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**An Economic Assessment of
the Impacts of the MOSE
Barriers on Venice Port
Activities**

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Summary

Due to its hydro-geological features, the lagoon of Venice is especially vulnerable to climate change. In particular, it is strongly affected by gradual global warming that brings about the so-called '*acqua alta*' (high water) phenomenon with greater frequency and intensity. In order to protect the city of Venice from the more and more frequent phenomenon of flooding, some protective measures have been adopted. Among them, the system of mobile barriers commonly known as MOSE: however, by separating the lagoon from the Adriatic Sea, it interferes with ship traffic and has negative impacts on port activities. Against this background, the aim of the present work is to provide an estimate of the *direct costs* of ship traffic interruption due to the functioning of the MOSE, i.e. the additional costs resulting from longer waiting time for ships passing through the Venice lagoon. The estimate uses inputs from the application of a specific hydrodynamic model and the elaboration of ship traffic data during the period 2000-2002. Results indicate that the additional costs would range between 347,943 and 1,288,067 €/year, depending on the hypothesis assumed.

Keywords: Climate Change, '*Acqua Alta*', MOSE, Ship Traffic, Direct Costs

JEL Classification: Q51, Q54

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An economic assessment of the impacts of the MOSE barriers on Venice port activities

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Abstract

Due to its hydro-geological features, the lagoon of Venice is especially vulnerable to climate change. In particular, it is strongly affected by gradual global warming that brings about the so-called ‘*acqua alta*’ (high water) phenomenon with greater frequency and intensity. In order to protect the city of Venice from the more and more frequent phenomenon of flooding, some protective measures have been adopted. Among them, the system of mobile barriers commonly known as MOSE: however, by separating the lagoon from the Adriatic Sea, it interferes with ship traffic and has negative impacts on port activities. Against this background, the aim of the present work is to provide an estimate of the *direct costs* of ship traffic interruption due to the functioning of the MOSE, i.e. the additional costs resulting from longer waiting time for ships passing through the Venice lagoon. The estimate uses inputs from the application of a specific hydrodynamic model and the elaboration of ship traffic data during the period 2000-2002. Results indicate that the additional costs would range between 347,943 and 1,288,067 €/year, depending on the hypothesis assumed.

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Introduction

The Venice lagoon is a complex natural system hosting a number of economic activities. Due to its hydro-geological conformation, it is consistently threatened by climate change. In particular, it is strongly threatened by global warming and average sea level rise that bring about the *acqua alta* phenomenon (i.e. the periodic flooding of the city centre due to particular astronomical and meteorological conditions) with a higher frequency and intensity.

In order to protect Venice from the damages produced by the more and more frequent flooding events, various mitigation and prevention measures have been adopted, among which the system of mobile barriers (MOSE) at the inlets. The adoption of such a protection measure limits the damages caused to Venetians and to the economic activities carried out within the lagoon (trade, tourism, public services, etc.) nevertheless, it could interfere with port traffic, currently still one of Venice's most relevant economic activities. The mobile barrier closing procedure not only isolates the lagoon from the open Adriatic Sea but interrupts the passage of ships in and out of the harbour. Longer waiting time for ships entering or exiting from the lagoon could therefore give rise to additional costs, such as charter costs for example and, for ships blocked in the lagoon as a result of the closure of the mobile barriers, even mooring costs. As a consequence, the analysis of the potential negative effects of the functioning of the MOSE system on port activities represents a relevant component of the analysis of the '*acqua alta*' impacts on the Venice lagoon.

Moving from this background, the present paper is aimed at estimating the costs induced by the interruption of the regular passage of ships due to the closing of the MOSE barriers by means of a hydrodynamic model applied to port traffic in the period 2000-2002. A partial analysis is proposed that takes into account only the estimated costs for port users (*direct costs*) and not the costs deriving from the possible reduction of the passage of ships (*indirect costs*). Nevertheless, the

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present paper contributes to the analysis of the effects of the functioning of the MOSE on Venice port activities by integrating, albeit by means of different methodologies, the study proposed by Nunes *et al.* (2005) regarding the benefits of the functioning of the MOSE on the commercial activities carried out in the city centre and by enlarging the paper of Chiabai and Nunes (2008) on the negative effects on port activities. Our results show that the negative effects, excluding indirect costs, are limited.

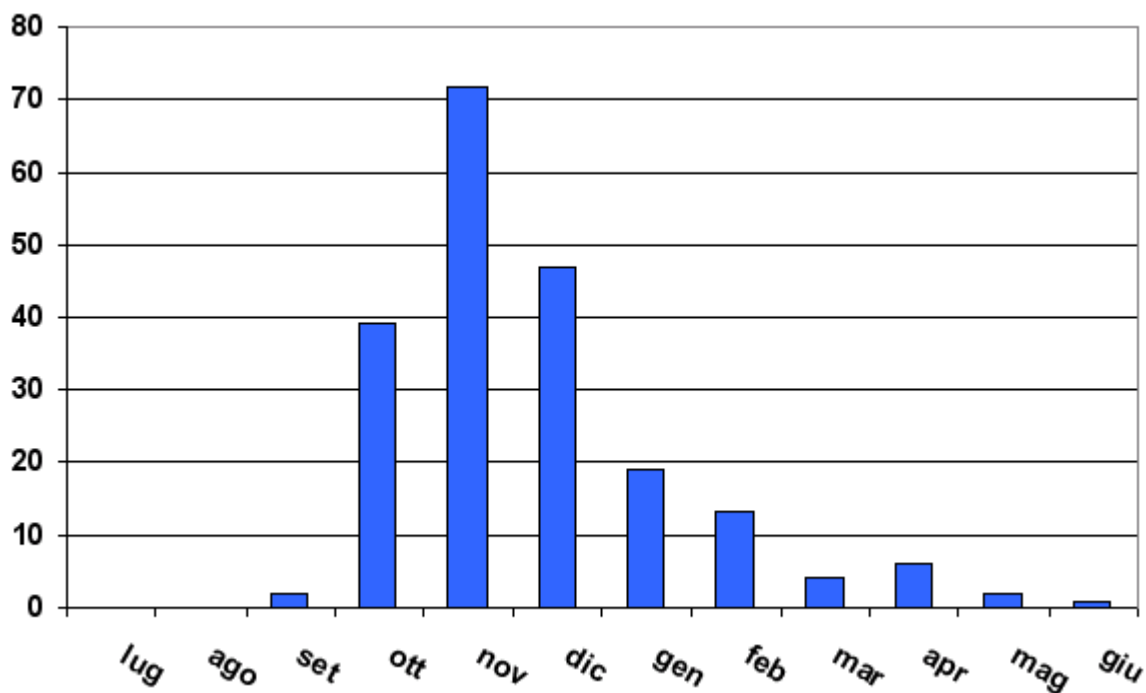
The present paper is structured as follows: Section 1 briefly describes the '*acqua alta*' phenomenon and its evolution over the last century. Section 2 introduces the MOSE and how it works. Section 3 discusses the effects of the closing of the MOSE barriers on the Venetian port activities, taking the evolution of ship traffic since the Second World War into consideration. Section 4 provides a hydrodynamic analysis of hypothetical MOSE interferences on Venetian port traffic during the period 2000-2002. Section 5 provides an estimate of the direct costs for port users due to the functioning of the MOSE. Finally, in Section 6 conclusions are drawn.

1. The '*acqua alta*' phenomenon

In autumn and winter, due to astronomical and meteorological factors, the lagoon of Venice is characterised by a phenomenon commonly known as '*acqua alta*', that causes the periodic flooding of the city centre (Figure 1). This phenomenon, more frequent during the morning hours (Figure 2), occurs when the tidal level reaches +80 cm over the Punta della Salute¹ tidal datum (Canestrelli *et al.*, 1998).

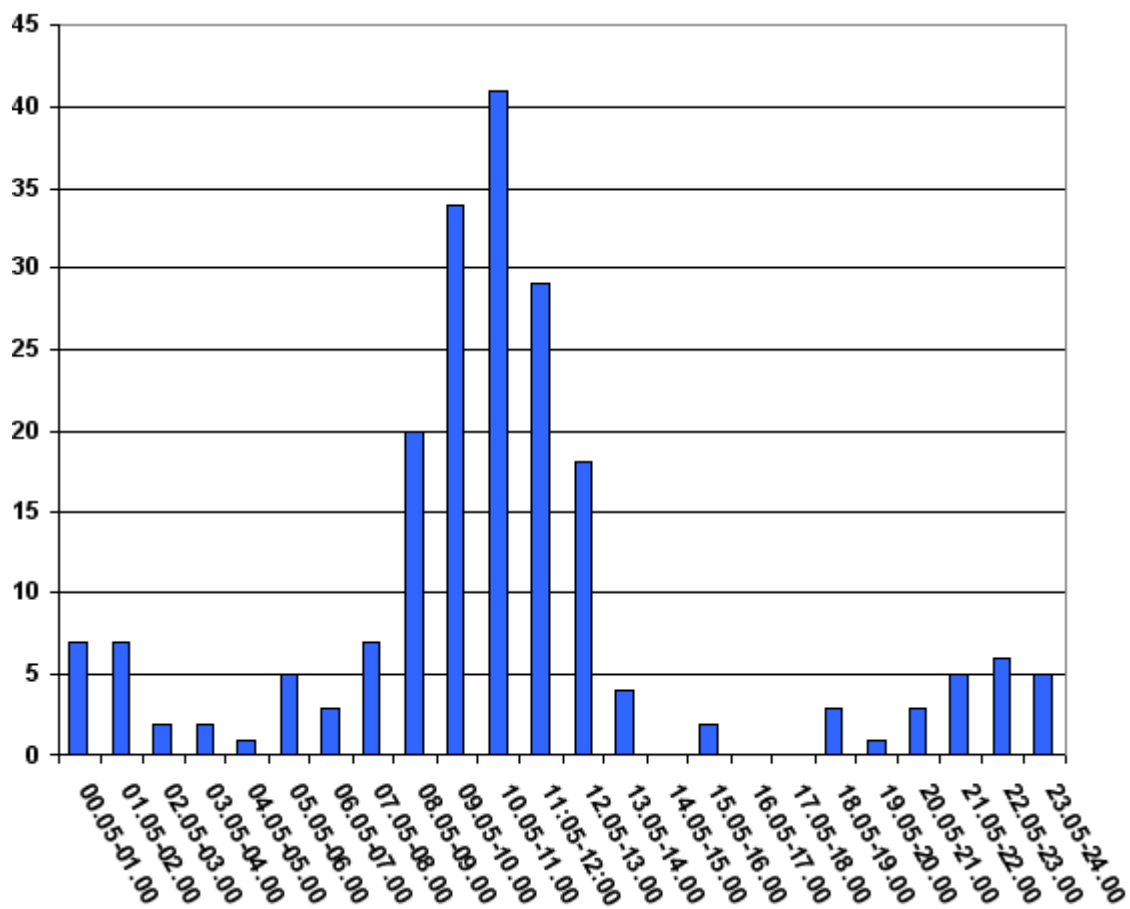
¹ 'Punta della Salute' is the Venetian main reference tide gauge since the 19th century. The many islands that make up the city are located at different levels respect to the sea: for example, St. Mark's Square is at +80 cm with respect to 'Punta della Salute', while others are at +170 cm.

Figure 1 – Monthly distribution of tidal level $\geq +110$ cm in Venice, 1872-2006



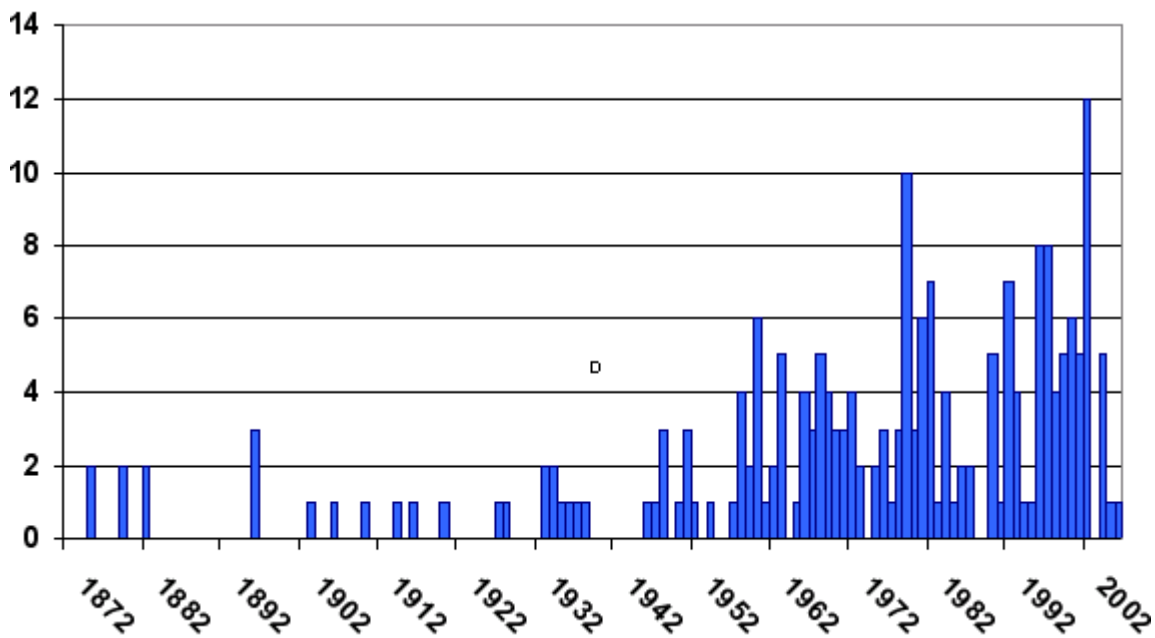
Sources: www.comune.venezia.it

Figure 2 –Hourly distribution of tidal level $\geq +110$ cm in Venice, 1872-2006



During the last decades the frequency and intensity of the phenomenon have increased (Figure 3). This trend is primarily due to the relative sea level rise – 23 cm during the 20th century (Ceccone and Ardone, 2000; Ramieri, 2000; www.comune.venezia.it) – induced by a rise in the average Adriatic Sea level (*eustasy*), mainly as a result of global warming, in addition to the lowering of the islands of Venice (*subsidence*, both naturally and anthropogenically induced).

Figure 3 – Yearly distribution of tidal level $\geq +110$ cm in Venice, 1872-2006



Sources: www.comune.venezia.it

According to the most recent forecasts (IPCC, 2007), in the next decades climate change should worsen the *eustasy* phenomenon at a global level. Although specific forecasts for the Adriatic Sea or for the Mediterranean Sea as a whole are not available, being a semi-enclosed basin, the Mediterranean and the Adriatic Sea too, could indeed be less influenced by the global sea level rise (L. Carbognin *et al.*, forthcoming)².

² As stressed by the authors, in terms of sea level trends in particular, the Adriatic Sea has very peculiar and different characteristics due to its shape and low depth.

Both citizens and economic activities are greatly affected (Chiabai, Nunes, 2008): in the case of exceptional *acqua alta* episodes (+140 cm), about 90% of the historical centre of the city of Venice is flooded. As a consequence, in recent years some measures to protect Venice from flooding have been adopted. Among them, the system of mobile barriers commonly known as MOSE is particularly relevant. The next section briefly describes how it works.

2. Measures to protect Venice from climate change effects: the MOSE

For a long time, Venetians have individually adopted various measures in order to minimise the damages induced by the '*acqua alta*' phenomenon, such as hydraulic pumps, '*vasche*', '*paratie*' and the raising of pavements (Breil *et al.*, 2005). Nevertheless, the most relevant among them is the system of mobile barriers more commonly known as MOSE ('Modulo Sperimentale Elettromeccanico' i.e. Experimental Electromechanical Module), which consists in free moving elements inserted at the inlets (18 at 'Chioggia', 19 at 'Malamocco', 20 at 'Lido – Treporti' and 21 at 'Lido – S. Nicolò'), raised during high tide in order to block the water from entering the lagoon.

This engineering solution has been conceived in order to separate the lagoon from the Adriatic Sea from a hydraulic point of view (up to a maximum water level of 2 metres) every time the sea level exceeds an established *safety level*, i.e. the level at which the mobile barriers closing procedure is activated, corresponding to + 110 cm³ above the 'Punta della Salute' tidal datum (www.salve.it).

Whenever the Tidal Office of the city of Venice (www.comune.venezia.it), in charge of monitoring and forecasting the tidal trend, forecasts a tidal level higher

³ This level does not correspond to a functioning limit for the MOSE and it can be modified and lowered if necessary.

than the safety level⁴, an alarm is raised and the procedure for closing the mobile barriers is activated (Ministero dell' Ambiente - Magistrato alle Acque, 1997)⁵.

The mobile barriers are usually filled with water and lie on the sea floor. When the closing procedure starts, compressed air is introduced into the barriers and pushes out the water. The barriers are then raised until their extremity emerges from the sea surface, as shown in Figure 4.

Figure 4– The mobile barriers functioning



Source: www.salve.it/it/soluzioni/f_acquealte.htm

According to official estimates, the mobile barriers remain closed for a total time of around 4-5 hours on average (www.salve.it); this includes the duration of the 'acqua alta' event and the mobile barriers raising procedure,. Nevertheless, this value strongly depends on the meteorological situation and the hypothesized Adriatic Sea level rise.

3. The impact of the MOSE on Venetian economic activities

According to a recent study (Nunes *et al.*, 2005), the introduction of the MOSE should contribute to lowering the short term monetary costs induced by the periodical flooding of business activities carried out in the city centre. This study, is nevertheless limited to a specific sector and does not take into account the potential negative effect the functioning of the MOSE could cause to the port, an

⁴ Forecasts are relative to the following 48 hours and are updated every 3 hours according to the evolution of some meteorological parameters such as wind and rain intensity.

⁵ More precisely, in the quoted document, a safety level equal to +100 cm is mentioned. Nevertheless, as will be briefly discussed further on, recently the safety level has been set at +110 cm (www.salve.it).

economic sector still particularly relevant to the city.

Even though the MOSE has been projected so as to minimise the interruption of maritime traffic, the interference with port activities during the closing of the mobile barriers is unavoidable. The construction of a navigation channel, strongly demanded by the Venice Port Authority and the Italian Ministry of Transport, was started in 2005 at the 'Malamocco' inlet. By means of a system of dams, it brings about a reduction⁶ in waiting time for ships entering or exiting the lagoon (Magistrato alle Acque di Venezia, 2002). As a consequence, as highlighted even by Chiabai and Nunes (2008), the functioning of the MOSE induces additional costs to port activities.

3.1 The MOSE impacts on Venice port activities

The additional costs Venetian port activities have to bear, corresponding to the difference between the costs connected to port activities before and after the introduction of the MOSE, can be split into two different components, the *direct* and the *indirect* ones (Costa, 1993). The first component affects port users (ship owners and charterers) directly and includes all the additional costs consequent to inlet closures resulting in ships waiting in roadstead for a longer period (for those waiting to enter the lagoon) and/or in ships staying in wharf/quay for a longer period (for those waiting to leave the lagoon). Therefore, this includes, for example, potential charter costs and mooring costs, the potential costs of hiring on board staff, costs due to the clogging up of loading and downloading operations, warehousing costs of commodities (see Table 1 for a more detailed list of additional mooring costs). The second component instead includes losses due to the potential reduction of port traffic: due to the additional costs, the port of Venice could become less competitive compared to other ports. Thus, the port bears the entire burden.

Table 1 – List of the principal costs for ships clinched in the port of Venice

Technical services

Mooring

Fire surveillance

Services for ships

Board feed movement

Industrial laundry and drier

Floats and fender provision

Services for passengers

Tourist guide/interpreter

Luggage carrier from/to ship

General Services

Parking and car court management

Electricity, water and natural gas provision and thermotechnical systems management

Maintenance management and coordination

Cleaning and waste elimination coordination

Passage surveillance coordination

Landing places management

Information, telecommunication services

Security for the port of Venice

Logistics for port users

Source: our elaboration on data www.port.venice.it

Moving from this distinction, the indirect costs of the functioning of the MOSE are strongly correlated with the direct costs. The first cost component depends on the geographic and organisational characteristics of the port of Venice, in particular with reference to the temporal distribution of activities scheduled during the day.

As recognised by an international panel of experts and the Commission of the Italian Ministry of Environment in charge of evaluating the environmental impact of the MOSE (Valutazione di Impatto Ambientale – VIA), a precise economic evaluation of the functioning of the MOSE on Venice port activities should include both the above-mentioned cost components (Collegio di Esperti di Livello Internazionale, 1998; Ministero dell’Ambiente, 1998a, 1998b). The present work focuses only on the estimate of the direct cost component consequent to the closing of the MOSE barriers for Venetian port activities. More

⁶ As will be more clearly discussed further on, the existence of a navigation basin should halve the ship waiting time.

precisely, the present work provides a lower bound for the direct cost component estimate.

Even though partial, this estimate represents a useful element for analysing the economic impacts of the MOSE on port activities. The topic is particularly relevant, because if the prevention measures introduced in order to face the forecasted intensification of the '*acqua alta*' phenomenon induced by climate change should interfere with port activities, this could result in substantial negative effects for the economy of Venice. Even though it has been affected by the changes in the Italian productive system that have taken place during the last decades, the port sector still plays a relevant role within the urban economy. As will be clarified in the next section, the port of Venice not only absorbs the growing tourist flow, but remains an important reference for commodities transiting through the North-Eastern part of Italy.

3.2 Venice port traffic development since the Second World War

Empirical evidence shows that during the last sixty years the port of Venice has experienced a substantial development (Costantini, 2004; www.port.venice.it). As shown in Figure 5, passengers grew from 10,000 units after the Second World War to almost 1.5 million in 2006. This increase strongly reflects the tourist boom registered during the last ten years.

After the Second World War, the supply ship traffic experienced a consistent boom, primarily due to the industrial and oil sectors, but during the 1970s it slowed down (Figure 6). Nevertheless, during the last ten years the commercial sector gave rise to a new growth in the volume of goods transported.

Figure 5 – Passenger ship traffic (1947-2006)

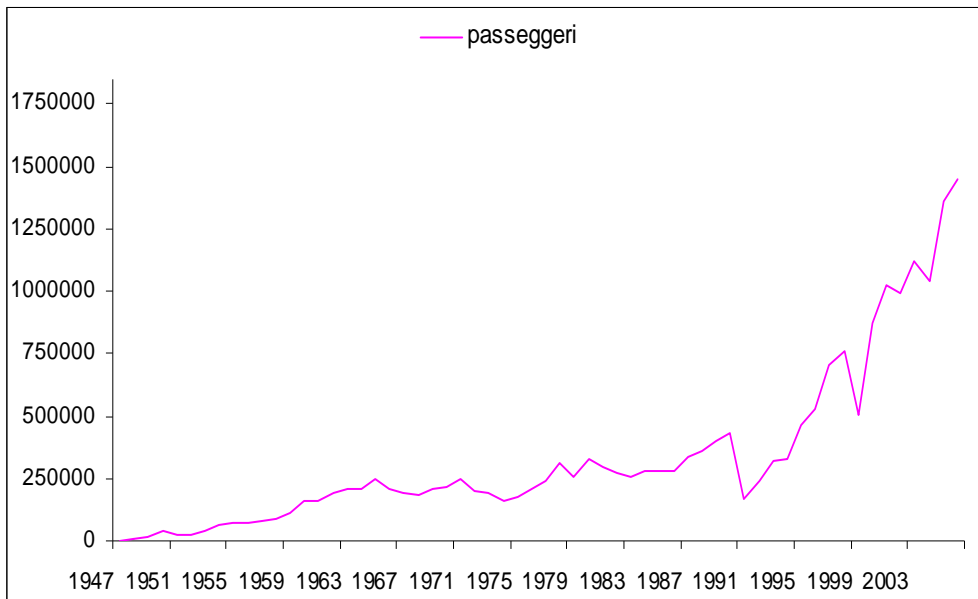
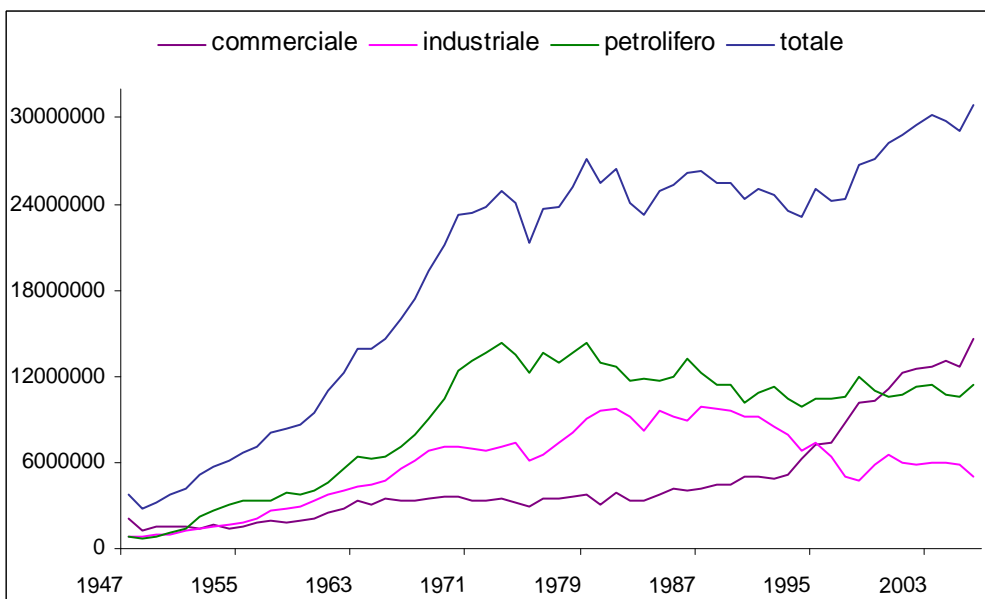


Figure 6 – Supply ship traffic (1947-2006)



4. Hydrodynamic tools for the analysis of the functioning of the MOSE

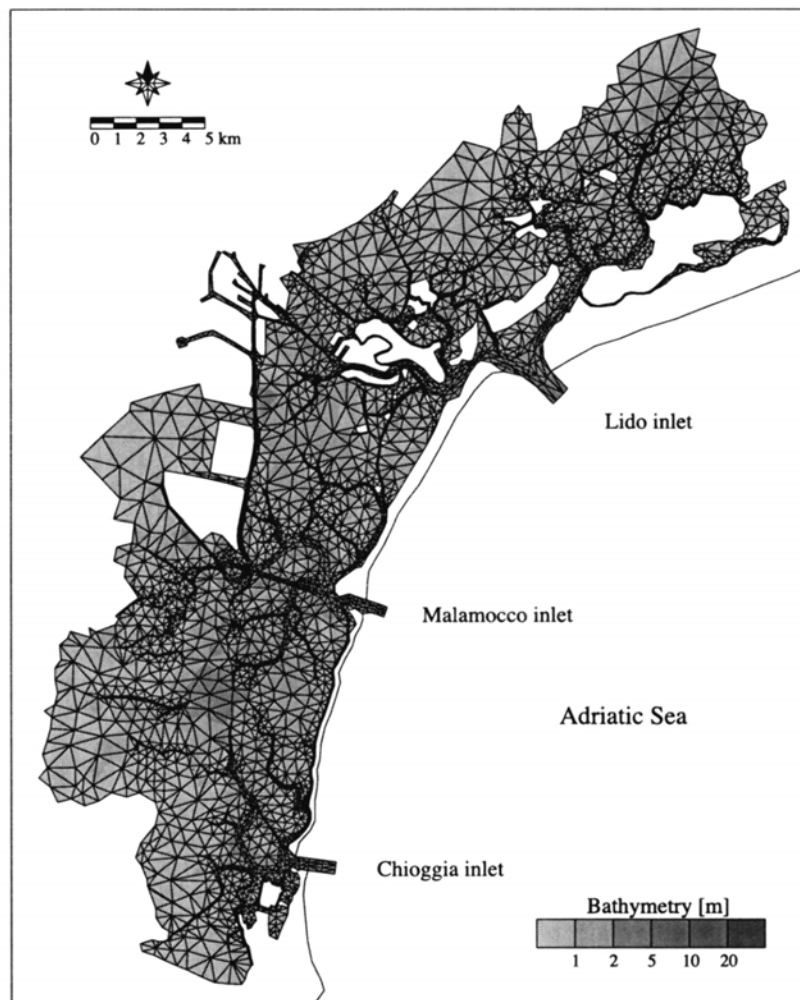
4.1 The model

Before describing in detail the estimation methodology applied and the results obtained, it is useful to briefly explain the hydrodynamic model used in the analysis of the functioning of the MOSE.

The evaluation of the direct costs resulting from port traffic interruption due to

the MOSE is based on the analysis of how the mobile barrier closure interferes with ship traffic through the lagoon. For this analysis a hydrodynamic model developed at the ISMAR-CNR of Venice has been used. Such a two-dimensional finite element model (Umgiesser and Bergamasco, 1993, 1995; Umgiesser *et al.*, 2004) describes the lagoon hydrodynamics resulting from the geo-hydro-morphological and meteorological conditions (Umgiesser 1997, 1999, 2000; Umgiesser and Maticchio, 2006). As shown in Figure 7, the numerical grid describing the Venice lagoon is made out of 7,842 triangular elements and 4,359 nodes.

Figure 7 – The grid of the finite element model of the lagoon



Source: Umgiesser, Cucco and Solidoro (2004)

Given the water level measured at the 'Lido', 'Malamocco' and 'Chioggia'⁷ inlets and the wind intensity measured within the lagoon, the model computes the water level with a time step of 5 minutes and simulates the propagation of the tidal wave and of the barotropic flow inside the basin at each node. Moreover, by means of a specific algorithm, the model simulates the closing procedure of the mobile barriers and given the data on ship characteristics (typology of vessel, distribution and intensity of ship flow) forecasts the length of ship traffic interruption.

The model predicts when and for how long the ship traffic is slowed down due to the closing of the MOSE barriers. In particular, the hydrodynamic analysis in the present work focuses on how the mobile barriers closing procedure would have interfered with ship traffic in the period 2000-2002. As will be discussed in more detail further on, the frequency of the mobile barrier closing procedure, and therefore the additional cost estimate for port activities, strongly depends on the hypotheses assumed on some relevant variables.

4.2 The model hypotheses

The hydrodynamic analysis performed is based on three main assumptions. Firstly, we consider an average Adriatic Sea level rise of 10 cm in 2030 with respect to the current level, due to global warming. As already pointed out, specific and reliable forecasts for the Adriatic and for the Mediterranean Sea are not available. For this reason, we have considered the data included in the last IPCC report (International Panel on Climate Change - IPCC, 2007); it refers to a general average sea level rise of 30 cm in 2090 with respect to the end of the previous century⁸.

Secondly, the safety level, which triggers the closing procedure of the mobile

⁷ As will be clarified further on, data used for the estimation do not include the ship traffic through the Chioggia inlet.

⁸ More precisely, it is an average datum resulting from the six scenarios taken into account by the IPCC panel of experts (IPCC, 2007). Nevertheless, according to Rahmstorf (2007) much higher estimates are available.

barriers in the model, is assumed to be equal to +110 cm with respect to the 'Punta della Salute' tidal datum. This value corresponds to the tidal level that the water in the lagoon should not exceed and results from an agreement reached by the relevant authorities taking into account the current sea level and water quality, the protection of the lagoon morphology and landscape and the maintenance of port activities. Moreover, this level is consistent with the quota at which the raising of the shore of the lowest areas of the lagoon urban centres has been settled (*local defenses*): the old buildings in the areas of intervention require the respect of precise limits, above which it is not possible to proceed.

Finally, a precautionary rule is followed with respect to the future projections of the tidal movements in order to correct possible forecasting errors. In particular, not only the official tidal forecasts provided by the Tidal Office of the Venice Municipality ('Ufficio Maree') were taken into consideration but even the same data modified by an additional 10 cm (*security increment*). The aim is to avoid the underestimation of the water level that would result in a missed closure. In our simulation, which reflects the MOSE functioning procedure previously described, when the forecasted tidal level is lower than the real tidal level, and both are lower than the safety level, there would be no negative effects in terms of the simulated closing procedure of the mobile barriers. However, when the forecasted tidal level is lower than the safety level but the real tidal level is equal or higher than the same, the simulated closing procedure would not take place even though necessary. As a consequence, in case of forecasting errors, the MOSE would erroneously not be closed.

4.3 Data

Data on wind speed and direction during the period 2000-2002 come from the CNR oceanographic platform in the Adriatic Sea.

Carbognin *et al.* (forthcoming) refer to the last IPCC report (2007) and propose three scenarios (+17,+26 and +53 cm by 2100) for the relative sea level rise within the lagoon of Venice.

Data on daily rainfall in the same period come from the ‘Istituto Cavanis’ of Venice.

Data on the tidal level measured at the ‘Lido Diga Sud’ and at ‘Punta della Salute’ and the hourly forecasts for the subsequent 48 hours at ‘Punta della Salute’ have been elaborated by the Tidal Office of the Venice Municipality (‘Ufficio Maree’).

Data on port (both passengers and supply) traffic passing through the ‘Lido’ and ‘Malamocco’⁹ inlets during the period taken into consideration have been provided by the Venice harbour office (‘Capitaneria di Porto’). These data include the name and the origin of each ship, the date (year, day, hour and minutes), the direction of transit and the inlet. The dataset takes 3,072 ships into account corresponding to 29,506 movements, 8,418 of which through the ‘Lido’ inlet and 20,988 through the ‘Malamocco’¹⁰ inlet.

The information on the ships’ characteristics (ship type, overall length, deadweight, gross tonnage, number of passengers) necessary for cost estimation was found in the 2006-2007 electronic version of Lloyd’s Register of Ships (Lloyd’s Register – Fairplay limited 2006). Table 2 illustrates the percentage of each ship type respect to total ships and movements. Table 3 provides the ship classification used in the present work.

Table 2 – Port traffic composition

	<i>% of ships</i>	<i>% of movements</i>
<i>Carrier</i>	21.22	16.04
<i>Cargo</i>	45.24	39.81
<i>Tanker</i>	18.16	21.3
<i>Container</i>	3.15	5.76
<i>Passenger</i>	6.35	13.59
<i>Others</i>	5.85	3.5

⁹ The dataset does not include the whole port traffic. For example, fishing ships which passed through the ‘Chioggia’ inlet are not taken into account.

¹⁰ Not reliable data (i.e. two or more consecutive arrivals or departures referring to the same vessel) have not been considered. When possible, the entry errors of the vessels' name have been corrected. Ingoing (outgoing) ship

Table 3 – Ship type classification

<i>Ship category</i>	<i>Ship type</i>
Carrier	Barge Carrier
	Bulk / Oil Carrier
	Bulk Carrier
	Cement Carrier
	Fish Carrier
	Heavy Load Carrier
	Ore / Oil Carrier
	Self-Discharging Bulk Carrier
	Vehicles Carrier
	Wood Chips Carrier
	Cargo
Passenger / General Cargo Ship	
Passenger / Ro-Ro Cargo Ship	
Refrigerated Cargo Ship	
Ro-Ro Cargo Ship	
Tanker	Bitumen Tanker
	Chemical / Oil Products Tanker
	Chemical Tanker
	Crude Oil Tanker
	LNG Tanker
	LPG Tanker
	Oil Products Tanker
	Oil-Sludge Tanker
	Vegetable Oil Tanker
	Water Tanker
	Wine Tanker
Container	Container Ship
	Passenger
Passenger Ship	
Others	Yacht
	Cable-Layer
	Crane Ship
	Crewboat
	Dredger
	Drilling Ship
	Fire-Fighting Vessel
	Fishing Vessel
	Hopper Dredger
	Motor Hopper
	Offshore Processing Ship
	Offshore Supply Ship
	Offshore Support Vessel
	Offshore Tug / Supply Ship
	Other Non-Merchant Ships
	Pollution Control Vessel
	Pusher Tug
	Research Vessel
	Training Ship
	Trawler
	Tug

movements without the corresponding outgoing (ingoing), i.e. vessels that have arrived but not left (or vice versa),

From data analysis, it emerges that ship movements, both ingoing (ins) and outgoing (outs), are not uniformly distributed during the day: about 59% of the ins are concentrated between 6.00 and 11.00 am (Figure 8), when the frequency of ‘acqua alta’ phenomena is higher, while about 34% of the outs is concentrated between 5.00 and 7.00 pm (Figure 9).

Figure 8 – Hourly distribution of ins

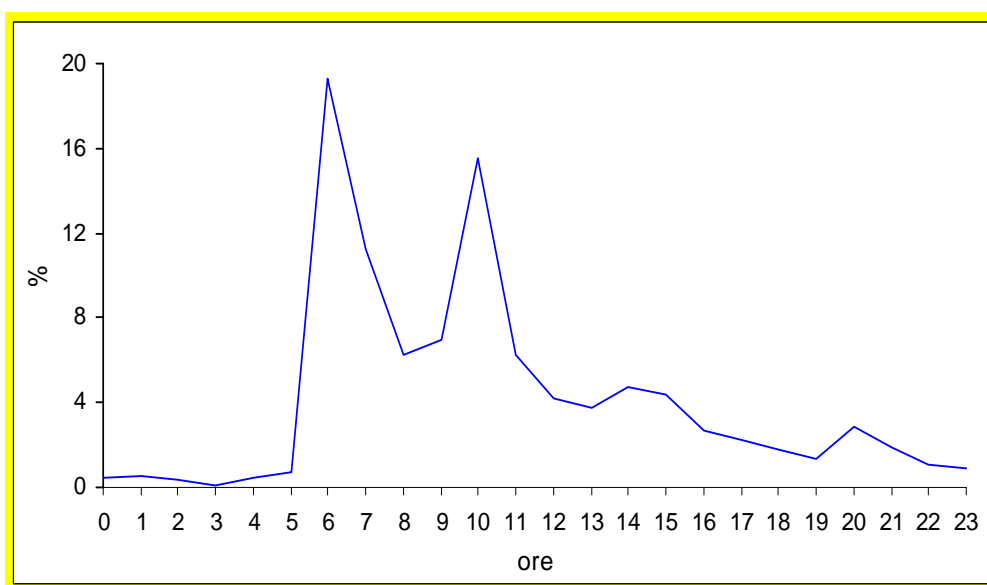
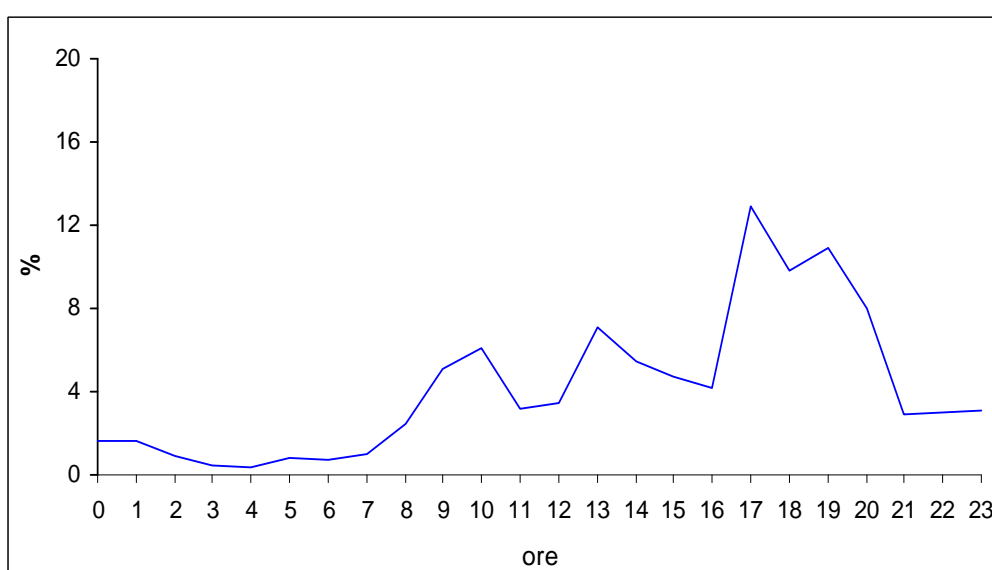


Figure 9 – Hourly distribution of outs



have not been considered.

4.4 Results

From the hydrodynamic analysis carried out it emerges that, if the MOSE were functioning, 8.64% (9.41%) of the ins (outs) during the period 2000-2002 would have been delayed due to the mobile barrier closing procedure. In particular, the average delay per movement would have been equal to 1 hour 17 minutes (1 hour 10 minutes). By considering also a safety increment of 10 cm as previously mentioned, the percentage of delayed ins (outs) would rise to 17.81% (19.72%) and the average delay per movement would be equal to 1 hour 17 minutes (1 hour 13 minutes).

A graphic representation of the results obtained for the original data and for data after applying a safety increment of 10 cm to the tidal forecast is presented in Figures 10 and 11 respectively. The red line identifies ships in the Venice harbour. The green (blue) line corresponds to ships inside (outside) the lagoon waiting to leave (enter into) the harbour: it then captures the outs (ins) delayed because of the functioning of the MOSE.

Figure 10 – The interference of the MOSE with port traffic (original data)

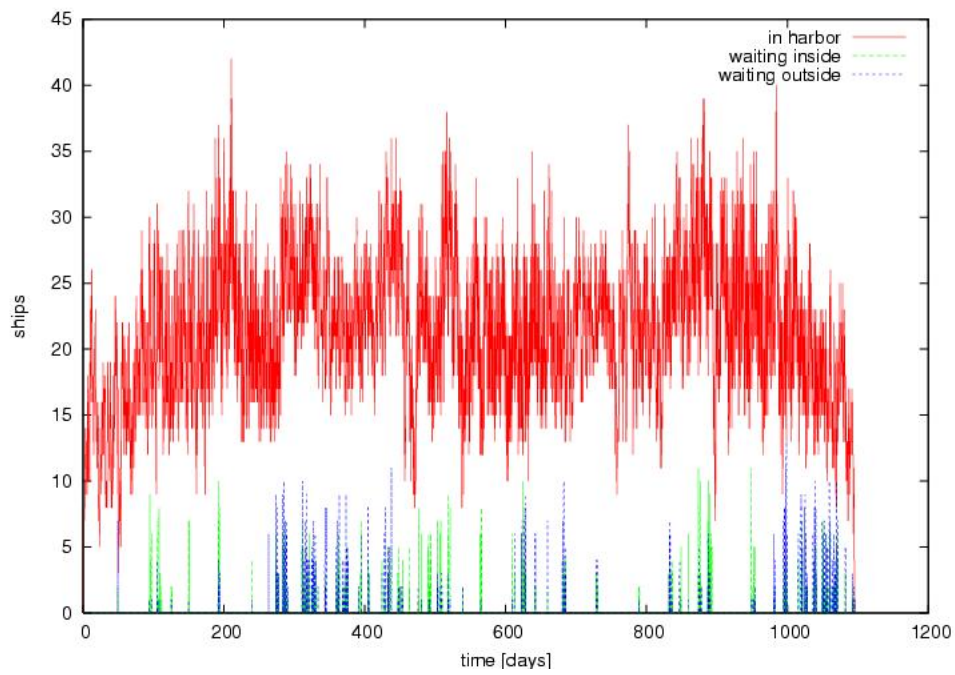
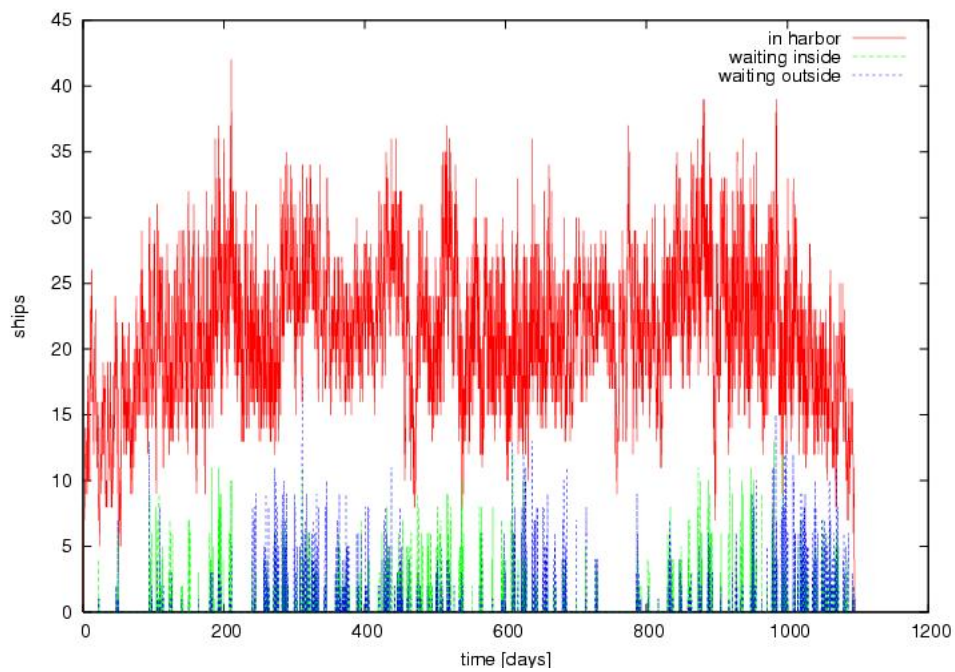


Figure 11 – The interference of MOSE with port traffic (with security increment of 10 cm)



5. Economic analysis: estimate of the direct costs resulting from the functioning of the MOSE for the port of Venice

5.1 Methodology

The analysis carried out provides an estimate only of the direct costs induced by the interruption of ship traffic for the port of Venice users. The results obtained therefore provide only a partial estimate of the total additional costs connected to the functioning of the MOSE. A complete cost-benefit analysis of the MOSE project, available from the official documents already quoted, is not proposed here. Our aim is rather to complete such an analysis, by looking at a specific cost component, which, though considered relevant, has not been estimated within the mentioned official documents.

The estimate has been carried out by assuming that these costs correspond to the sum of the additional *charter costs* due to the longer time necessary to enter and exit from the lagoon and, for ships that cannot exit from the lagoon due to the mobile barriers closure, even *mooring costs*. The first cost component varies substantially according to the contract clauses, which reflect the ship type¹¹ and the relationship between the ship owner and the charterer. Being impossible to trace back to the contract of each specific ship, the estimate is based on the assumption that additional charter costs are equal to the usual charter costs and that there are no particular penalty clauses connected with an extension of the charter period.

However, charter contracts include a number of clauses concerning the additional costs due to delay in vessel delivery. When the charterer is responsible for the delay, usually monetary penalties are applied, that vary according to what was agreed by the owner and the charterer. When the delays are due to circumstances beyond one's control, such as exceptional natural events (ice, seaquake, fog), collisions, quarantine, war outbreak, no penalty is applied. In the future, the

¹¹ For example, for oil tankers *time charters* contracts refer to 10 or even more years; *consecutive trips charters* contracts include a specific number of trips or time duration; *spot charters* contracts refer to a single trip between two ports (www.eniscuola.net).

mobile barriers closure could be considered as an exceptional natural event and charter contracts could include specific clauses concerning the delay in vessel delivery due to the functioning of the MOSE. In this case, the additional costs due to port traffic interruption during the mobile barriers closing procedure would probably be lower.

5.2 Data

Mooring costs (Table 4) have been inferred from the price lists of the main maritime agencies operating within the lagoon for the year 2005: Venezia Trasporti Passeggeri (VTP) for passenger ships, Terminal Intermodale Venezia for the other ship types. Data on charter costs (Table 5) have been kindly provided by some operators contacted by telephone. When expressed in a foreign currency, costs have been converted into euros according to the average official exchange rates for the period January 2005 – May 2006 (Ufficio Italiano Cambi - UIC, www.uic.it).

Table 4 – Mooring costs by ship category (2005 prices)

	€/hour
Carrier and Container	1,000.00000
Cargo and Tanker	1,333.33333
	€/m/hour
Passenger Ship	0.16699
Yacht	0.45306

Table 5 – Charter costs by ship category (2005 prices)

	tons	€/ton/hour
Crude oil tanker	x < 90,000	0.02614
	90,000 ≤ x < 100,000	0.02831
	x ≥ 100,000	0.03025
Wine, water and vegetable oil tanker^a	x < 1,000	0.13445
	1,000 ≤ x < 1,500	0.12325
	x ≥ 1,500	0.11204
LNG tanker	x < 7,000	0.28538
	7,000 ≤ x < 20,000	0.18685
	x ≥ 20,000	0.14269
Container	x < 15,000	0.03105
	15,000 ≤ x < 23,500	0.02497
	23,500 ≤ x < 28,000	0.02261
	28,000 ≤ x < 34,500	0.02390
	34,500 ≤ x < 40,000	0.01935
	40,000 ≤ x < 48,000	0.01899
	x ≥ 48,000	0.02087
Cargo	4,500 ≤ x < 27,500	0.00843
	x ≥ 27,500	0.01243
Carrier	x < 4,500	0.02614
	4,500 ≤ x < 27,500	0.00843
	27,500 ≤ x < 80,000	0.01243
	x ≥ 80,000	0.00759
		€/pass/hour
Passenger Ship		1.60064
Yacht		46.76871

^a Only for this ship category tons refer to deadweight and not to gross tonnage

5.3 The evaluation scenarios

5.3.1 The navigation channel

Our estimates include the effects on Venetian ship traffic of a navigation channel (sluice gate) at the ‘Malamocco’ inlet by assuming specific hypotheses on its absorption capacity relative to ship traffic.

As previously pointed out, a navigation channel at the ‘Malamocco’ inlet has been planned in order to minimise the problems caused to big sized ships during the functioning of the MOSE. The navigation channel has indeed been conceived for big sized ships (up to a length of 280 m, a width of, 39 m and a draught of 12 m), excluding those for passenger transport. According to the data provided by

the Magistrato alle Acque di Venezia (2002), the estimates are based on the assumption that the opening of the navigation channel relieves the supply ship traffic congestion at the Malamocco inlet by about 50%¹².

Two factors contribute to this reduction: on the one hand, the number of ships waiting at the Malamocco inlet is reduced; on the other hand, the waiting time for ships passing through the navigation basin is reduced. Nevertheless, our hydrodynamic model does not take into account the congestion problems of ingoing and outgoing port traffic due to the closing of the mobile barriers. In other words, the analysis carried out is based on the assumption that the waiting time of each ship depends only on the mobile barriers closure and not even on the waiting time of the other ships. For this reason too the results obtained provide only an underestimate of the additional costs due to the functioning of the MOSE.

5.3.2 The ship traffic

The analysis has been carried out by considering different hypotheses on the ship traffic trend in the port of Venice. In particular, we considered two different assumptions separately: firstly, that ship traffic remained constant at the volume recorded during the period 2000-2002 and secondly that it has developed according to the trend observed in the period 1947-2006. We assumed specific separate hypotheses for the future passenger and supply ships (industrial, oil, commercial) traffic.

As previously underlined, the historic and artistic relevance of Venice attracts a number of tourists every year and this explains the consistent increase in the tourist flow experienced during the last years (Figure 5). It is likely that such a flow will continue to grow even in the next decades and its trend will evolve independently from the trend of supply ships. Nevertheless, an increase in tourist flow at the same recent rate even for the next decades is not consistent with the absorption capacity of the city of Venice. Concerning the supply ship traffic, it is

¹² More precisely, in the quoted document the ship traffic congestion relieve of 50% is referred to a safeguarding

rather hard to assume realistic hypotheses on future trends, because they strongly depend on the role the industrial, oil and commercial components will play.

Therefore, moving from the above-mentioned considerations and the results obtained by the extrapolation of the available data (for a more detailed description of the methodology applied, see the Appendix at the end of the paper), our estimates are based on the following hypotheses regarding the evolution of passenger and supply ship traffic:

- 1) no variation;
- 2) 9.73% increase of supply ship traffic, 24.43% increase of passenger ship traffic in 2030 with respect to 2006.

5.4 The estimation results

The estimation results obtained are shown in Table 6. The variability of the estimated costs reflects the different hypotheses considered. In particular, the minimum values correspond to a constant flow of ship traffic and reduced transit time due to the functioning of the navigation channel. Similarly, the maximum data refer to the absence of the navigation channel and the hypothesis of an increase in both passenger (9.73%) and supply ship flow (24.43%). In this case, the effects of not being able to reduce the transit time through the navigation channel are added to the effects of the growth in port traffic flow.

Table 6 – Estimation results (€/Year), expressed in 2005 prices

Ships' type	Charter costs			Mooring costs			Total		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Commodities	55.648	262.643	137.891	322.411	719.320	511.358	383.417	970.206	649.249
Passengers	51.471	176.712	108.561	113.436	141.148	127.292	164.907	317.860	235.853
Total	107.119	439.355	246.452	435.847	860.468	638.650	548.323	1.288.067	885.102

It can be noticed that the mooring costs, on average higher than charter costs, represent the most relevant component of the total estimated costs; in particular,

level of +110 cm and a sea level rise of +10 and + 22 cm.

among the mooring costs, those associated with supply ships. This result derives from a reduced intensity and a more propitious seasonal frequency of passengers ships with respect to other ship types. In fact the data used (Table 2) show that the ferries and cruises passing through the lagoon of Venice are less than the other ship types and are concentrated mainly during the summer, when the '*acqua alta*' episodes are less frequent.

5.4.1 *The off shore terminal*

In order to complete our analysis, our estimates include the condition in which an off shore terminal is functioning at the 'Lido' inlet. In doing so, we assume that it absorbs all the oil ship traffic, so that the negative effects of the functioning of the MOSE for oil traffic are avoided. A project for a similar terminal has been proposed by the 'Magistrato alle Acque di Venezia' (2003) for the 'Lido' inlet, but it has been rejected by the competent authorities and no other projects have been proposed until now. Table 7 shows how the estimates included in Table 6 would change if an off shore terminal were functioning and all the oil traffic congestion were avoided.

Table 7 – Estimation results (€/Year), expressed in 2005 prices, oil off shore

Ships' type	Charter costs			Mooring costs			Total		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Commodities	33.031	162.912	84.362	253.719	568.568	403.307	292.107	719.724	487.669
Passengers	51.471	176.712	108.561	113.436	141.148	127.292	164.907	317.860	235.853
Total	84.501	339.624	192.923	367.155	709.717	530.599	457.013	1.037.584	723.522

It can be noticed that the introduction of an off-shore oil terminal with the described characteristics would induce a reduction of the costs due to the functioning of the MOSE equal on average to 25% for supply ships. This result derives from the relevance of the oil respect to the total supply ship traffic (about 18%). In particular, such a reduction would reflect the drop in charter costs, on average equal to 39%. The total reduction of additional costs due to the

functioning of the MOSE would reach 18% on average. Therefore, without considering its construction and maintenance costs, the functioning of an off-shore oil terminal would reduce the additional costs induced by the functioning of the MOSE for the port of Venice.

5.4.2 Reorganisation of port access and use schedule

A further measure aimed at reducing the negative effects of the functioning of the MOSE for port activities would be the reorganisation of the port access and use schedule for vessels. As previously mentioned, the 'acqua alta' phenomena are mainly concentrated during 8.00 am and 1.00 pm (73%), when 39% of ingoing movements and 20% of outgoing movements are concentrated (Figure 7 and 8). Therefore, if this traffic volume could be absorbed before 8.00 am, the costs related to the functioning of the MOSE would decrease by 36% (Figure 8). In this case, the cost reduction would, on average, be almost uniformly partitioned between the supply and passengers ships and between the charter and mooring costs.

Table 8 – Estimation results (€/Year), expressed in 2005 prices, ships' movements reschedule

Ships' type	Charter costs			Mooring costs			Total		
	Min	Max	Average	Min	Max	Average	Min	Max	Average
Commodities	36.290	175.943	91.595	205.687	458.067	325.930	245.014	627.343	417.524
Passengers	32.126	110.297	67.760	70.802	88.099	79.451	102.928	198.396	147.210
Total	68.416	286.239	159.354	276.489	546.166	405.380	347.943	825.739	564.735

6. Conclusions

The estimates resulting from our analysis show that the additional *direct costs* induced on port activities by the functioning of the mobile barriers are rather limited. In particular, they are limited when compared to the benefits associated with the functioning of the MOSE in terms of minor damages caused to the city of Venice by the 'acqua alta' episodes. This is true even when considering only

the direct benefits, expressed in physical terms (for example, a smaller reduction of tourists flow, minor damages and discomforts induced by the interruption of the economic activities carried on at ground floor (Nunes *et al.*, 2005), minor damages to the historical-artistic heritage of the city), without taking into account the indirect benefits, which could be expressed through the revealed preference methods (*travel cost method, hedonic pricing method*).

Nevertheless, the results obtained strongly reflect the cost calculation method used and the assumptions of the hydrodynamic model. In particular, the calculation of the direct costs due to the functioning of the MOSE for the users of the port of Venice provides an underestimation of the total direct costs, because they result only from two specific components (charter and mooring costs). The hydrodynamic model instead assumes a 10 cm Adriatic Sea average level rise in 2030 as an effect of climate change. Therefore, if the sea level forecasts should shift downward (upward), the frequency of closing of the MOSE would become less (more) intense and as a consequence our estimates should shift downward (upward).

Moreover, according to our analysis, even other measures should be undertaken in order to minimize the impacts of the functioning of the MOSE on Venetian port activities. To achieve this aim, we mentioned and briefly discussed the introduction of both a navigation channel and an oil off shore terminal, but even a different time schedule of port traffic management could have positive effects. For example, a different distribution of the ingoing movements during the day, currently mainly concentrated during the last hours of the morning when the '*acqua alta*' episodes are more frequent, could reduce the slowing down of port traffic due to the functioning of the MOSE.

According to our estimates, with an operating navigation channel and a constant ship traffic flow, the additional costs for port activities induced by the mobile barriers closure would reach a minimum of 548,323 €Year, while in the absence of this further engineering solution and under the assumption of a more intense

traffic flow such costs would increase up to a maximum of 1,288,067 €Year. The introduction of an off shore terminal capable of absorbing all the oil ship traffic would induce an additional cost on the port of Venice ranging between 457,013 and 1,037,584 €Year. Finally, a different time schedule of port traffic management during the day would further lower such costs, which would range between 347,943 and 825,739 €Year.

Moving from these considerations and results, the functioning of the MOSE would not necessarily induce a port traffic reduction in favour of other ports, economically more competitive, and the city of Venice would not necessarily suffer the decline of one of the most relevant sectors of its economy. Nevertheless, public decision makers in charge of planning and managing the urban development should carefully consider the potential negative effects of the functioning of the MOSE for the economic activities of the city and therefore propose some measures aimed to limit them.

Methodological appendix

Forecasts on Venetian port traffic development until 2030 have been obtained through a non-linear extrapolation of historical data. More precisely, it is assumed that both the supply and passenger ships port traffic develops according to a logarithmic trend. This assumption reflects the Venetian port absorption limits of commodities and passengers due to its physical constraints.

In particular, supply ship data for the period 1947-2006 have been considered. Figure 12 shows both the historical data trend and the (logarithmic) trend-line for supply ships as a whole.

For passenger ships, instead, the extrapolation has been done only for a subset of the historical data (1990-2006, Figure 13). As shown in Figure 5, the flow development of passengers passing through the port of Venice experienced a sharp rise at the beginning of the 1990s. Therefore, we assumed that in the

coming decades the passengers flow will be closer to the one experienced during the last two decades rather than during the previous decades.

The extrapolations carried out show a 9.37% rise of supply ship flow in 2030 with respect to 2006 and a 24.37% increment of passenger ship flow with respect to the same year.

Figure 12– Extrapolation of supply ships trend data

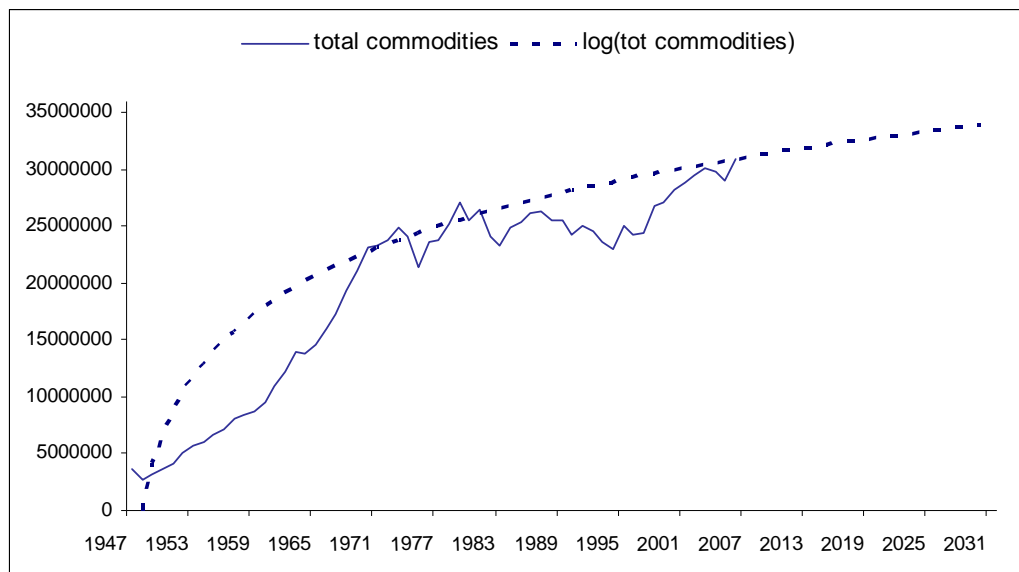
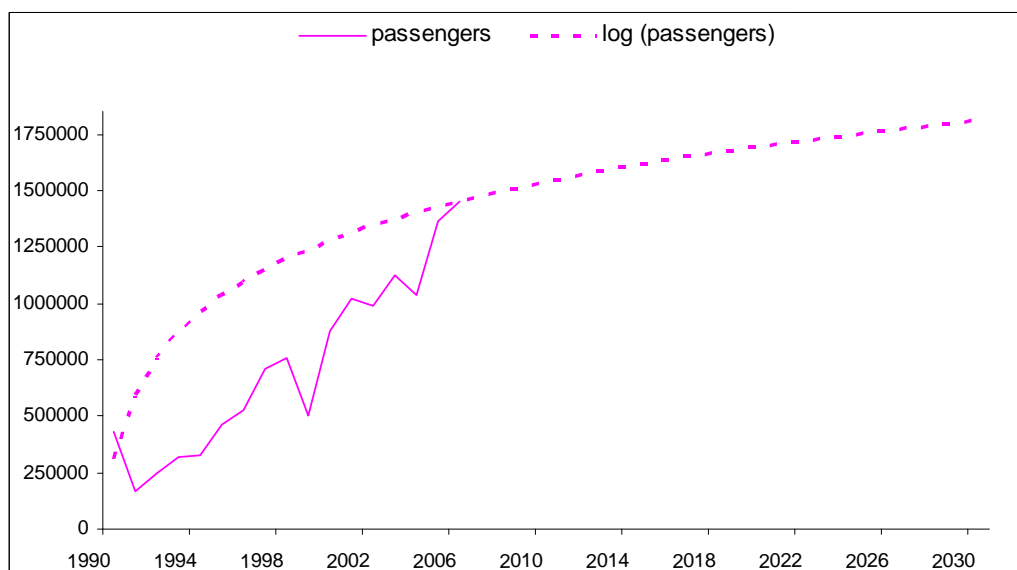


Figure 13 – Extrapolation passenger ships trend data



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