weaver, 2005; Rodrigue and Notteboom, 2013; Cruise Market Watch, 2018**).

LNG systems require a considerable amount of space, since the density of LNG is almost half of that of conventional fuels (0.41–0.5 t/m3; **Kumar et al., 2011; Klein, 2015**). Therefore, it occupies twice as much space. Also, additional space must be added between tanks placed on deck for safety (**IMO, 2016a**); the cylindrical shape of the tanks further aggravates the loss of space (**Klein, 2015**). **Le Fevre (2018)** determined that the volume occupied by LNG tanks is roughly 80% larger than that of storage for fuels with high sulfur content. Furthermore, there is a loss associated with LNG evaporation during storage (**Le Fevre, 2018; Rao and Karimi, 2018**). At cryogenic temperatures, LNG vaporizes by generating boil-off gas (BOG), meaning that it cannot be stored for prolonged periods (**SSPA Sweden AB, 2013b**). According to **Shin, Shin, Choi, and Yoon (2008)**, more than 0.1% of the volume of LNG in a tank evaporates daily under normal conditions.

The results of the analysis on the number of lost cabins (i.e., as a result of LNG system installation) as a function of vessel size are summarized in **Table 5.3**. They have been grouped by ship size according to their gross tonnage. The average value of lost cabins is indicated for each vessel size. Here, we assumed that cruise ships can sail without refueling for a minimum of seven days. This travel time is typical for cruises (**Rodrigue and Notteboom, 2013; Cruise Mapper, 2019**). The number of lost cabins has been calculated according to the necessary LNG volume required to sail without refueling for seven days, assuming that the vessel spends 60% of the time sailing at service speed and 40% of the time moored at a dock and an estimated 0.1% daily fuel loss due to evaporation (**Shin, Shin, Choi, and Yoon, 2008**). The fuel volume has been calculated for each vessel according to **Equation 5.1**. To calculate the number of lost cabins, the cabin area for each ship has been taken from **Ward (2015)**, assuming a cabin height of two meters.

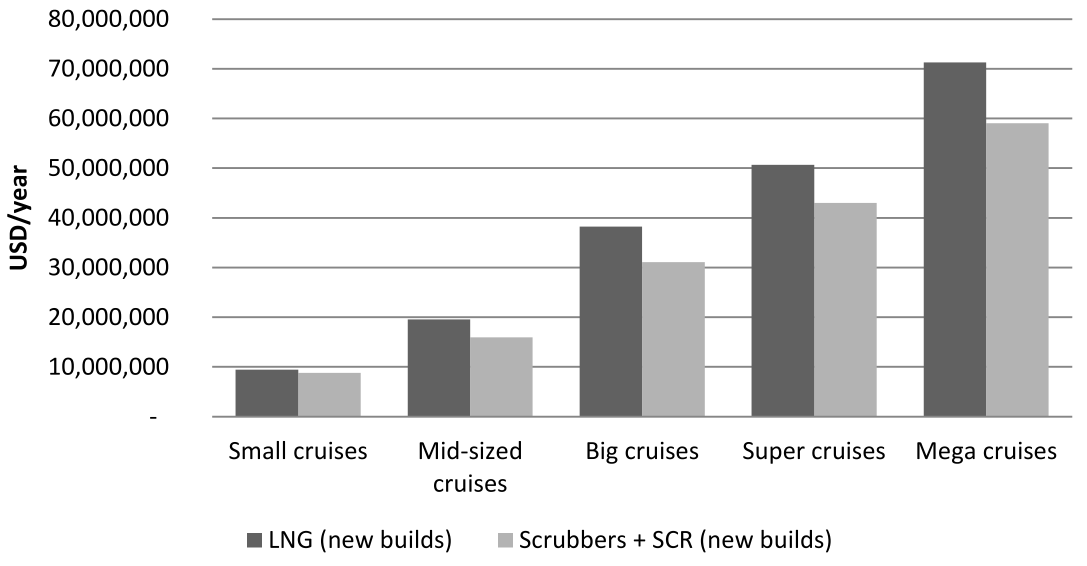
Table 5.3. *Cabin's loss due to the installation of the LNG system.*

	Gross Tonnage	LOA (m)	Number of cabins (actual)	Number of cabin's loss	Cabin's loss (%)	Annual cost due to cabin's loss (USD/year)
Small cruises	<20,000 GT	118	107	18	-21%	5,766,225
Mid-sized cruises	20,000 - 60,000 GT	205	493	40	-9%	12,855,671
Big cruises	60,000 - 120,000 GT	277	1.177	81	-7%	25,163,107
Super cruises	120,000 - 200,000 GT	325	1.724	117	-7%	32,561,313
Mega cruises	>200,000 GT	361	2.718	181	-7%	46,343,496

As indicated in **Table 5.3**, in small and mid-sized cruises with a gross tonnage less than 60,000 GT, it would not be feasible to install an LNG system because a high proportion of the cabins would be lost. In contrast, for ships 60,000 GT and upwards, the percentage of cabins lost drops to 7% and stabilizes in the same range for super- and mega-cruise ships. Assuming that the average cabin area value is 0.0215 million USD/m^2 (**Klein, 2015**), that cruises sail at full occupancy, that operations are carried out according to the calendar established for 2020 (**Cruise Mapper, 2019**), and that two passengers occupy each cabin, it was observed that the largest cruise ships (> 200,000 GT) would have greater losses. This is because this type of ship operates throughout a longer portion of the year (i.e., for more days), and their large size means that would have more lost cabins if converted to LNG.

If we consider the cost due to cabin's loss in the overall cost calculation of LNG, the results are reversed and the system consisting of scrubbers plus SCR is more cost-effective than LNG (**Figure 5.5**). In vessels over 60,000 GT, the total cost is between 7 and 12 million USD a year less than LNG. This estimation highlights the importance of the shape and dimensions of the vessel. Therefore, it is very important that cruise ships have good designs, in order to optimize space and avoid the loss of cabins.

Figure 5.5. *Overall cost comparison (USD/year) considering CAPEX, OPEX and additional costs in new build cruise ships.*



5.3.6. Bunkering operations

Another fundamental consideration for the development of LNG use in cruise ships is the method of gas supply (i.e., bunkering). Currently, three bunkering methods exist: truck-to-ship (TTS), ship-to-ship (STS), and tank-to-ship via pipeline (TPS). Factors such as the fuel volume required and the physical limitations of the port itself determine the most appropriate solution for each case (**SSPA Sweden AB, 2013a**).

TTS is a very good option for small volumes (**Raof, Lim, Suharto, and Rahim, 2018**). However, from 100 m^3 and up it is no longer viable because the refueling times involved in connection, disconnection, and transfer in addition to the slow transfer rate would make the bunkering operation too long. Therefore, any of the two other methods would be preferable in this scenario. In addition, it requires specific security measures, such as establishing a safety zone of 10 m wide and 24 m long protected by concrete blocks and fencing, avoiding possible impacts from other vehicles and preventing the entry of people outside the activity. TTS has an impact that limits other operations involving passengers or cargo due to the presence of the truck (**Carnival Maritime, 2016**). Other essential safety measures are sensors to detect gas leaks and firefighting equipment.

STS is more versatile than the TPS because it does not require ground space since it is carried out by vessels (i.e., barges or methane tankers) in sheltered waters and following safety protocols. On the other hand, restrictions and controls of navigation traffic near the LNG supply location are necessary (**EMSA, 2018**), requiring passing distances for other vessels and a safety zone of at least 10 meters around the bunker ship (**SMTF,**

2011). It is also important to have a secure mooring during the bunkering operation. The hose handling is one of the possible risks, which must be precise and fast to guarantee safety (**EMSA, 2018**).

In contrast, the TPS method requires fixed installations on land, such as a dock dedicated to the loading of LNG, pipelines, and LNG storage tanks near to the port. This method may present difficulties when taking the cruise to the berth, due to the availability of berthing length. As safety measures in bunkering operations, the moorings, loading arms and supply hoses must be checked. TPS is also restricted to good weather conditions (**EMSA, 2018**).

As large volumes of LNG (i.e., up to 3,500 m^3 in modern LNG cruise ships) are required to achieve the necessary autonomy, STS or TPS will likely be established as the primary refueling methods (**Molitor, Bakosch, and Forsman, 2012; SSPA Sweden AB, 2013a**), despite the fact that TPS has not been adopted by cruise ships yet.

Table 5.4. *Comparison between all LNG bunkering methods.*

	Maximum volume (m^3)	Maximum flow (m^3/h)	Auxiliary operations time (h)	Time to refuel 3,500 m^3 (h)
LNG - via TTS	< 100	< 60	1.5	60 h
LNG - via STS	100 – 10,000	2,000	2.5	4.5 h
LNG - via TPS	> 100	200	1	18.5 h

Source: European Commission (2012).

As summarized in **Table 5.4**, the most suitable refueling method for cruise ships would likely be STS, since it has a higher flow rate and a shorter refueling time. Additionally, a cruise ship's time in a port is limited. Cruise ships stay a maximum of eight hours at a port of call (**Brida, Pulina, Riaño, and Zapata-Aguirre, 2012**). Thus, TTS and TPS are rendered unfeasible, leaving STS as the only currently viable method to service large cruise ships.

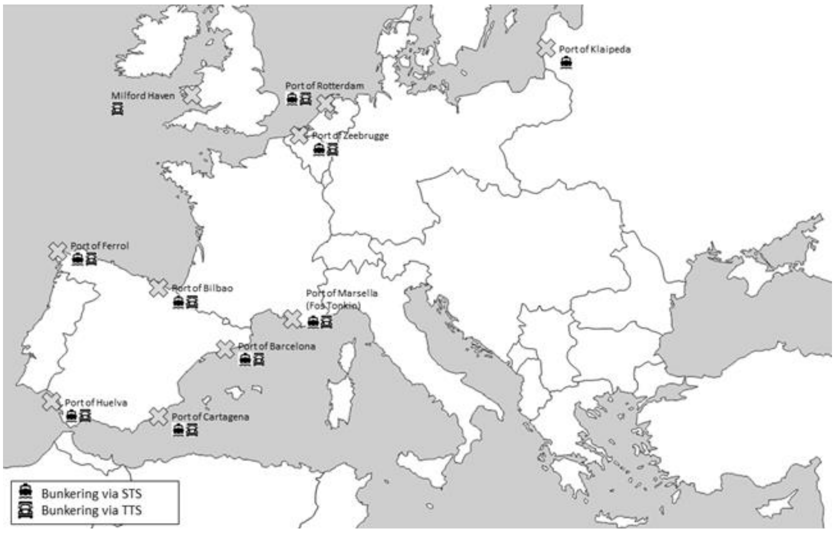
5.3.7. Itinerary impacts

The implementation of LNG technology in cruise ships would also play an important role in itinerary planning. Cruise companies largely choose home and call ports based on factors such as the attractiveness of the port, the availability of resources, the compatibility between ports, and the minimization of port fees and fuel costs. (**Barron and Greenwood, 2006; Mancini and Stecca, 2018**). Moreover, the availability of LNG infrastructure in a port is a factor that was not a relevant criterion for port selection until the present.

Route planning is a critical issue for cruise lines (**Zhen, Li, Hu, Lv, and Zhao, 2018**). A ship's occupancy rate depends on its itinerary and destinations (**Lee and Ramdeen, 2013**). Thus, itinerary decisions invariably affect resource allocation and the company's capacity to generate income (**Mancini and Stecca, 2018**).

The fact that new LNG-powered cruise ships operate exclusively on LNG fuel will influence itinerary plans, as relatively few ports currently have the necessary infrastructure to supply LNG to ships. According to **King and Spalding (2018)**, there are only 28 large-scale LNG import terminals in Europe; this number is further reduced to 10 only those European cruise ports with the capacity to offer LNG bunkering services via STS or TTS are considered (**Figure 5.6**).

Figure 5.6. European cruise ports with LNG bunkering services to cruises today.



Source: King and Spalding (2018)

A fundamental aspect to consider when planning itineraries for LNG-fueled cruise ships is the vessel's autonomy. The autonomy of a ship is determined by its LNG tank volume. The first LNG-operated cruise ships (i.e., AIDAPrima and Costa Smeralda) have estimated tank volumes of approximately 3,500 m^3 (**Cruise Industry News Quarterly Magazine, 2018**). Assuming a consumption of 150 t/day (**Molitor, Bakosch, and Forsman, 2012**) and an LNG density of 450 kg/m^3, this would provide autonomy for 10 days. This level of autonomy would be sufficient for most cruise ships, since their itineraries are between three and seven days, with seven days being the most frequent duration (**Rodrigue and Notteboom, 2013; Cruise Mapper, 2019**). According to **Wuersig, Chiotopoulos, and Adams (2015)**, more than 80% of cruise fleets worldwide could operate with only 1,500 m^3 LNG tank capacity vessels.

If the assumptions above are true, cruise ships would only need to refuel in home ports at the beginning or end of each trip, without the need to refuel in ports of call. Through an analysis of European cruise ports from the **Cruise Mapper (2019)** database as well as the itineraries established for 2020, it was observed that 87% of the cruise ships could call in any of the ports that can currently supply LNG or use one of them as a home port. Therefore, LNG adoption would have a lesser impact on itineraries than expected.

5.3.8. Recommendations to incentivize the adoption of LNG

5.3.8.1. Obligatory requirements to establish an ECA zone in the Mediterranean

The establishment of ECAs in seas and oceans is undoubtedly one of the main reasons why shipping companies are beginning to invest in LNG. The establishment of ECA zones involves very strict requirements to prevent atmospheric pollution. For example, one zone establishes a 0.1% sulfur limit for fuels, thereby prohibiting the use of fuels with high sulfur content (**Thomson, Corbett, and Winebrake, 2015**).

This regulation indirectly favors the use of LNG. The other available options that would allow compliance with ECA standards (i.e., distillate fuels, scrubbers, or cold ironing) are seemingly less economically advantageous than LNG adoption (**Thomson, Corbett, and Winebrake, 2015; Ammar and Seddiek, 2017**).

The four ECA areas established since 2006 are in the Baltic Sea, the North Sea, North America, and the American Caribbean (**Chang, Park, Lee, and Kim, 2018; Zhen et al., 2018**). However, the prospect of a Mediterranean ECA has been under consideration for years. Therefore, it would be pertinent for the governments of cities and regions surrounding the Eastern Mediterranean (i.e., in France, Italy, Spain, and North Africa) to commit to this proposal and promote the establishment of an ECA in the Mediterranean. The socioeconomic benefits would be numerous. According to a study by the French government presented to the International Maritime Organization (**Ineris, 2019**), the implementation of a SECA area would reduce levels of SO_x, NO_x, and PM (i.e., particulates) up to 95%, 5%, and 80%, respectively.

5.3.8.2. Implementation of new incentives

Another way to promote the implementation of LNG in cruise ships is through the creation of new environmental incentives by port authorities that would reward cruise companies that adopted LNG fuel in their ships, thereby reducing pollution.

Currently, aiming to reduce air pollution, port authorities offer discounted port fees to shipping companies based on certain environmental certifications such as ISO 14.001 or through indexes that assess ship emissions, such as the Environmental Ship Index (ESI), the Green Award (GA), or the Clean Ship Index (CSI; **Kim and Seo, 2018**). However, none of these incentives have proven to be very effective, as they do not encourage vessels to pollute less.

European port authorities have begun offering incentives in addition to those already applied by the ESI index which reward the use of LNG. These discounts vary between 10% and 20% of the GT component of the port rate or of the total port fees; these incentives amount to a maximum discount range between 2,000 and 6,000 euros. However, considering the significant investment necessary to install an LNG system, these bonuses are not sufficiently attractive to justify LNG implementation.

These issues suggest that the application and effectiveness of environmental incentives can be improved and that it is important to rethink the system by which these incentives are awarded. Significantly, of March of 2019, environmental bonuses can be regulated by European regulation (EU) 2017/352, which establishes that rates for port infrastructure that may differ depending on the port's economic strategy and territorial arrangement policies.

With this development, port authorities are evaluating a more complex incentive system that includes bonuses for reduced ship emissions in ports, whereby tariffs are imposed on those who pollute the most. To achieve this, it would be necessary for port authorities to carry out inventories of emissions from port activities through estimations, given that it is not yet possible to record the emissions of each vessel during its time in a port.

Given the high degree of competitiveness between ports, these regulations may affect their attractiveness and consequently lead to a loss of maritime traffic. Thus, it could be beneficial for port authorities to agree upon and unify the criteria for environmental benefits. Additionally, as more ports offer this type of incentive, the effect of such programs will be accentuated and incentives will gain increased significance. Thus, port authorities should pledge to increase the impact of said incentives through collaboration between ports.

5.4. Conclusions

This study demonstrates that LNG propulsion is a highly viable and attractive option for cruise companies seeking to comply with new environmental regulations. Compared to the other possible alternatives (i.e., distilled fuels, scrubbers plus SCR, or cold ironing), LNG has substantial advantages.

From an economic standpoint, the extra investment required to implement an LNG system is very high, on the order of 16 million USD for a 40,000 kW newly built vessel (**Figure 5.1**). However, this cost would be offset by savings in fuel costs; LNG is currently sold for 213 USD/t, which is roughly a third of the cost of distilled fuels (637 USD/t) and half of the cost of heavy fuels (USD/t). Therefore, it would take less than four years to recover the investment associated with LNG adoption, compared with the continued use of HFO in conjunction with a scrubber system plus SCR (**Figure 5.4**). These results are consistent with other studies for different ship types. For example, **Burel, Taccani, and Zuliani (2013)** suggested a payback period of three years for tanker ships, **GL & MAN (2013)** between two and four years for a 14,000 TEUS container ship, **Verbeek et al. (2011)** between five and 10 years for ferries according to fuel cost, **Ammar and Seddiek (2017)** 12 years for ro-ro cargo vessels, and **Hagedorn (2014)** between 3.4 to 7.4 years for cruise ships according to their time spent in ECA zones. It should be noted that if the payback period exceeds ten years, it is unlikely that companies will undertake to an investment (**Raof, Lim, Suharto, and Rahim, 2018**).

From our economic analyses, it was also concluded that it would not be profitable to retrofit an existing cruise ship to use LNG, as the cost would be almost double that of the installation of an LNG system in new ships (**Molitor, Bakosch, and Forsman, 2012; Danish Maritime Authority, 2012**). However, some studies have proposed potential solutions for conversion (**Wuersig, Chiotopoulos, and Adams, 2015**). It could be carried out through the installation of prefabricated modules on ships, which include the LNG system, additional cabins, and public spaces. Thus, the space devoted to cabins would not be lost, and implementation would be more economical. Still, no cruise ship has yet been retrofitted to use LNG.

Nor does it seem feasible to implement LNG on small cruises (below 60,000 GT), since the percentage of lost cabins due to the space required by this technology is too high. In this way, a good design of the ship is essential to maximize the spaces destined for cabins.

Cruise ship companies continue to rely on scrubbers and SCR to comply with current emission restrictions for ships already in service, since the capital cost of scrubbers plus SCR is much less than that of retrofitting a cruise ship to use LNG (i.e., between 633,000 and 11.6 million USD per year; **Figure 5.2**).

LNG seems to be more suitable for new and large vessels. In fact, most of the cruise ships planned for the next eight years exceed 160,000 GT and a capacity of 4,000 passengers (**Table 5.2**). This is because ship investments are generally amortized for large vessels, as more tickets are sold and the average cabin loss is lower (i.e., roughly 7%; **Table 5.4**).

Another challenge to be addressed in the future is the lack of infrastructure to supply LNG at all cruise ports. According to **King and Spalding (2018)**, currently only 10 cruise ports are capable of supplying LNG in Europe. This only moderately influences established routes, since cruise ships with at least seven days of autonomy would have enough time to complete their entire journey without refueling. An analysis of 2020 schedules (**Cruise Mapper, 2019**) reveals that more than 87% of cruise ships will call in one of these ports; thus, impacts on itineraries would be minimal.

Much development is still required to optimize policies incentivizing LNG implementation. Although the policies that will take effect in 2020 will likely reduce air pollution associated with marine vessels, a new incentive system that truly rewards ships that pollute less must still be developed. Also, the incentives offered should better encourage cruise companies to invest in LNG-powered vessels.

Chapter 6

Final discussion and conclusions

6.1. Conclusions

This thesis addressed the analysis of the cruise phenomenon worldwide from different perspectives. The aim of these analyses was to understand the evolution of the cruise industry, what impacts it has on the port and the city that hosts them, what measures can be taken to minimize the impacts, and the direction that the cruise industry may take in coming years.

All the aspects analysed in this thesis have been the subject of relatively few studies in the scientific literature. The cruise phenomenon as we know it today is relatively recent. For this reason, it has not yet been thoroughly studied. Most papers on cruise ships focus only on their economic impact.

The aspects studied in this thesis should serve as a starting point for public agencies (port authorities and governments), cruise companies and other companies in the sector associated with cruise activity to improve the concept of the cruise ship in every way.

In view of the growing evolution of cruise ships, cruise companies should ask themselves and reflect on whether it makes sense to build ever-larger cruise ships exceeding a gross tonnage of 220,000 GT, which are the largest cruise ships today.

Another question that arises in this thesis is associated with problems of mobility on land in the port and host city, caused by the coincidence in time and space of cruise ships. It is something that was not considered before, due to the simple fact that there were not as many cruise ships in the past, and those that existed had much smaller capacity.

The third but no less important aspect analysed in this thesis is air pollution caused by gas emissions, due to the burning of marine fuels. This aspect increasingly worries civil society and public administrations. Hence, it was considered vital in the thesis to investigate this issue and determine which is the best solution as an alternative fuel to heavy fuel oil.

To be clear, this thesis aims to identify the main problems caused by the new reality of cruise ships, so that the main actors involved are aware of this reality and can act accordingly.

The main conclusions associated with each specific chapter are summarized below.

<u>1. In relation to the analysis of the growth in size of cruise ships (Chapter 3)</u>

- It is clear that cruise ships have evolved since the beginning of the modern era to larger vessels. Cruise companies choose to build larger ships to achieve economies of scale, facilitate revenue capture and expand the market of passenger demand.
- The cost model results show that economies of scale for cruises are met up to a certain ship size between 60,000 and 120,000 GT. For larger sizes, the total unit cost (per passenger) increases. These results are in accordance with the current market for the cruise industry, where 52% of the existing fleet is within this range.
- There is a stagnation in the size of the ships at 227,700 GT (mega cruises), due to the exhaustion of economies of scale beyond 120,000 GT of gross tonnage.
- In the mega cruise ship typology, cruise companies are more focused on maximizing income than reducing costs through economies of scale.
- As the size of the cruise ship increases, the greatest reduction in unit costs occurs in travel costs, above capital and operational costs.

<u>2. In relation to the impact on mobility caused by cruise passengers for the particular case of the Port of Barcelona (Chapter 4)</u>

- The passenger exit flow behaves linearly and has three stages at different speeds. In the first stage (between 1 and 3 hours from when the ship docks), the flow of passengers is between 9–13 pax/min, depending on whether the ship is a transit or turnaround type. In the second stage (from three to four and a half hours), the greatest exit rate occurs of between 15–27 pax/min (depending on the type of operation) and with a duration of 1.5 hours. In the third and last stage (from four and a half hours until the last passenger has disembarked), the flow is drastically reduced to 1–2 passengers per minute. Therefore, the passenger exit flow depends on the variables: type of operation and arrival time of the cruise ship.

- Regarding the transport taken by passengers when they leave the cruise terminal, taxis are the predominant mode of transport (35% of passengers), followed by excursion buses (22%). But the criteria for choosing transport mode strongly depends on the type of operation. In the case of the homeport, the majority of passengers choose a taxi (48%), while if the cruise ship is a transit type, the majority of passengers choose excursion buses (49%). Private transport remains residual with only 5% of the modal share.
- It is very difficult to estimate new road traffic generated by cruise ships, since it depends on many variables. Naturally, it has little impact on the general traffic of the city, since it is small compared to the total of the city and has multiple destinations. However, it greatly affects the internal traffic of the port since it is generated at peak times and the accesses to the port have limited capacity.
- Barcelona Port Authority is working to improve the management of traffic generated by cruise ships. After mobility analyses, it was determined that taxis are responsible for generating the highest volume of traffic. In addition, if the port becomes a pure homeport in the future, the proportion of taxis will be higher and therefore there will be a greater number of vehicles on the internal roads of the port, which will cause more queues and long waiting times. To solve this, two solutions are proposed. The first is associated with the creation of a massive system for transporting passengers called a people mover. Following the model of the Miami cruise port, the idea is to connect the cruise terminals with a tram that transports passengers to a parking lot outside the dock where all taxis are located. Another proposed solution is to take passengers by shuttle bus from the cruise terminals to a mobility centre away from the cruise ship dock. From there, passengers would be able to take a taxi to reach their main destination.

3. Regarding the implementation of LNG as an alternative fuel for cruise ships (Chapter 5)

- LNG is one of the most interesting options as an alternative fuel for cruise ship propulsion. This is mainly due to the increase in emission restrictions foreseen by the IMO for 2020 and the competitive cost of LNG as a fuel in relation to the other available options (distilled fuels, scrubbers plus SCR or cold ironing).

- LNG has a high investment cost (in the order of 16 million dollars for a 40,000 KW vessel). But this cost could be compensated with savings obtained from the change of fuel (from heavy or distillate fuels to LNG). According to the calculations, it would be possible to recover the investment in less than 4 years.
- LNG would not be profitable on existing cruise ships since its installation cost practically doubles. On these ships, the cruise companies use the combined system of scrubbers plus SCR, since this is the system that has the lowest cost for existing ships.
- LNG is not indicated for small-size cruises (<60,000 GT), since its installation requires a lot of space, so the percentage of lost cabins would be too high. It is very important to establish good ship design to maximize the space for cabins.
- LNG is recommended for new, large ships. All new LNG cruises exceed 160,000 GT.
- There is a clear lack of infrastructure to supply LNG at all cruise ports. For example, in Europe there are only 10 ports that can supply LNG. This has a moderate impact on itineraries, as most seven-day trips call at least once in a port with LNG.
- There is a need for public administrations to create a new incentive system that really compensates cruise companies for investing in LNG.

6.2. Future research

In this thesis, we have brought together all the aspects that are believed to be currently relevant in the cruise industry today that have never been investigated before and needed to be studied.

However, some aspects have not been addressed that are believed to be important in the near future for the proper development of the cruise industry.

The first aspect to be researched in future works is associated with the physical limitations of ports that host large cruise ships. In view of the rapid evolution of cruise ships to very long ships, an increasing number of ports must adapt their facilities to accommodate this type of ships. For example, to receive a mega cruise, terminals must guarantee at least 10 m draft, 425 berth length and 132 m of navigation channel (**PIANC, 2016**). These dimensions are not easy to achieve for cruise ports. In addition, free spaces must be added on land to correctly carry out the embarkation and disembarkation operations. Spaces such as the apron area, the ground transportation area and road communications are necessary, and all of them must be well-dimensioned to accommodate a large cruise ship. The development of this topic would require a detailed analysis in an article, which could be used as a guideline for ports and operators wishing to host large cruise ships.

A second aspect to study, which was briefly described in Chapter 4, is the development of a comprehensive system for the mobility of cruise passengers. The results of the mobility study show that taxis are the most commonly used mode of transport. In addition, if the port is a home port, there will be a greater number of taxis, since in this type of ports passengers mainly choose taxis as their mode of transportation. To resolve this problem, it would be interesting to investigate the design of a space away from the cruise terminals to manage passenger mobility and locate taxis. The idea would be to implement a shuttle bus system that picks up passengers from cruise terminals and takes them to a modal hub far enough from the port. From there, passengers would take taxis to their destination. Through this system, the mobility problems on the internal roads of the port could be solved.

A third important aspect is associated with current regulations to promote the use of LNG as a fuel for cruise ships. After the analysis of LNG implementation in cruise ships in Chapter 5, we realized that its widespread use in the cruise industry is very difficult, as there are not enough instruments to encourage its use. To date, the only instrument is the IMO regulation, which requires any type of ship to reduce its emissions. There is no regulation or law that implements incentives to encourage LNG technology. For this reason, a bonus system should be developed rewarding companies for the installation of systems such as LNG on their ships, so that significant financial aid is put in place to incentivize shipping companies to make the necessary investments. Currently, the established system only rewards shipping companies that have certain environmental certifications or comply with certain indexes.

Finally, a hot topic that cannot be forgotten in analyses of the evolution of cruise ships is how and in what way the COVID-19 pandemic will affect the cruise industry. As a result of the virus, cruise activity around the world was temporarily suspended. In addition, at the beginning of the outbreak, a dozen cruise ships had trouble finding a port to dock, because they had positive cases of COVID-19 on board. All this will surely have significant negative effects on the cruise industry over time. A high percentage of passengers are regular cruise ships users and these events may have produced fear and rejection of cruise ships, which could lead to never taking a cruise trip again.

Be that as it may, the cruise industry is working to regain the trust of users and to start operations again when authorities allow it. The main changes expected in the cruise industry are that trips will be shorter. This will be mainly due to the fact that the reopening of the ports will not be the same in all countries. Control measures for passengers will also be more exhaustive, and periodic health checks will be carried out on embarking and disembarking.

Another important change that is expected in the cruise industry is to keep only smaller capacity ships operational, since large ships are only profitable if they are practically full, due to the significant associated costs. This will undoubtedly slow down the construction plans for the new larger ships expected in coming years. Thus, the industry could rethink its strategy and instead of betting on mega cruises with over 5,000 passengers, return to its beginnings with ships of less than 1,000 passengers.

The entirely new situation caused by COVID-19 gives rise to diverse studies. Research could focus on analysing the effect that the pandemic will have on passengers and how to regain their confidence in cruise ships. Studies could also be undertaken to determine what measures the cruise industry must take to be operational again. Finally, the economic and social impacts of the pandemic on cruise ships could be analysed. In short, all these studies are proposed to answer the question of what cruise ships will be like from now on.

Bibliography

Ammar, N. R., and Seddiek, I. S. (2017). Eco-environmental analysis of ship emission control methods: Case study RO-RO cargo vessel. *Ocean Engineering, 137,* 166-173. doi:10.1016/j.oceaneng.2017.03.052

Andriotis, K., and Agiomirgianakis, G. (2010). Cruise visitors' experience in a Mediterranean port of call. *International Journal of Tourism Research, 12*(4), 390-404.

AQR-Lab. (2015). Impacto de la actividad de cruceros del Port de Barcelona sobre la economía catalana. *Universitat de Barcelona. Institut de Recerca en Economia Aplicada (IREA).*

Armellini, A., Daniotti, S., and Pinamonti, P. (2015). Gas Turbines for power generation on board of cruise ships: a possible solution to meet the new IMO regulations?. *Energy Procedia, 81,* 540-547. doi:10.1016/j.egypro.2015.12.127

Armellini, A., Daniotti, S., Pinamonti, P., and Reini, M. (2018). Evaluation of gas turbines as alternative energy production systems for a large cruise ship to meet new maritime regulations. *Applied Energy, 211,* 306-317. doi:10.1016/j.apenergy.2017.11.057

Azzara, A., Rutherford, D., and Wang, H. (2014). Feasibility of IMO annex VI tier III implementation using selective catalytic reduction. *The International Council on Clean Transportation, 4*, 1-9.

Baker, D. (2015). Exploring Cruise Passengers' Demographics, Experience, and Satisfaction with Cruising the Western Caribbean. *International Journal of Tourism & Hospitality Reviews, 1(1),* 23-31.

Ballini, F. (2013). Air Pollution from Ships in Danish Harbours: Feasibility Study of Cold-ironing Technology in Copenhagen (Doctoral dissertation, PhD Thesis, Department of Naval, Electrical, Electronic and Telecommunication Engineering, University of Genoa, Italy). Retrieved from: http://www.ops.wpci.nl/_images/_downloads/_original/1379921104_airpollutionfromshipsindanishharbours.pdf

Ballini, F., and Bozzo, R. (2015). Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology. *Research in Transportation Business & Management, 17,* 92-98. doi:10.1016/j.rtbm.2015.10.007

Bandara, Y. M. and Nguyen, H. O. (2016). Influential Factors in Port Infrastructure Tariff Formulation, Implementation and Revision. *Transportation Research Part A: Policy and Practice 85,* 220-232.

Baresic, D., Smith T., Raucci, K., Rehmatulla, C., Narula, N. and Rojon, I. (2018). LNG as a marine fuel in the EU: Market, bunkering infrastructure investments and risks in the context of GHG reductions. London: University Maritime Advisory Services.

Barron, P., and Greenwood, A. B. (2006). Issues determining the development of cruise itineraries: A focus on the luxury market. *Tourism in Marine Environments*, *3(2)*, 89-99. doi:10.3727/154427306779435238

Bennett, M. (2016). Competing with the sea: Contemporary cruise ships as omnitopias. *Performance Research 21(2),* 50–57.

Bittante, A., Jokinen, R., Pettersson, F., and Saxén, H. (2015). Optimization of LNG supply chain. *Computer aided chemical engineering*, *37*, 779-784. doi:10.1016/B978-0-444-63578-5.50125-0

Boer, L. C., and Hoen, M. (2015). Scrubbers: An Economic and Ecological Assessment. Delft: CE Delft, 45. Report no. 5.4F41.20. Retrieved from: https://www. nabu.de/downloads/150312-Scrubbers.pdf.

Boulougouris, E. K., and Chrysinas, L. E. (2015). LNG Fueled Vessel Design Training. Glasgow, Scotland: University of Strathclyde.

Brida, J. G., and Zapata, S. (2009). Cruise tourism: economic, socio-cultural and environmental impacts. *International Journal of Leisure and Tourism Marketing, 1(3),* 205-226.

Brida, J. G., Bukstein, D., Garrido, N., Tealde, E., and Zapata Aguirre, S. (2010). Impactos económicos del turismo de cruceros: Un análisis del gasto de los pasajeros de cruceros que visitan el Caribe colombiano. *Estudios y perspectivas en turismo, 19(5),* 607-634.

Brida, J. G., Pulina, M., Riaño, E., and Zapata-Aguirre, S. (2012). Cruise passengers' experience embarking in a Caribbean home port. The case study of Cartagena de Indias. *Ocean & Coastal Management, 55,* 135-145. doi: 10.1016/j.ocecoaman.2011.10.003

Bull, A. (1996). The Economics of Cruising: An Application to the Short Ocean Cruise Market. *Journal of Tourism Studies*, *7(2)*, 28-35.

Burel, F., Taccani, R., and Zuliani, N. (2013). Improving sustainability of maritime transport through utilization of Liquefied Natural Gas (LNG) for propulsion. *Energy, 57,* 412-420. doi:10.1016/j.energy.2013.05.002

Butt, N. (2007). The impact of cruise ship generated waste on home ports and ports of call: a study of Southampton. *Marine Policy, 31,* 591-598.

Cambridge Dictionary. (2020). [online] Available from: http://www.dictionary.cambridge.org/ [Accessed 28 January 2020].

Caric, H. (2015). Challenges and prospects of valuation - cruise ship pollution case. *Journal of Cleaner Production*, *30*, 1e12.

Carić, H., and Mackelworth, P. (2014). Cruise tourism environmental impacts–The perspective from the Adriatic Sea. *Ocean & coastal management*, *102*, 350-363. doi: 10.1016/j.ocecoaman.2014.09.008

Carnival Corporation (2017). Annual Report [online] Available from: http://phx.corporate-ir.net/phoenix.zhtml?c=140690&p=irol-reportsannual [Accessed 29 March 2018]

Carnival Corporation. (2018). Fiscal Year 2018 Corporate Sustainability Report. [online] Available from: https://www.carnivalcorporation.com/transparency-and-reporting/sustainability-reports/ [Accessed 2 April 2020].

Carnival Corporation. (2019). Annual Report. [online] Available from: https://www.carnivalcorp.com/financial-information/annual-reporting/ [Accessed 27 March 2020].

Carnival Maritime. (2016). LNG Fuelling of AIDA Hyperion Class. US: Carnival Corporation.

Cartwright, R., and Baird, C. (1999). The development and growth of the cruise industry. Elsevier.

Castillo-Manzano, J. I., Fageda, X., and Gonzalez-Laxe, F. (2014). An analysis of the determinants of cruise traffic: An empirical application to the Spanish port system. *Transportation Research Part E: Logistics and Transportation Review*, *66*, 115-125.

CENIT. (2016). Cálculo de emisiones de gases contaminantes CO_2, NO_x, PM y SO_x producidos por el tráfico de cruceros en el Puerto de Barcelona.

Chang, Y. T., Park, H. K., Lee, S., and Kim, E. (2018). Have emission control areas (ECAs) harmed port efficiency in Europe?. *Transportation Research Part D: Transport and Environment*, *58*, 39-53. doi: 10.1016/j.trd.2017.10.018

Chaug-Ing, H. S. U. and Hsieh, Y. P. (2005). Shipping Economic Analysis for Ultra Large Containership. *Journal of the Eastern Asia Society for Transportation Studies 6*, 936-951.

Cheong, C. (2013). Harboring Tourism. Cruise ships in historic port communities. In *Report of an international symposium held in Charleston, South Carolina, USA* (p. 29).

CLIA. (2019). Cruise trends and industry outlook. Retrieved from https://cruising.org/-/media/research-updates/research/clia-2019-state-of-the-industry-presentation-(1).pdf

CLIA. (2020). *State of the cruise industry Outlook.* Washington DC: CLIA.

Cofala, J., Amann, M., Heyes, C., Wagner, F., Klimont, Z., Posch, M., and Stavrakaki, A. (2007). *Analysis of policy measures to reduce ship emissions in the context of the revision of the national emissions ceilings directive.* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Commoy, J., Polytika, C. A., Nadel, R., and Bulkley, J. W. (2005). The environmental impact of cruise ships. *World Water and Environmental Resources Congress 2005*.

Cooper, D., Gustafsson, T., (2004). *Methodology for Calculating Emissions from Ships. 1. Update of Emission Factors.* Report Series for SMED and SMED&SLU, SMHI, Norrköping, Sweden: SMHI. ISSN: 1652-4179.

Corbett, J. J. and Winebrake, J. J. (2008). Emissions Tradeoffs Among Alternative Marine Fuels: Total Fuel Cycle Analysis of Residual Oil, Marine Gas Oil, and Marine Diesel Oil. *Journal of the Air & Waste Management Association 58(4),* 538-542.

Cordeau, J. F., Laporte, G., Legato, P., and Moccia, L. (2005). Models and tabu search heuristics for the berth-allocation problem. *Transportation Science, 39(4),* 526-538.

Cox, R., and Long, J. C. (2004). Embarkation/Disembarkation Of Cruise Ship Passengers Between the Terminal and the Ship. *Ports 2004,* ASCE, 10.1061/40727(2004)1.

Cruise Industry News (2018). Cruise Ship Orderbook [online] Available from: http://www.cruiseindustrynews.com/cruise-news/cruise-ship-orderbook.html/ [Accessed 30 December 2019]

Cruise Industry News (2019). *2018-2019 Cruise Industry News Annual Report.* New York: Cruise Industry News.

Cruise Industry News (2019). Seatrade Cruise Orderbook. Retrieved from: https://www.cruiseindustrynews.com/cruise-news/cruise-ship-orderbook.html

Cruise Industry News Quarterly Magazine. (2018). Summer 2018. Preparing for LNG Bunkering. p.120.

Cruise Industry News. (2017). Cruise Ship Orderbook. 〈http://www.cruiseindustrynews.com/cruise-news/cruise-ship-orderbook.html〉 (Mar.27, 2017).

Cruise Industry News. (2018). *Cruise Industry News Annual Report and Industry Growth Forecast.* New York: Cruise Industry News.

Cruise Industry News. (2020a) Cruise Ship Orderbook. [online] Available from: http://www.cruiseindustrynews.com/cruise-news/cruise-ship-orderbook.html/ [Accessed 28 March 2020].

Cruise Industry News. (2020b). *Cruise Industry News Annual Report and Industry Growth Forecast.* New York: Cruise Industry News.

Cruise Lines International Association (CLIA). (2015). 2015 Cruise Industry Outlook. Cruising to New Horizons and Offering Travelers More. 〈http://www.cruising.org/docs/default-source/research/2015-cruise-industry-outlook.pdf?sfvrsn=2〉 (Mar.14, 2016).

Cruise Lines International Association (CLIA). (2017). 2017 Cruise Industry Outlook. 〈 https://www.cruising.org/docs/default-source/research/clia-2017-state-of-the-industry.pdf?sfvrsn=0 〉 (Mar.27, 2017).

Cruise Lines International Association (CLIA). (2019). *State of the Industry*. Washington DC: CLIA.

Cruise Mapper. (2018). Cruise Ship Cost to Build [online] Available from: http://www.cruisemapper.com/wiki/759-how-much-does-a-cruise-ship-cost/ [Accessed 7 February 2019]

Cruise Market Watch (2018) Financial Breakdown of Typical Cruiser [online] Available from: http://www.cruisemarketwatch.com/home/financial-breakdown-of-typical-cruiser/ [Accessed 29 March 2019]

Cruise Market Watch. (2020). Cruise Market Watch Statistics. [online] Available from: http://www.cruisemarketwatch.com/ [Accessed 27 March 2020].

Cullinane, K. and Khanna, M. (2000). Economies of Scale in Large Containerships: Optimal Size and Geographical Implications. *Journal of transport geography 8(3),* 181-195.

Danish Maritime Authority. (2012). *A feasibility study for an LNG filling station infrastructure and test of recommendations. North European LNG Infrastructure Project.* Copenhagen: Danish Maritime Authority. ISBN: 87-7454-986-3

Dauer, R.R.M. (2000). The Composition of the Crews of the Vessels Entering Barcelona Harbour WIT Transactions on the Built Environment 51.

De Cantis, S., Ferrante, M., Kahani, A., and Shoval, N. (2016). Cruise passengers' behavior at the destination: Investigation using GPS technology. *Tourism Management, 52*, 133-150.

De la Vina, L., and Ford, J. (1999). Economic impact of proposed cruiseship business. *Annals of Tourism Research, 26*(1), 204-207.

Dehoorne, O., Murat, C., and Petit-Charles, N. (2008). The cruise tourism in the Caribbean space: spatial rationale and development rationale. *Geo Journal of Tourism and Geosites, 2(2),* 96-105.

Deniz, C., and Zincir, B. (2016). Environmental and economical assessment of alternative marine fuels. *Journal of Cleaner Production, 113,* 438-449. doi:10.1016/j.jclepro.2015.11.089

DeSombre, E. R. (2006). *Flagging Standards: Globalization and Environmental, Safety, and Labor Regulations at Sea.* Cambridge: The MIT Press.

Di Vaio, A. and D'Amore, G. (2011). Governance of Italian Cruise Terminals for the Management of Mediterranean Passenger Flows. *International Journal of Euro-Mediterranean Studies 4(1),* 119-137.

Di Vaio, A., and Varriale, L. (2013). Coordination and key performance indicator in cruise event management: An empirical analysis in Italian market. In *Selected Proceedings, 13th WCTR 2013 (World Conference Transport Research)*.

Dickinson, R.H. and Vladimir, A.N. (1997). *Selling the Sea: An Inside Look at the Cruise Industry.* New York: Wiley.

DNV GL. (2016). LNG as ship fuel. Benefits and challenges for conversions to LNG fuel. Retrieved from: https://www.dnvgl.com/

DNV GL. (2017). LNGi status update. Comprehensive insights on worldwide LNG bunkering availability and market data on LNG as fuel for ships. Retrieved from: https://www.dnvgl.com/

Douglas, N., and Douglas, N. (2004). Cruise ship passenger spending patterns in Pacific island ports. *International Journal of Tourism Research, 6(4),* 251-261.

Doymo. (2011). Analysis of the current situation and proposal of future alternatives for road traffic in the access roads to the cruise terminals. *Barcelona Port Authority*, 2011.

Dragovic, B., Tzannatos, E., Tselentis, V., Mestrovic, R., and Skuric, M. (2015). Ship emissions and their externalities in cruise ports. *Transportation Research Part D: Transport and Environment*.

Drewry Maritime Research. (2018). LNG: fuel of the future? Retrieved from: https://www.drewry.co.uk/maritime-research-opinion-browser/maritime-research-opinions/lng-fuel-of-the-future

Dwyer, L., and Forsyth, P. J. (1996). Economic impacts of cruise tourism in Australia. *Journal of Tourism Studies*, *7(2),* 36.

Elgohary, M. M., Seddiek, I. S., and Salem, A. M. (2015). Overview of alternative fuels with emphasis on the potential of liquefied natural gas as future marine fuel. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, *229(4),* 365-375

Ellis, N. and Sampson, H. (2003). *The Global Labour Market for Seafarers Working Aboard Merchant Cargo Ships.* Cardiff: SIRC.

EMSA. (2018). Guidance on LNG Bunkering to Port Authorities and Administrations. Retrieved from: http://www.emsa.europa.eu/news-a-press-centre/external-news/item/3207-guidance-on-lng-bunkering-to-port-authorities-and-administrations.html

Energy Information Administration. (2020). Natural Gas Weekly Update. Retrieved from: https://www.eia.gov/naturalgas/weekly/#itn-tabs-3

Ericsson, P., and Fazlagic, I. (2008). *Shore–Side Power Supply*. Goteborg, Sweden: Chalmers University of Technology.

Erol, S. (2016) Calculating the Unit Voyage Cost in Maritime Transportation: An Implementation Study. Paper presented at the International Social Science, Humanity and Education Research Congress (SSHERC-16), Bali, July 20-21.

Esteve-Perez, J. and Garcia-Sanchez, A. (2015). Cruise market: Stakeholders and the role of ports and tourist hinterlands. *Maritime Economics & Logistics 17(3),* 371-388.

Esteve-Perez, J. and Garcia-Sanchez, A. (2017). Characteristics and consequences of the cruise traffic seasonality on ports: the Spanish Mediterranean case. Maritime Policy and Management, 44(3), 358-372.

European Commission. (2009). *Tourist facilities in ports – Growth opportunities for the European maritime economy: economic and environmentally sustainable development of tourist facilities in ports.* Study report. Luxembourg: Office for Official Publications of the European Communities. doi:10.2771/10327.

European Commission. (2015). Mapping and Performance Check of the Supply of Accessible Tourism Services (220/PP/ENT/PPA/12/6491) Case Study: Barcelona - Accessible Cruise Destination, Spain.

Fernández Duménigo, M. (2008). *La modalidad de turismo de Cruceros: evolución, desempeño y perspectivas*. Doctoral dissertation, Tesis en opción al título de Licenciada en Turismo. Universidad de la Habana.

Ferrante, M., De Cantis, S., and Shoval, N. (2016). A general framework for collecting and analysing the tracking data of cruise passengers at the destination. *Current Issues in Tourism*, 1-26.

Fogg, J. A. (2001) Cruise Ship Port Planning Factors. Thesis (PhD). Florida International Univ Miami.

Foss, B. (1969). A Cost Model for Coastal Shipping. A Norwegian Example. *Journal of Transport Economics and Policy, 3(2),* 195-222.

Fricke, H., and Schultz, M. (2008). Improving aircraft turn around reliability. In *Third International Conference on Research in Air Transportation*.

Garay Tamajón, L. A. (2015). Luces y sombras del turismo de cruceros: el caso de Barcelona. *Documents d'anàlisi geogràfica, 61*(3), 0563-580.

Ge, J., Zhu, M., Sha, M., Notteboom, T., Shi, W. and Wang, X., (2019). Towards 25,000 TEU vessels? A comparative economic analysis of ultra-large containership sizes under different market and operational conditions. *Maritime Economics & Logistics*, DOI: https://doi.org/10.1057/s41278-019-00136-4.

Geertsma, R. D., Negenborn, R. R., Visser, K., and Hopman, J. J. (2017). Design and control of hybrid power and propulsion systems for smart ships: A review of developments. *Applied Energy, 194,* 30-54. doi:10.1016/j.apenergy.2017.02.060

Ghosh, S., Lee, L. H. and Ng, S. H. (2015). Bunkering Decisions for a Shipping Liner in an Uncertain Environment with Service Contract. *European Journal of Operational Research 244(3),* 792-802.

Gibson, P. (2006). *Cruise operations management*. Burlington: Butterworth Heinemann.

Gibson, P. (2008). Cruising in the 21st Century: Who Works While Others Play? *International Journal of Hospitality Management 27(1),* 42-52.

Gibson, P., and Parkman, R. (2018). *Cruise operations management: hospitality perspectives*. Routledge.

Gilbert, P., and Bows, A., (2012). Exploring the scope for complementary sub-global policy to mitigate CO2 from shipping. *Energy Policy, 50,* 613–622. doi:10.1016/j.enpol.2012.08.002

Gilman, S. (1983). The Competitive Dynamics of Container Shipping Aldershot: Gower.

GL & MAN. (2013). Costs and benefits of LNG as ship fuel for container vessels. Hamburg: Germanischer Lloyd SE.

Green Cruise Port. (2018). *Sustainable Energy Supply and Innovative Solutions for Emission Reduction Green Bunkering of Cruise Vessels with Sustainable Fuel Options.* Esbjerg, Denmark: Green Cruise Port. Retrieved from: http://www.greencruiseport.eu/green-bunkering-of-cruise-vessels.html

Gui, L., and Russo, A. P. (2011). Cruise ports: a strategic nexus between regions and global lines—evidence from the Mediterranean. *Maritime Policy & Management, 38(2),* 129-150.

Hagedorn, M. (2014). *LNG Engines Specifications and economics. LNG Shipping.* Rostock: Wärtsilä.

Hall, J. A., and Braithwaite, R. (1990). Caribbean cruise tourism: a business of transnational partnerships. *Tourism Management*, *11(4),* 339-347.

Haralambides, H.E. (2019). Gigantism in container shipping, ports and global logistics: a time-lapse into the future. *Maritime Economics & Logistics, 21(1),* 1-60.

Henthorne, T. L. (2000). An analysis of expenditures by cruise ship passengers in Jamaica. *Journal of Travel Research*, *38(3),* 246-250.

Hobson, J. P. (1993). Analysis of the US cruise line industry. *Tourism management*, *14(6)*, 453-462.

Horonjeff, R. (1969). Analyses of passenger and baggage flows in airport terminal buildings. *Journal of Aircraft*, *6*(5), 446-451.

Hoseason, J. (2000). Capacity management in the cruise industry. *Yield Management: Strategies for the Service Industries*, 289-302.

IAPH. (2007). *Tool Box for port Clean Air Programs. Improving Air Quality While Promoting Business Development.* International Association of Ports and Harbors, Netherlands.

IMO MEPC 72. (2018). *Initial strategy on greenhouse gas emissions reduction for ships*. UK: IMO.

IMO Resolution MSC.99. (1973) Amendments to the International Convention for the Safety of Life at Sea, 1974, as amended' (5 December 2000), IMO.

IMO. (1983). *International Conference On Tonnage Measurement of Ships, 1969.* London: IMO.

IMO. (2016a). IGF Code: International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels. 2016 Edition (I109E). ISBN 13: 9789280116533

IMO. (2016b). *Studies on the feasibility and use of LNG as a fuel for shipping.* Suffolk, UK: IMO.

Ineris. (2019). *ECAMED: a Technical Feasibility Study for the Implementation of an Emission Control Area (ECA) in the Mediterranean Sea.* France: Ineris.

International Transport Forum. (2018). *Fuelling Maritime Shipping with Liquefied Natural Gas: The Case of Japan.* France: ITF.

International Transport Workers' Federation (ITF). (2017). ITF ILO Minimum Wage Scale [online] Available from: http://www.itfseafarers.org/files/seealsodocs/46024/ILO%20Min%20Wage%20%20JAN%202016%20-%20Consolidated%20Interpretation.xls/ [Accessed 16 February 2017]

ISO (2017). *ISO 20519. Ships and marine technology — Specification for bunkering of liquefied natural gas fuelled vessels.* Beijing, China: ISO/TC8.

Jaakson, R. (2004). Beyond the tourist bubble?: cruiseship passengers in port. *Annals of tourism* research, 31(1), 44-60.

Jansson, J. O. and Shneerson, D. (1982). The Optimal Ship Size. *Journal of transport economics and policy 16(8),* 217-238.

Jeong, B., Lee, B. S., and Zhou, P. (2017). Quantitative risk assessment of fuel preparation room having high-pressure fuel gas supply system for LNG fuelled ship. *Ocean Engineering*, *137*, 450-468. doi: 10.1016/j.oceaneng.2017.04.002

Johnson, T. L. (1996). *Fishing Vessel Insurance-How Much is Enough?* Fairbanks: Alaska Sea Grant College Program.

Karlis, T. and Polemis, D. (2018). Cruise homeport competition in the Mediterranean. *Tourism Management*, *68,* 168-176.

Kendall, P. M. H. (1972). A Theory of Optimum Ship Size. *Journal of Transport Economics and Policy,* 128-146.

Kerswill, M. (2013). Big Ships, Small Towns: The Impact of New Port Developments in the Cruise Tourism Industry. The case of Falmouth Jamaica.

Kim, A. R., and Seo, Y. J. (2019). The reduction of SOx emissions in the shipping industry: The case of Korean companies. *Marine Policy, 100,* 98-106.

King and Spalding. (2018). *LNG in Europe 2018: An Overview of Import Terminals in Europe.* Georgia, US: King and Spalding.

King, M. (1999). *The US Cruise Industry-Evaluation of National Economic Development Benefits*. ARMY ENGINEER INST FOR WATER RESOURCES ALEXANDRIA VA.

Klein, R. A. (2002). *Cruise ship blues: The underside of the cruise ship industry*. New Society Publishers.

Klein, R. A. (2006). Turning Water into Money: The Economics of the Cruise Industry. *Cruise Ship Tourism*, 261. DOI: http://dx.doi.org/10.1079/9781845930486.0261.

Klein, R. A. (2009). *Cruising Without a Bruising. Cruise Tourism and the Maritimes.* Canadian Centre for Policy Alternatives.

Klein, R. A. (2011). Responsible cruise tourism: Issues of cruise tourism and sustainability. *Journal of Hospitality and Tourism Management, 18(1),* 107-116. doi: 10.1375/jhtm.18.1.107

Klein, R. A. (2015). *Cruise ship concepts applying LNG fuel.* Finland: Aalto University.

Kruse, C. J., DeSantis, L. M., Eaton, S. J., and Billings, R. (2018). *Marine Transportation and the Environment: Trends and Issues.* TR News, (313).

Kumar, S., Kwon, H. T., Choi, K. H., Cho, J. H., Lim, W., and Moon, I. (2011). Current status and future projections of LNG demand and supplies: A global prospective. *Energy Policy, 39(7),* 4097-4104.

Le Fevre, C.N. (2018). *A review of demand prospects for LNG as a marine fuel.* UK: Oxford Institute for Energy Studies. DOI: 10.26889/9781784671143.

Lee, S. and Ramdeen, C. (2013). *Cruise ship itineraries and occupancy rates. Tourism Management, 34,* 236–237. DOI: 10.1016/j.tourman.2012.03.009.

Lekakou, M. B., Pallis, A. A., and Vaggelas, G. K. (2009). Which homeport in Europe: The cruise industry's selection criteria. *Tourismos: An international multidisciplinary journal of tourism, 4(4),* 215-240.

Lekakou, M., Stefanidaki, E., and Vaggelas, G. K. (2011). The economic impact of cruise to local economies. The case of an island. *Athens Tourism Symposium,* 2-3.

Lepistö, V., Lappalainen, J., Sillanpää, K., and Ahtila, P. (2016). Dynamic process simulation promotes energy efficient ship design. *Ocean Engineering, 111,* 43-55. DOI: 10.1016/j.oceaneng.2015.10.043

Lim, S. M. (1998). Economies of Scale in Container Shipping. *Maritime Policy & Management 25(4),* 361-373.

Livanos, G. A., Theotokatos, G., and Pagonis, D. N. (2014). Techno-economic investigation of alternative propulsion plants for Ferries and RoRo ships. *Energy Conversion and Management, 79,* 640-651. doi: 10.1016/j.enconman.2013.12.050.

Lloyd's Register. (2012). *LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025.* London, UK: Lloyd's Register.

Lois P. and Wang J. (2006). Cost, Benefits and Risk Assessment for Improving Performance of the Marine Tourism Industry. *Tourism Management and Research 7,* 179-210.

Lois, P., Wang, J., Wall, A., Ruxton, T. (2004). Formal safety assessment of cruise ships. *Tourism Management, 25(1),* 93-109.

London, W. R., and Lohmann, G. (2014). Power in the context of cruise destination stakeholders' interrelationships. *Research in Transportation Business & Management, 13,* 24-35.

MacNeill, T. and Wozniak, D. (2018). The economic, social, and environmental impacts of cruise tourism. *Tourism Management 66,* 387-404.

Mahoney, I., and Collins, V. E. (2019). The capitalist voyeur: commodification, consumption and the spectacle of the cruise. *Leisure Studies, 44(3),* 1–14.

MAN Diesel & Turbo. (2012). *Dual fuel low speed engine.* Copenhagen, Denmark: MAN Diesel & Turbo. Retrieved from: https://marine.man-es.com.

Mancini, S., and Stecca, G. (2018). A large neighborhood search based matheuristic for the tourist cruises itinerary planning. *Computers & Industrial Engineering, 122,* 140-148. DOI: 10.1016/j.cie.2018.05.045.

Maragkogianni, A., and Papaefthimiou, S. (2015). Evaluating the social cost of cruise ships air emissions in major ports of Greece. *Transportation Research Part D: Transport and Environment, 36,* 10-17.

Marquez, J. (2006). *An analysis of cruise ship management policies in parks and protected areas in the Eastern Canadian Arctic* (Master's thesis, University of Waterloo).

Mau, J. (1969). The Ratio of Displacement Deadweight Cargoes of General Goods. [La rapport de deplacement au port en lourd des cargoes pour merchandises generals.] Bulletin du Bureau Veritas.

McCarthy, J. (2003). The cruise industry and port city regeneration: The case of Valletta. *European Planning Studies*, *11*(3), 341-350.

Molitor, E., Bakosch, A., and Forsman, B. (2012). *Feasibility Study on LNG Fuelled Short Sea and Coastal Shipping in the Wider Caribbean Region.* Sweden: SSPA Sweden AB.

Molyneaux, N., Hänseler, F., and Bierlaire, M. (2014). Modeling of train-induced pedestrian flows in railway stations. *STRC Proceedings*.

Moretti, M. (2012). Venice, Italy: Balancing Antiquity and Sustainability. In *Green Cities of Europe* (pp. 129-154). Island Press/Center for Resource Economics.

Morgan, P. and Power, L. (2011). Cruise Tourism and the Cruise Industry. *Research Themes for Tourism,* 276.

Murray, W. (2016). *Economies of Scale in Container Ship Costs.* United States Merchant Marine Academy.

Navarro-Ruiz, S., Casado-Díaz, A. and Ivars-Baidal, J. (2019). Cruise tourism: the role of shore excursions in the overcrowding of cities. *International Journal of Tourism Cities*. in press.

Norwegian Cruise Line (2017). Annual Report [online] Available from: http://www.nxtbook.com/nxtbooks/ncl/annualreport_2016/ [Accessed 29 March 2018]

Norwegian Cruise Line. (2019). Annual Report. [online] Available from: https://www.sec.gov/Archives/edgar/data/1513761/000155837020001661/nclh-20191231x10kc19a9c.htm [Accessed 27 March 2020]

Notteboom, T. E. and Vernimmen, B. (2009). The Effect of High Fuel Costs on Liner Service Configuration in Container Shipping. *Journal of Transport Geography 17(5),* 325-337. DOI:10.1016/j.jtrangeo.2008.05.003.

Özen, S. and Güler, N. (2001). Determining Optimum Ship Capacity by Application of Inventory Theory in Freight Management. *Pomorski zbornik, 39(1),* 249-266.

Page, K. (1987). The future of cruise shipping. *Tourism management*, *8(2)*, 166-168.

Pallis, A. A., Rodrigue, J. P., and Notteboom, T. E. (2014). Cruises and cruise ports: Structures and strategies. Research in Transportation Business & Management, (13), 1-5. DOI: 10.1016/j.rtbm.2014.12.002.

Pallis, A. A. (2015). Cruise Shipping and Urban Development: State of the Art of the Industry and Cruise Ports. International Transport Forum Discussion Paper 2015-14.

Pallis, A. A. and Arapi, K. P. (2016). A Multi-Port Cruise Region: Dynamics and Hierarchies in the Med. *Tourismos, 16(1),* 1-27.

Pallis, A. A. and Vaggelas, G. K. (2018). Cruise Shipping and Green Ports: A Strategic Challenge. In: Monios J. and Bergqvist R. (eds): *Green Ports: Inland and Seaside Sustainable Transportation Strategies, 255-273*, Cheltenham: Edward Elgar.

Pallis, A. A., Parola, F., Satta, G. and Notteboom T. E. (2018). Private entry and emerging partnerships in cruise terminal operations in the Mediterranean Sea. *Maritime Economics and Logistics, 20(1),* 1-28.

Pallis, A. A., Arapi, K. P., and Papachristou, A. A. (2019). Models of cruise ports governance. *Maritime Policy and Management, 46(5),* 630-651.

Pallis A.A. and Vaggelas G.K. (2020). The changing geography of cruise shipping. In: Wilmsmeier G., Monios J., Browne M. and Woxenius J. (eds.) *Geographies of waterborne transport: Transitions from transport to mobilities, 170-191.* Cheltenham: Edward Elgar.

Palmer-Huggins, D., and Foss, M. M. (2016). *LNG marine fuel applications.* Texas, US: BEG CEE. Retrieved from: http://www.beg.utexas.edu/files/energyecon/think-corner/2016/CEE_Research_Note-LNG_Marine_Fuel_Applications-Nov16.pdf

Papathanassis, A. (2012). Guest-to-Guest Interaction on Board Cruise Ships: Exploring Social Dynamics and the Role of Situational Factors. *Tourism Management 33(5),* 1148-1158.

Papatheodorou, A. (2006). The Cruise Industry: an Industrial Organization Perspective. *Cruise Ship Tourism*, 31-40. DOI:10.1079/9781845930486.0031.

Peisley, T. (2014). *End of the Beginning for Cruising.* Colchester: Seatrade Communications Ltd.

PIANC, (2016). WG 152. Guidelines for Cruise Terminals. Report of PIANC InCom WG 152.

Polat, N. (2015). Technical innovations in cruise tourism and results of sustainability. *Procedia-Social and Behavioral Sciences, 195,* 438-445.

Poplawski, K., Setton, E., McEwen, B., Hrebenyk, D., Graham, M., and Keller, P. (2011). Impact of cruise ship emissions in Victoria, BC, Canada. *Atmospheric Environment, 45(4),* 824-833.

Port Canaveral. (2016). Governing Rates, Rules & Regulations of Marine and Port Services provided by the Canaveral Port Authority. Tariff No.15 [online] Available from: https://www.portcanaveral.com/PortCanaveral/media/Business-With-Us-Tariffs/CPA-Tariff-15_final-10012016-rev1.pdf/ [Accessed 17 February 2017]

Port de Barcelona. (2014). Previsión cruceros 2015. Available from: http://content.portdebarcelona.cat/cntmng/d/d/workspace/SpacesStore/a642cb20-34fd-427d-8d8e-97a7f0732e2e/2015anual_es.pdf [Accessed 14 March 2016]

Port of Barcelona. (2015). Memoria Estadística [online] Available from: http://content.portdebarcelona.cat/cntmng/d/d/workspace/SpacesStore/1d204488-9656-4938-a40c-2f432fe246f3/2015_Estadistica_es.pdf/ [Accessed 10 November 2016]

Port of Barcelona. (2016). Taxes and Tariffs [online] Available from: http://www.portdebarcelona.cat/en/web/port-dels-negocis/tasas-y-tarifas/ [Accessed 17 February 2017]

Port de Barcelona. (2017). Estadístiques de tràfic del Port de Barcelona. Dades acumulades desembre 2016. [online] Available from: 〈 http://content.portdebarcelona.cat/cntmng/d/d/workspace/SpacesStore/e3476a6c-47d5-4e8c-a57f-7aaae44963d2/PortBcnTrafic2016_12_ca.pdf [Accessed 28 March 2017]

Port de Barcelona. (2019). Estadístiques de tràfic del Port de Barcelona. [online] Available from: http://www.portdebarcelona.cat/es_ES/web/autoritat-portuaria/estadisticas [Accessed 1 April 2020]

Port Everglades. (2016). Port Everglades Tariff No.12 [online] Available from: http://www.porteverglades.net/development/tariff/ [Accessed 17 February 2017]

Port Miami. (2016). Rates Rules and Regulations for the Seaport Facilities of Miami-Dade County Florida [online] Available from: http://www.miamidade.gov/aopdfdoc/aopdf/pdffiles/IO4-4.pdf/ [Accessed 17 February 2017]

Ports and Harbors. (2018). July/August 2018. Singapore banks on LNG bunkering. pp. 20-21.

Raluca, D. C., and Monica, G. C. (2008). The impact of the cruising industry on local destination. *Annals of Oradea University, Economic Sciences, http://steconomiceuoradea. ro/anale, 2008*.

Rao, H. N., and Karimi, I. A. (2018). Optimal design of boil-off gas reliquefaction process in LNG regasification terminals. *Computers & Chemical Engineering, 117*, 171-190. DOI: 10.1016/j.compchemeng.2018.06.003.

Raof, M. B. A., Lim, C. S. M., Suharto, N. N. B., and Rahim, M. H. B. A. (2018*). What is preventing ship owners from converting to LNG fuel engine.* Singapore: Singapore Maritime Academy.

Río, M. C., and Cruz, M. T. K. (2008). Perfil y análisis del gasto del crucerista: el caso de Bahías de Huatulco (México). *Cuadernos de turismo, (22)*, 47-78.

Rivarolo, M., Rattazzi, D., and Magistri, L. (2018). Best operative strategy for energy management of a cruise ship employing different distributed generation technologies. International Journal of Hydrogen Energy, *43(52)*, 23500-23510. DOI: 10.1016/j.ijhydene.2018.10.217.

Robinson, P., Heitmann, S., and Dieke, P.U. (2011). *Research themes for tourism*. Wallingford: CABI.

Robles, L. T., Galvão, C. B. and Pereira, S. R. (2015). Cruise Shipping in Brazil: An Emergent or Established Market?. *Tourism Management Perspectives 16*, 298-305.

Rodrigue, J. P., and Notteboom, T. (2012). The geography of cruise shipping: itineraries, capacity deployment and ports of call. In *In Atti Della IAME 2012 Conference, Taipei (Taiwan)* (pp. 6-8).

Rodrigue, J. P. and Notteboom, T. (2013). The geography of cruises: Itineraries, not destinations. *Applied Geography 38*, 31-42. DOI: 10.1016/j.apgeog.2012.11.011

Royal Caribbean (2017). Annual Report [online] Available from: http://quicktake.morningstar.com/stocknet/secdocuments.aspx?symbol=rcl/ [Accessed 29 March 2018].

Royal Caribbean. (2019). Annual Report [online] Available from: https://sec.report/Ticker/RCL/ [Accessed 27 March 2020].

Sanz-Blas, S., Buzova, D., and Carvajal-Trujillo, E. (2015). Investigating the moderating effect of information sources on cruise tourist behaviour in a port of call. *Current Issues in Tourism*, 1-9.

Saurí, S., Spuch, B. and Morales-Fusco, P. (2009). Long-run marginal cost in the RoRo industry. Transportation Research Board Annual Meeting. "88th Transportation Research Board Annual Meeting", Washington, January 11-15.

Scherrer, P., Smith, A. J., Randall, M., and Dowling, R. (2011). Environmental and cultural implications of visitor access in the Kimberley region, Australia. *Australian Geographer*, *42(3)*, 257-271.

Sharples, J. (2019). *LNG supply chains and the development of LNG as a shipping fuel in Northern Europe*. UK: University of Oxford. DOI: 10.26889/9781784671266

Shin, M. W., Shin, D., Choi, S. H., and Yoon, E. S. (2008). Optimal operation of the boil-off gas compression process using a boil-off rate model for LNG storage tanks.

Korean Journal of Chemical Engineering, 25(1), 7-12. DOI: 10.1007/s11814-008-0002-9.

Ship & Bunker (2017). World Bunker Prices [online] Available from: http://shipandbunker.com/ [Accessed 11 January 2017]

Ship and Bunker (2020). World Bunker Prices. [online] Available from: http://shipandbunker.com/ [Accessed 7 February 2020]

Silos, J. M. et al. (2012). Trends in the Global Market for Crews: A Case Study. *Marine Policy 36(4),* 845-858.

SMTF. (2011). LNG ship to ship bunkering procedure. Uddevalla, Sweden: Swedish Marine Technology Forum. Retrieved from: http://www.lngbunkering.org/lng/sites/default/files/SMTF%2C%20Ship%20to%20Ship%20Bunkering.pdf

SSPA Sweden AB. (2013a). LNG in Baltic Sea Ports. LNG Handbook. SSPA report No: RE20136642-01-00-A. Sweden: Baltic Ports Organization. Retrieved from: https://es.scribd.com/document/283427330/HANDBOOK-of-LNG-Baltic-Sea-Ports-pdf

SSPA Sweden AB. (2013b). LNG in Baltic Sea Ports II. LNG Handbook. Sweden: Baltic Ports Organization. Retrieved from: https://ec.europa.eu/inea/sites/inea/files/download/project_fiches/multi_country/fichenew_2013eu21007s_final.pdf

Stefanakos, C. N. and Schinas, O. (2014). Forecasting Bunker Prices; A Nonstationary, Multivariate Methodology. *Transportation Research Part C: Emerging Technologies 38*, 177-194.

Stefanidaki, E. and Lekakou, M. (2014). Cruise Carrying Capacity: A Conceptual Approach. *Research in Transportation Business & Management, 13*, 43-52.

Steuer, C. (2019). *Outlook for Competitive LNG Supply*. UK: Oxford Institute for Energy Studies. DOI: 10.26889/9781784671310.

Stopford, M. (2002). Is the Drive For Ever Bigger Containerships Irresistible?, Lloyds List Shipping Forecasting Conference, 26th April 2002.

Stopford, M. (2009). *Maritime Economics, 3rd edition.* Abingdon: Routledge.

Stynes, D. J. (1997). Economic impacts of tourism: a handbook for tourism professionals. *Urbana, IL: University of Illinois, Tourism Research Laboratory*, 1-32.

Sun, X., Feng, X., and Gauri, D. K. (2014). The cruise industry in China: Efforts, progress and challenges. *International Journal of Hospitality Management*, *42*, 71-84.

Sun, X., Feng, X., and Gauri, D. K. (2014). The cruise industry in China: Efforts, progress and challenges. *International Journal of Hospitality Management*, *42*, 71-84.

Svanberg, M., Ellis, J., Lundgren, J., and Landälv, I. (2018). Renewable methanol as a fuel for the shipping industry. Renewable and Sustainable Energy Reviews, *94*, 1217-1228. DOI:10.1016/j.rser.2018.06.058.

Sys, C., Blauwens, G., Omey, E., Van De Voorde, E., and Witlox, F. (2008). In search of the link between ship size and operations. *Transportation Planning and Technology, 31*(4), 435-463.

Taljegard, M., Brynolf, S., Grahn, M., Andersson, K., and Johnson, H. (2014). Cost-effective choices of marine fuels in a carbon-constrained world: results from a global energy model. *Environmental science and technology, 48(21),* 12986-12993. DOI: 10.1021/es5018575.

Taylor-Powell, E., and Steele, S. (1996). Collecting evaluation data: Direct observation. *Program Development and Evaluation. Wiscounsin: University of Wisconsin-Extension*, 1-7.

Terry, W. C. (2011) Geographic Limits to Global Labor Market Flexibility: The Human Resources Paradox of the Cruise Industry. *Geoforum, 42(6),* 660-670.

Thomson, H., Corbett, J. J., and Winebrake, J. J. (2015). Natural gas as a marine fuel. *Energy Policy, 87,* 153-167. DOI:10.1016/j.enpol.2015.08.027.

Torbianelli, V. (2012). The local economic impact of cruises: From figures to the active policies of the European Harbour cities. *Pomorstvo: Scientific Journal of Maritime Research*, *26(1),* 139-150.

Tovar, B., Tichavska, M., Gritsenko, D., Johansson, L., and Jalkanen, J-P. (2019). Air emissions from ships in port: Does regulation make a difference? *Transport Policy, 75,* 128-140. DOI:10.1016/j.tranpol.2017.03.003.

Tran, N. K. and Haasis, H. D. (2015). An Empirical Study of Fleet Expansion and Growth of Ship Size in Container Liner Shipping. *International Journal of Production Economics*, *159,* 241-253.

Tzannatos, E. (2010). Costs and benefits of reducing SO_2 emissions from shipping in the Greek seas. *Maritime Economics & Logistics,12(3),* 280-294.

Tzannatos, E., Papadimitriou, S., and Koliousis, I. (2015). A techno-economic analysis of oil vs. natural gas operation for Greek Island Ferries. *International Journal of Sustainable Transportation, 9(4),* 272-281. DOI: 10.1080/15568318.2013.767397.

Van Hassel, E., Meersman, H., Van de Voorde, E., and Vanelslander, T. (2016). Impact of scale increase of container ships on the generalised chain cost. *Maritime Policy & Management, 43(2),* 192-208. DOI:10.1080/03088839.2015.1132342.

Verbeek, R. P., Kadijk, G., van Mensch, P., Wulffers, C., van den Beemt, B., Fraga, F., and Aalbers, A. D. A. (2011). *Environmental and Economic aspects of using LNG as a fuel for shipping in The Netherlands.* Delft: TNO.

Véronneau, S., and Roy, J. (2009). Global service supply chains: An empirical study of current practices and challenges of a cruise line corporation. *Tourism Management*, *30*(1), 128-139.

Vickerman, M. J., and Beatley, D. K. (2004). Port Everglades New International Cruise Terminal and Airport People Mover Connection: Development Strategy for the Largest Cruise Terminal Complex on the US East Coast. *Ports 2004,* ASCE. DOI:10.1061/40727(2004)3.

Vogel, M. P. (2011). Monopolies at Sea: The Role of Onboard Sales for the Cruise Industry's Growth and Profitability. Tourism Economics 211-229.

Vogel, M., P., A. and Wolber, B. (2012). *The Business and Management of Ocean Cruises.* Wallingford: CABI.

Wang, F., and Lim, A. (2007). A stochastic beam search for the berth allocation problem. *Decision Support Systems*, *42(4),* 2186-2196.

Wang, G., Li, K. X., and Xiao, Y. (2019). Measuring marine environmental efficiency of a cruise shipping company considering corporate social responsibility. *Marine Policy, 99*, 140-147. DOI: 10.1016/j.marpol.2018.10.028.

Ward, D. (2015). *Berlitz Cruising and Cruise Ships 2016*. London: Berlitz Publishing.

Watson, D. G. (2002). *Practical ship design (Vol. 1)*. Kidlington: Elsevier.

Weaver, A. (2005). Spaces of containment and revenue capture:'super-sized'cruise ships as mobile tourism enclaves. *Tourism geographies*, *7(2),* 165-184.

Weaver, A. (2005a). Spaces of Containment and Revenue Capture: 'Super-sized 'Cruise Ships as Mobile Tourism Enclaves. *Tourism geographies, 7(2),* 165-184. DOI: 10.1080/14616680500072398.

Weaver, A. (2005b). The McDonaldization Thesis and Cruise Tourism. *Annals of tourism research, 32(2)*, 346-366.

Wie, B. W. (2005). A Dynamic Game Model of Strategic Capacity Investment in the Cruise Line Industry. *Tourism Management*, *26(2),* 203-217.

Wong, H. L., Hsieh, S. H. and Wang, C. C. (2007). Optimizing Containership Size and Speed: Model Formulation and Implementation. *WSEAS Transactıons on Busıness and Economıcs*, *4(7)*, 111-116.

Wood, R. E. (2000). Caribbean cruise tourism: globalization at sea. *Annals of tourism research*, *27(2)*, 345-370.

Wood, R. E. (2004). Cruise ships: deterritorialized destinations. *Tourism and Transport,* 133-45.

Wood, R.E. (2007). Cruise ships: deterritorialized destinations. In *Tourism and transport* (pp. 148-161). Routledge.

Wu, B. (2005). *The World Cruise Industry: A Profile of the Global Labour Market*. Cardiff: Seafarers International Research Centre (SIRC).

Wuersig, D. G. M., Chiotopoulos, A., and Adams, S. (2015). *LNG as ship fuel.* Hamburg, Germany: DNV GL.

Zhen, L., Li, M., Hu, Z., Lv, W., and Zhao, X. (2018). The effects of emission control area regulations on cruise shipping. *Transportation Research Part D: Transport and Environment*, *62*, 47-63. DOI:10.1016/j.trd.2018.02.005

Zhou SH, Shen X, Liu XJ, Li G, Yang Y. (2013). Prospect of LNG application to inland water transportation in China. Natural Gas Industry, 33(2), 81–89.

Zhou, K. (2012). Optimization of Container Liner Speed and Deployment Based on New Environment and Bunkering Regulation. Doctoral dissertation, The Pennsylvania State University.

Zincir, B., and Deniz, C. (2014). An investigation of hydrogen blend fuels applicability on ships. In INT-NAM 2014, 2nd International Symposium on Naval Architecture and Maritime, 22–23 October 2014, Proceedings Book, 137-147.