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Modeling an offshore container terminal: The Venice case study

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ABSTRACT

In order to reduce marine transportation times and related costs, as well as the environmental impacts, an alternative multimodal route to the current Suez-Gibraltar-North Sea corridor for the containers shipped from Far and Middle East was identified as potentially very effective. A key operational problem to achieve this result is the capacity and the effectiveness of the terminals within the concerned new logistic chain. In this framework, the Venice Port Authority is developing a project aimed to improve relevantly the potential of its container terminals to al-low loading/unloading of containers to and from the Central Europe. The project includes a new offshore terminal for mooring huge ships (up to 18.000 TEU) in the Adriatic Sea and a link operated by barges with an onshore terminal in Venice to overcome the constraints for the navigation of the containers ships in the Venetian lagoon. This innovative operational scheme requires a deep functional analysis to ensure the full capacity operation, assess the reachable performances and correspondingly dimensioning the required equipment (cranes, barges, quays, etc.). For this purpose, the authors developed a specific discrete-events simulation model. The paper includes the presentation of the model and the results of its application to Venice case study, by identifying the benefits achievable with this approach and the potential wider application fields.

1. Introduction

The increasing requirements of maritime transport customers towards a reduction of transport cost and time, as well as the need to reduce the environmental impacts, suggested the Venice Port Authority to create the infrastructural and operational opportunities for an alternative container route from Suez to Central Europe via the North Adriatic. The starting condition is anyway poor, both in terms of seaside and landside accessibility: big oceanic ships cannot enter Porto Marghera intermodal terminal and the continental connections, particularly by rail, are scarce.

To solve these problems, the Venice Port Authority elaborated an innovative project, including a high-tech offshore terminal capable to host ships with 20 m draft and 18,000 TEU capacity, with operational yearly capacity of 1 million TEU (Autorità Portuale di Venezia. Direzione pianificazione strategica e sviluppo, 2012; Ministero delle Infrastrutture e dei Trasporti. Magistrato delle Acque di Venezia, 2012).

The new offshore terminal operates in combination with the onshore Montesyndial terminal, where the containers will arrive by special barges and all commercial and intermodal landside handling will happen.

The success of the whole project is strictly depending upon the effectiveness of containers transfer between the two terminals, with flexibility and minimum impact on environmental equilibrium of the high-sensitive Venice lagoon.

The innovative solution is basing on a shuttle service of Lighter Aboard Ships (LASH), boarding the containers on special barges thanks to flooding of the hold, named 'Mama Vessel'. The relevance of the transfer process convinced the Port

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Authority to develop a simulation of the global offshore-onshore system, to identify the best dimension and typology of the fleet compatible the minimum amount of human resources and other operational costs.

It refers to a large set of operational scenarios, differing each other mainly according to the time intervals between the arrivals of the deep-water ships, their capacity and the amount of Mama Vessels in operation.

Key performance indicators to analyse results include:

1. the average time to transfer the containers from the offshore to the onshore terminal
2. the average waiting time of the Mama Vessels before boarding the barges
3. the daily TEU traffic

2. Modeling software and tools

The Modeling process is basing on the Planimate© software, which allows creating highly interactive and animated tools to simulate the concerned logistic processes and the interaction among the elements of the system.

Planimate offers a simple and intuitive interface with a working sheet, where are sequentially located and linked by 'paths' the 'objects' simulating the actions performed in the system by the 'items'.

The 'objects' are entities fixed and capable to host 'items' passing through them during the process simulation.

The 'items' are dynamic classified entities (e.g. ships) moving within the simulation sheet following the 'paths' passing through 'objects', where actions happen according to the typology of concerned 'object'.

On this basis, the modelling process includes four steps to build a multiple graph representing the static features of the system:

1. objects building
2. flows design
3. interactions implementation
4. graphical representation.

On the other side, the network execution represents the dynamic features of the system: an event happens as soon as all the pre-conditions are active and the event itself deactivates all the pre-conditions and activates all the post-conditions.

The set of the activated conditions represents permanently the state of the system.

The 'items' moving among 'objects' represent the evolution of the system by means of 'paths' representing logical sequence of events.

The 'objects' require the system modelling, linked each other to represent the sequence of actions of the 'items' created by the 'paths', which they execute (Figure 1). The set of 'paths' for a class of 'items' is the flow, along which the articles can run simultaneously during the simulation.

As soon as an 'item' meets an 'object' running through it, an interaction happens: it may be simple, whenever the 'object' is only keeping the 'item' for a fixed time, or conditional, whenever the 'item' passing through the 'object', is subject to fixed conditions.

3. Modeling of offshore terminal

The first step is the modelling of the offshore terminal by subsystems (portals) linked each other by 'paths' differentiated according to the involved element (ship or container), which simulate the operations of cranes for loading and unloading goods (Ricci et al., 2012; Ricci, 2014).

Figure 2 represent the offshore terminal, equipped with a 1,000 m long quay, capable to host two large container ships (upper part of the figure) served simultaneously by five portainers and eight groups of four RTG cranes each (lower part of the figure) capable to load/unload two barges simultaneously.

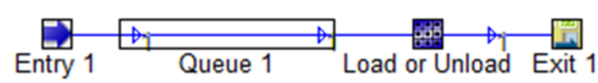
Under the portainer, the stocking capacity is 10,000 TEU.

This layout allows the containers arriving from the container ships to proceed through the offshore terminal to the onshore terminal by barges and Mama Vessels. The model reproduces the landing of container ships and the sequence of unloading and loading processes.

In figure 3, the ships 'items' enter through the green paths on the upper left part and exit from the violet path on the lower left part.

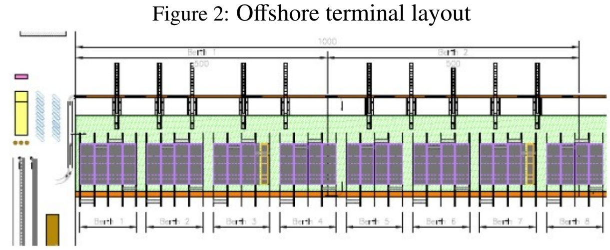
Before reaching the portals for unloading ('Scarico Main Vessel 1') and loading ('Carico Main Vessel 1') of containers, the ships 'items' pass through the objects simulating the approach to quays ('Accosto banchina 1') and the mooring ('Ormeggio 1').

Figure 1: Example of 'path'



Source: Authors

Figure 2: Offshore terminal layout

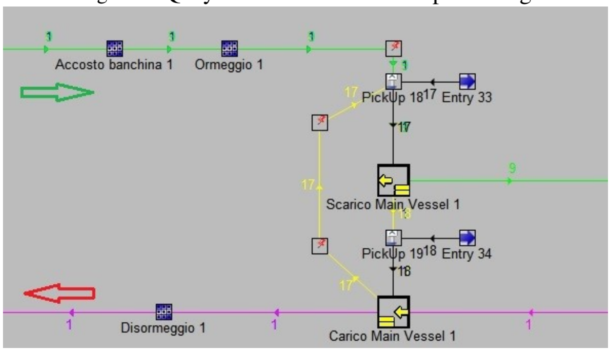


Source: Port Authority of Venice

After the end of the containers loading, the ships 'items' leave the system passing through the multi-server 'Disormeggio 1' to simulate the unmooring operation.

The unloaded units proceed to the opposite side of the quay dedicated to the barges, following the green path exiting from the portal 'Scarico Main Vessel 1', while the loaded units coming from the stocking area under the cranes dedicated to loading

Figure 3: Quay model for offshore ships landing



Source: Authors

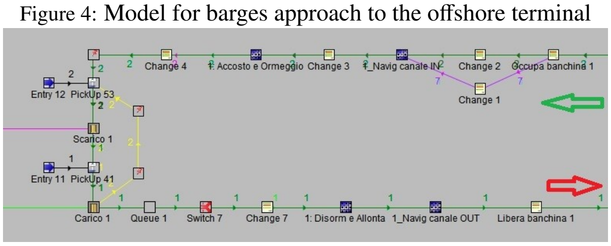
and unloading of barges exit from the portal 'Carico Main Vessel 1' by the violet 'path'.

The model does not take into account the transfer time of units through the offshore terminal, under the hypothesis that the containers to board on the barges are permanently available under the cranes and the related time is negligible in comparison to the time to transfer them to the Montesyndial onshore terminal.

A switch enabling a 'path' for entering the offshore terminal subsystem regulates the occupation of the quays by the two oceanic ships.

Figure 4 represents the model satisfying the mooring requirements of the barges arriving from onshore Montesyndial terminal.

Figure 4: Model for barges approach to the offshore terminal



Source: Authors

The model in figure 4 reproduces the operation of a group of RTG cranes working on two barges simultaneously.

The model includes, also in this case, two portals for containers loading and unloading operations: the barges follow the dark green 'path' entering from the green arrow.

Before reaching the portals 'Scarico 1' and 'Carico 1' the 'items' of the two barges passes through the multi-servers '1_Navig.Canale IN' and '1_Accosto e Ormeggio', where they remain for times simulating respectively the navigation within the offshore terminal channel and the landing from the Mama Vessel, the approach and the mooring of the barges.

After the end of the loading phase, the couple of barges exit from the portal 'Carico 1' and waits for the arrival of first available Mama Vessel.

It passes in front of the Montesyndial onshore terminal passing through '1: Disorm e Allonta' and '1_Navig canale OUT' simulating their unmooring, moving away from the quay and navigating along the exit channel.

After the unloading in the portal 'Scarica 1', the units follow the violet 'path' to the stocking area and to the container ships, while the units destined to the barges arrive from the green 'path' entering in 'Carica 1' for the loading operation itself.

The models replicate the quay for the barges and the 'switch' object manages their occupation.

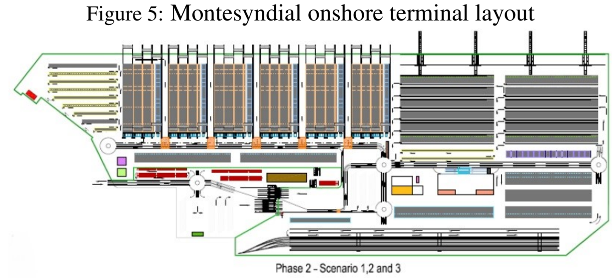
4. Modelling of onshore terminal

Figure 5 describes synthetically the onshore Montesyndial terminal.

It includes:

- Two traditional quays (right side of the terminal), where traffic of small container feeder ships, allowed to enter the lagoon, operate today
- A new area equipped with six groups of four RTG cranes dedicated to loading/unloading of barges from/to the offshore terminal.

Figure 5: Montesyndial onshore terminal layout



Source: Port Authority of Venice

In this terminal, the units arrive/continue from/to the barges depending upon landside operations, not considered in the model.

Therefore, the hypothesis is that the containers arriving from the barges feed continuously the RTG cranes.

The modelling criteria for this terminal is similar to those adopted for the onshore terminal, with the sole difference that the 'item' container are generated inside each portal dedicated to the loading of ships and barges.

In addition, the two traditional quays are included in the model to take into account the overlap of this traffic and barges movement on the seaside.

The route of the Mama Vessels between the offshore and the onshore terminal passes through Bocca di Malamocco reaching Porto San Leonardo and continuing along the coastal channel to Montesyndial area, along 18 nautical miles (figure 6).

The model takes into account the constraints due to the impossible bidirectional simultaneous navigation along the narrow coastal channel.

The maximum allowed speed is variable from 7 knots in the channel, 10 knots in the lagoon and 15 knots in the open sea out of the Bocca di Malamocco.

Once the models are finally in operation, the simulation is ready for the application to a large set of scenarios differentiated in terms of operational features and contexts for the offshore terminal.

5. Scenarios simulation and input data

Starting from the total volume of 1 million TEU/year, the scenarios are 48, varying in terms of operational fleet, frequency of arrivals of oceanic container ships, amount of loaded and unloaded TEUs.

The introduction of the following operational hypothesis and input data, most of them extracted by the analysed case studies, helps to take into account and manage this variety:

1. Container ships and barges are at first unloaded and reloaded later on.
2. RTG cranes are permanently operating on a couple of barges simultaneously;
3. The barges are always running in couples with a total capacity of 216 x 2 = 432 TEU;
4. The barges arrive and depart always full;
5. RTG and portainers have a productivity of 20 movements / hour, which, taking into account the mix of traffic in terms of container dimensions, is set to 30 TEU/h. (2 minutes/TEU);
6. Transit time in the offshore terminal is negligible due to the continuous presence of containers under the cranes;
7. The failures during the operation are not included in the model.

The considered fleet dimensions (number of Mama Vessels and barges) are in Table 1.

The intervals of arrivals of the oceanic container are variable with the total amount of ships approaching the offshore terminal, which is here set to values of 75, 100, 125, 150, 175 and 200 ships/year.

This difference reflects the ordinary variation of TEU/ship, which decreases from 13,200 to 5,000.

The correspondence between ships traffic and number of TEU per ship is in Table 2.

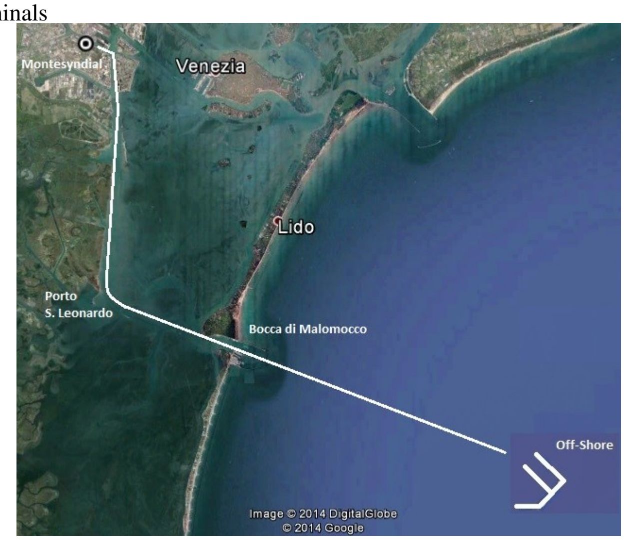
Table 1: Combinations between number of Mama Vessels and number of barges

NM[(a)]	NB[(b)]
1	4
2	4
2	6
2	8
3	6
3	8
3	10
4	10

Source: Authors
Where:
a = Number of Mama Vessel
b = Number of barges

The combination of data in Tables 1 and 2 generated 48 scenarios.

Figure 6: Route through the lagoon between onshore and offshore terminals



Source: Authors

Table 2: Combinations between number of Mama Vessels and number of barges

Ships/Year	Intervals between arrivals	Number of TEU/ Ship
75	4 days + 23 h	13,200
100	3 days + 15 h	10,000
125	2 days + 23 h	8,000
150	2 days + 11 h	6,600
175	2 days	5,800
200	1 day + 20 h	5,000

Source: Authors

6. Analysis of output data

The analysis is concentrated on the following functional features and related Key Performance Indicators (KPI), selected among those applied in many other studies (Arnold and Rall, 1998; Ballis and Abacoumkin, 1996; Malavasi et al., 2006; Marinacci et al., 2008).

1. Average TEU handling time: from the unloading from ship to the arrival to onshore terminal;
2. Average time for container ship handling: from the unloading of first container to the loading of last one;
3. Average time for handling two barges: from the loading of first container to the unloading of last one;
4. Average time for TEU handling;
5. Average waiting time of the Mama Vessel: from the unloading of a couple of barges to the loading of following couple.

Figure 7 shows the time for handling one TEU: fleets including four barges in combination with one or two Mama Vessels are not ensuring short transfer time.

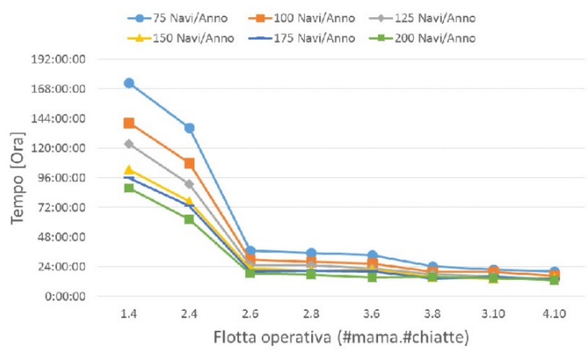
This is mainly due to the lack of capacity of operational fleet to handle the unit disembarked from the oceanic ships to the offshore terminal, which will stay in the stocking area of this terminal.

The solution is the increase of the number of barges, starting from the combination of two Mama Vessels with six barges, which allows the reduction of the average time for handling a TEU to 24 hours.

Figure 8 shows the times for handling one ship.

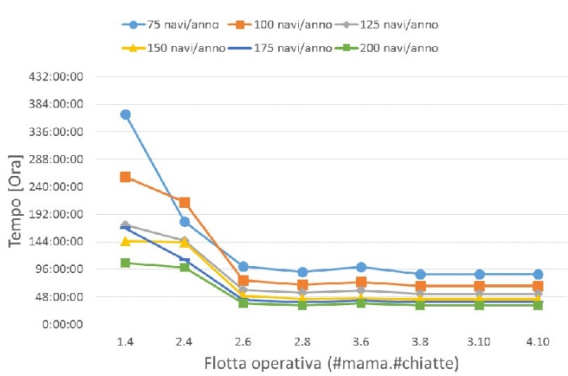
In this case, the fleet including four barges and one or two Mama Vessels is not enough for handling effectively a container ship, mainly due to the specular problem: the impossibility to feed continuously the offshore terminal with an amount of container enough to load the container ship, as soon as the stocking area is empty.

Figure 7: Diagram representing the average time for the handling of one TEU



Source: Authors

Figure 8: Average time to handle (unloading + re-loading) a container ship



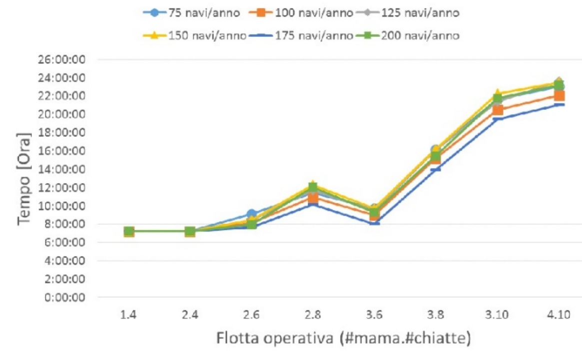
Source: Authors

All the combinations including a minimum of two Mama Vessels and six barges ensure the continuity of loading operation, with an almost stable average time for handling the container ship.

The results in figure 9 shows the effect of handling a couple of barges in the offshore terminal.

The average time is increasing dramatically when dimension of the fleet is over three Mama Vessels and six barges, mainly due to the increased waiting time of this large fleet between two arrivals of container ships, taking into account that the average time for unloading and re-loading a couple of barges (432 TEU) is 7 hours and 12 minutes.

Figure 9: Average time to handle (unloading + re-loading) a couple of barges



Source: Authors

The study of the daily operational capacity (Figure 10) shows that a minimum composition of two barges and six Mama Vessels is required to ensure the maximum value of around 2800 TEU/day.

Finally, the waiting time of a Mama Vessel before boarding the couple of barges is an indicator of the flexibility of the fleet involved in the operation and the existence of dead time between unloading and re-loading of barges.

According to Figure 11, the only configuration capable to avoid waiting time is that including one Mama Vessel and four barges, nevertheless, it is a solution without flexibility. With two Mama Vessels and four barges, the waiting time is set to zero for the barges but increases relevantly for the Mama Vessel.

Over two Mama Vessel and six barges, the average time of the Mama Vessels increases due to the lack of operation in the terminal between the arrivals of two container ships, in addition to the progressive decrease of interval between arrivals of two consecutive Mama Vessels in the offshore terminal.

It requires the increase of the waiting time due to the need to complete loading and unloading of barges.

7. Conclusions

In order to determine the optimal dimension of the fleet, the study is concentrated on three indicators only: average time for TEU handling, average waiting time of the Mama Vessels and daily operational capacity.

They are parameters measuring the operational and functional effectiveness of the system by varying the fleet components.

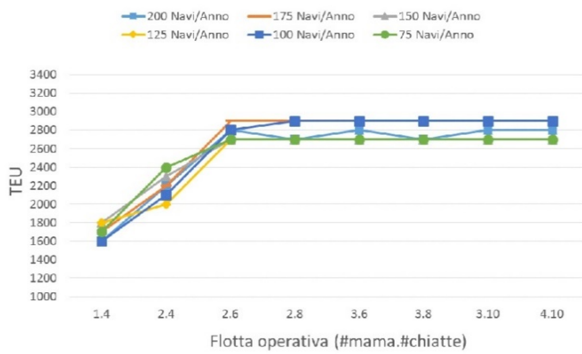
Figure 12 shows the calculated trends for the indicators above, to allow a comparison among the various fleet solutions.

Particularly, the average time to handle a unit is a relevant indicator for the comparison among ports, mainly in terms of their attractiveness for ship-owners.

Indeed, a too long time to handle a unit elapses also the total transport time, which increases the cost for customers.

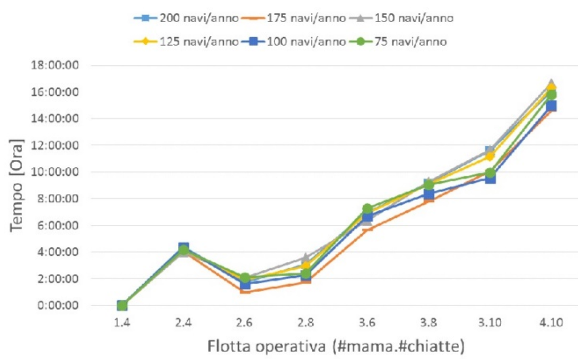
A long waiting time of the Mama Vessel highlights the fleet unproductivity, measured by the entity of the dead times, and,

Figure 10: Operational capacity [TEU/day]



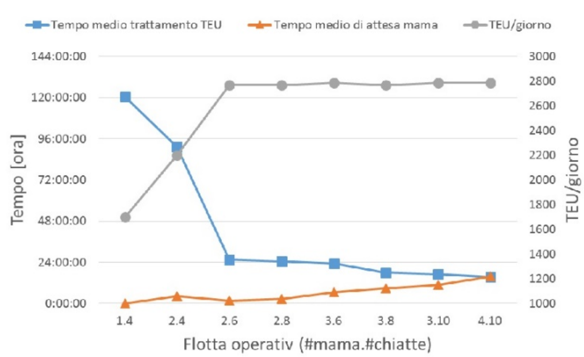
Source: Authors

Figure 11: Average waiting time of the Mama Vessels



Source: Authors

Figure 12: Trends of key decisional indicators



Source: Authors

consequently the incidence of capital personnel costs.

Finally, the daily capacity should reach the target traffic of 2800 TEU/day - 1 million TEU/year.

All the elements to determine the ideal dimension of the operative fleet are in Figure 12:

- Fleets with less than 2 Mama Vessels and 4 barges are not able to produce the standard requirement of 2800 TEU/day;
- Fleets with more than 2 Mama Vessels and 6 barges create a positive decrease of the average time per TEU but, simultaneously, a negative increase of the waiting time for the Mama Vessels, with the positive secondary effect to increase punctuality.

Therefore, the ideal situation is a trade-off between the values above.

The input data today do not include time deviations due to accidental incidents, but the model is able to work also with distributions of delays and perturbed traffic.

Nevertheless, the proposed model demonstrated to be a valid and effective tool under regime conditions.

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