



# Intermodal terminal simulation for operations management

Alessandro Baldassarra<sup>1\*</sup>, Stefano Impastato<sup>1\*</sup>, Stefano Ricci<sup>1\*</sup>

<sup>1</sup> “SAPIENZA” University of Rome – DITS Transport Area

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## Abstract

A freight terminal is a key node in a transportation network and the transit time of containers through this terminal represents one of the most relevant bottleneck in logistic chains.

The system performance reduction and the corresponding increase of transit time is often due to the increase of the freight flow without a corresponding increase of stacking and handling capacity.

For this purpose it was decided to approach the problem by a discrete event simulation model, in order to reproduce the activities carried out inside an intermodal terminal, to calculate the total transit time and to identify the bottlenecks.

The transit time of a cargo unit in a terminal is the summation of times required for the development of each phase of the process (waiting time + operational time).

Therefore, the first step was the identification of the main activities and the analysis of waiting and operational phases, in order to quantify the times of each phase.

For modelling the software Planimate® was used. Planimate® allows the simulation of a process as a set of discrete events, in series or in parallel, through the use of hierarchical networks.

In order to optimise handling operations on containers, different scenarios were simulated with various fleets of trailers and front cranes to investigate the corresponding variations of performance indicators.

For the application of the model an Italian case study was chosen: the container terminal inside the harbour of Livorno (Darsena Toscana Terminal).

*Keywords:* Intermodal terminal; Simulation; Freight; Logistic; Management.

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## 1. Introduction

Railway freight terminals play a key role within multimodal transport and the transit time through these terminals represents one of the most relevant bottlenecks in logistic chains.

A freight terminal is a basic node in a transportation network, where thousands of daily decisions are taken to manage relevant flows of containers.

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\* Corresponding authors: A. Baldassarra (alessandro.baldassarra@uniroma1.it), S. Impastato (stefano.impastato@uniroma1.it), S. Ricci (stefano.ricci@uniroma1.it)

To predict the traffic evolution inside and nearby a terminal is, moreover, important in order to manage the required flows and the available areas.

One of the main causes of the reduction of system performance is, in fact, the increase of the freight flow, without a corresponding increase of stacking and handling capacity. The consequences are the congestion of terminal flows and the corresponding increase of transit time.

In the research a decision support system for the management of an intermodal container terminal is presented and a simulation tool has been developed.

In the last years the role of simulation has become of high relevance in managing and planning such terminal's activities. For this purpose it was decided to approach the problem by a simulation model capable of reproducing the activities carried out inside an intermodal terminal.

A discrete event simulation tool has been implemented with the aim to calculate the total transit time and to identify the bottlenecks. It allows to reduce the probability of system performances reduction through optimisation of container unloading and handling operations. The simulation has been applied to Darsena Toscana Terminal in Livorno harbour.

This work is the follow-up of the activities developed by the research team devoted to the functional analysis and the modelling of intermodal terminals.

## **2. Intermodal terminal operation**

An important parameter for performance evaluation of an intermodal terminal is the transit time of a cargo unit, calculated as the lapse between the arrival of a single transport unit at the terminal, from an outside transport infrastructure, and the departure towards a different transport system.

The transit time of a cargo unit in a terminal is the summation of times required for the development of each phase of the process, in which a phase is normally composed by a waiting time and an operational time.

For the modelling of handling times, the activities related to the transfer of cargo units from the ship to the stacking area are analysed.

The first step was the identification of the main activities and the analysis of waiting and operational phases, in order to formalise the times of each phase:

- check-in operations on ship arrival;
- waiting for 1st transfer (transshipment – stocking area);
- 1st transfer (transshipment – stocking area).

A simulation model reproduced ship arrival and the related check-in operations:

- a) unloading and loading of container by port crane from ship to trailer;
- b) transfer of loaded trailer (from transshipment area to stocking area);
- c) downloading of trailer by reach stacker and drop off on stocking area.

Two different assumptions were made for trailer movement:

- 1) planning of routes to send the trailer where its service is required (port-crane without trailer queue): if a trailer arrives under a busy crane it is sent to the first free crane;

- 2) no operational traffic rules: the trailer is moving under the port crane and stops only where a queue is not present only, otherwise it moves to the next port-crane and so on.

One more assumptions was made about container distribution on the different areas of the ship (bow, central and stern):

- 1) fixed container distribution (equally splitted);
- 2) random container distribution.

The assumptions of random distribution of containers reproduces the real conditions of possible different load configurations.

### **3. Model structure description**

The software Planimate® was used to build the model. Planimate® allows the simulation of a process as a set of discrete events, in series or in parallel, by means of hierarchical networks.

The model for container handling in a maritime terminal is organised in two completely separate networks (“Intermodal terminal layout” and “Stocking area”). “Stocking area” is actually a subnet of “Intermodal terminal layout”. It is treated differently from the other subnets due to the complexity of the operations performed within the stocking area.

The top level network (“Intermodal terminal layout”) reproduces the system layout (Figure 1), including the hierarchical structure of the model, the stocking areas (the “Stocking area” subnet) and the quays. The paths followed by the handling vehicles (trailers) are also reproduced. It is described in 3.1. The “Stocking area” subnet is described in 3.2.

#### *3.1 Intermodal terminal layout*

A number of main phases were identified in order to simulate transfer activities. Each phase corresponds to a subnet. They are shown here in sequence:

- 1) ship arrival;
- 2) check-in;
- 3) trailer arrival;
- 4) port-crane activities;
- 5) trailer handling (to stocking area);
- 6) stocking area operation (including reach stacker operation);
- 7) exit of unloaded trailer from stocking area and trip back to crane.

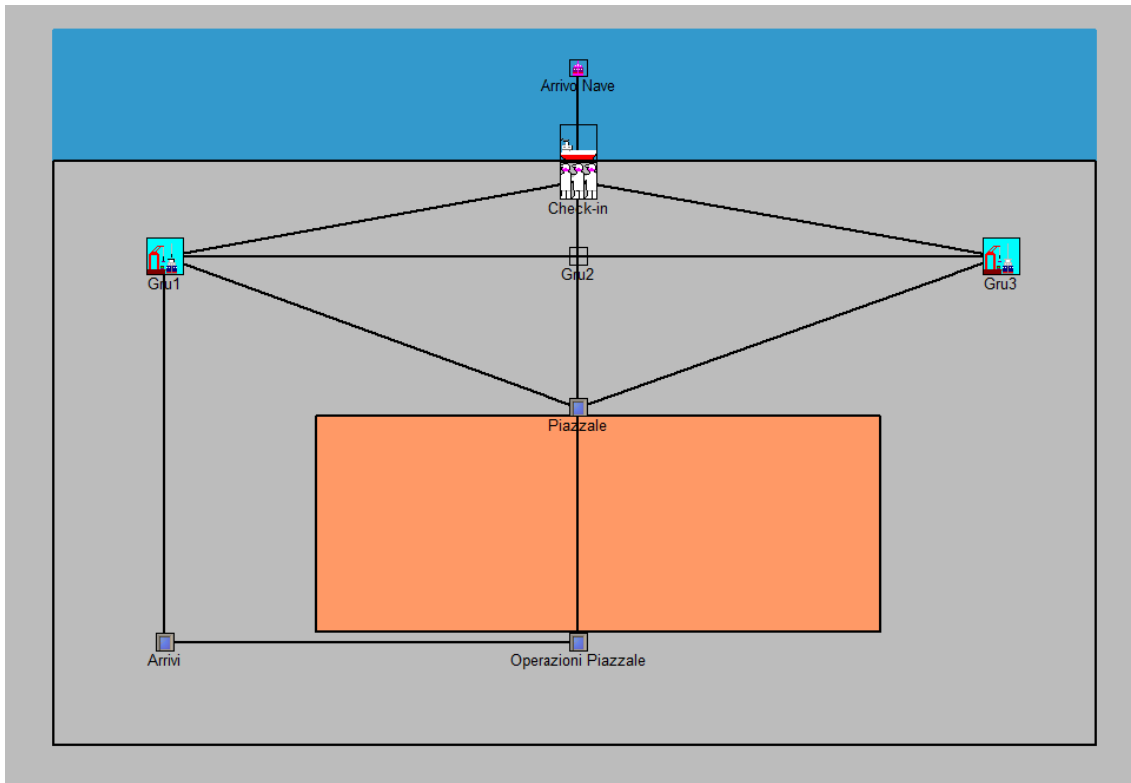


Figure 1: Terminal Layout.

A subnet was designed for each main phase. Each subnet reproduces the sequence of operations required for the implementation of the specific transshipment activity.

The general flowchart of the sequence of phases from ship arrival to storage of containers into the stocking area is shown in Figure 2.

The flowchart, in Figure 2, also shows the main assumptions and choices on the different variables and operational requirements considered for the development of the model. These assumptions regard:

- ship arrival timetable;
- ship load distribution (e.g. bow, central and stern);
- operational behaviour of the crane when the trailer is not under it;
- operational traffic rules of the trailers;
- trailer arrival frequency under the cranes;
- crane operational time;
- trailer handling time to the stocking area;
- travelling time of the trailer to the meeting point with the reach stackers;
- travelling time of the reach stackers to the meeting point with the loaded trailer.

The main operations of the subnets are detailed hereafter.

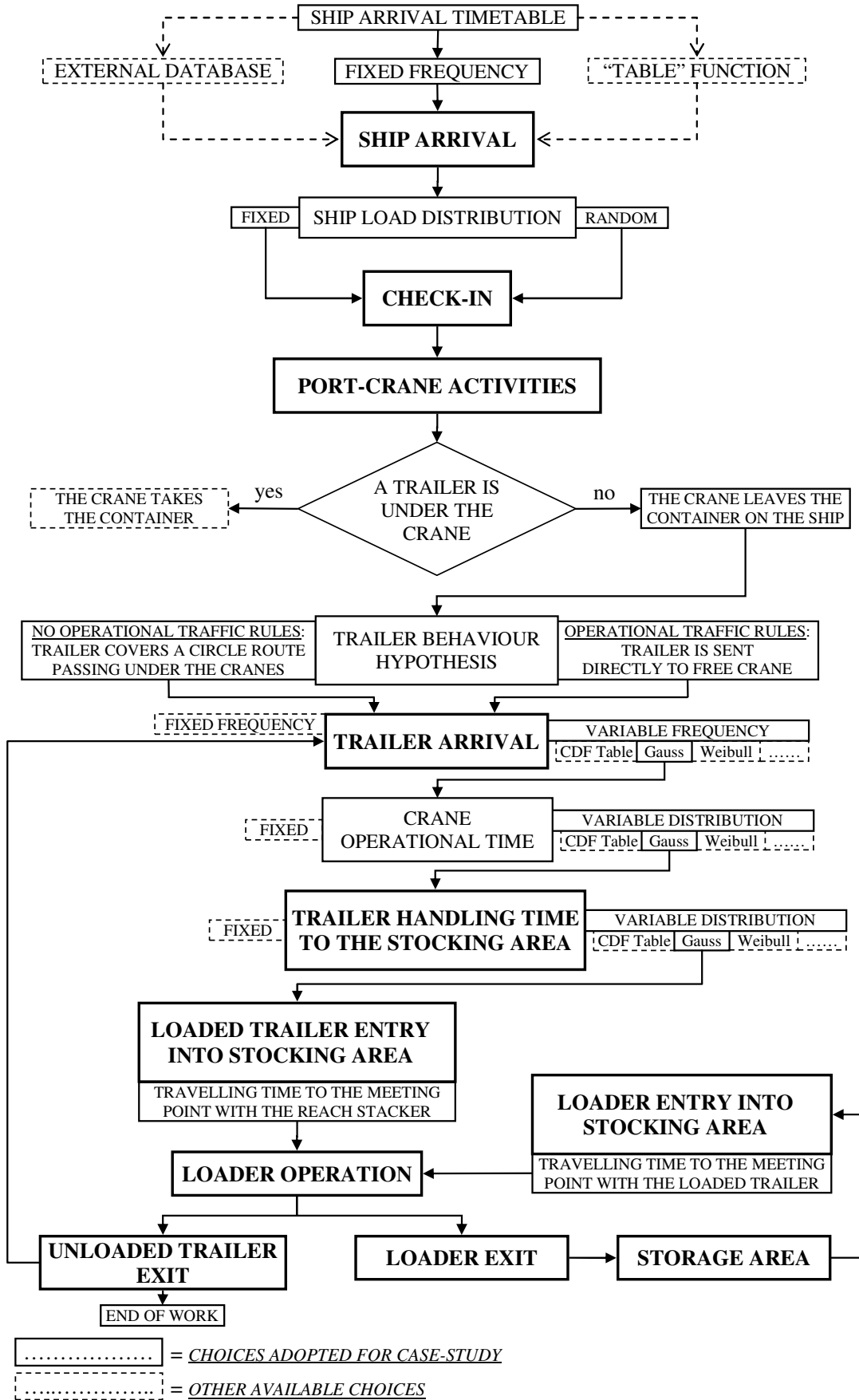


Figure 2: Sequence of main phases.

### 3.1.1 Ship arrival

The "ship arrival" subnet reproduces the operations concerning the phases of:

- approach of the ship to the port mouth;
- access into channel;
- evolution;
- quay approach;
- anchorage.

In particular, the time each phase takes is calculated considering movement and rotation (evolution phase) speed of the ship and the distance travelled, using the attributes of ship object and the characteristics of its route from the mouth approach phase to the anchorage phase.

Moreover Planimate® allows to specify a timetable both as linked to an external database or with the "table" function inside the structure of the program.

### 3.1.2 Check-in

The "check-in" subnet (Figure 3) reproduces check-in operations and the load conditions of the ship. This subnet reproduces the different possible distributions of ship load by identifying the number of containers located in different areas of the ship (e.g. bow, central and stern). It is possible to choose a fixed or variable distribution of ship load. Generally the load partitioning is different from ship to ship and therefore the assumption of a random distribution is the more suitable. It is assumed that an unloading crane is available in each of three ship areas.

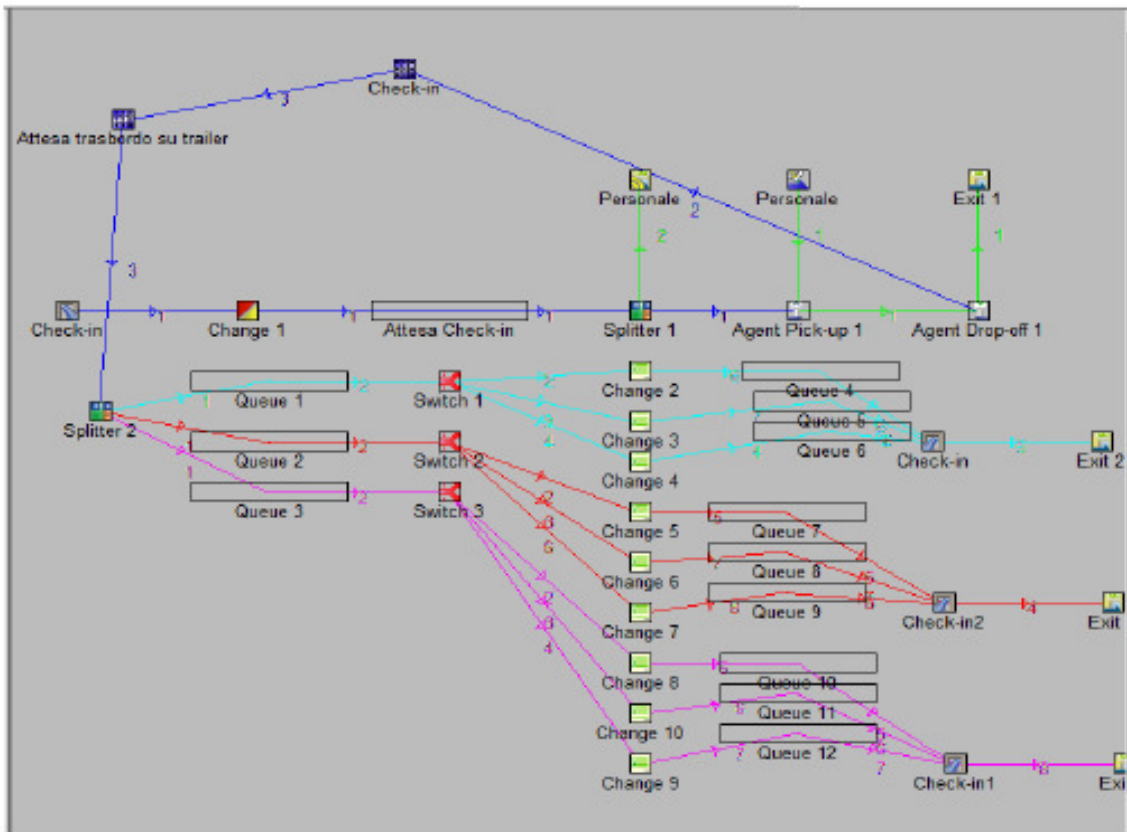


Figure 3: Check-in subnet.

### 3.1.3 Trailer arrivals

The subnet "trailer arrivals" simulates the apportionment, under the cranes, of the trailers for the transfer of containers from the quay to the stocking area, with a periodic frequency governed by variable or constant distributions.

In the case study a Gaussian distribution was used.

### 3.1.4 Port-crane activities

In "port-crane activities" subnets, the unloading operations of containers from the ship by the crane, the arrival of the trailer and the transfer of the containers from cranes to the trailer leaving the stocking area are simulated.

It was established that, if the trailer is not present under the crane, the container is waiting on the ship.

The subnet is structured in such a way that when a crane has completed the unloading of containers of its area, the trailers are sent to the crane still requiring transfer of containers.

In this subnet it is possible to account for two different trailer behaviours:

- the trailer covers a circle route passing under the first, second and third crane and stopping when it finds a free crane;
- the trailer is sent directly to a free crane.

The handling of the trailer from crane to stocking area is also reproduced.

The operational times of cranes and trailers are assigned a probabilistic distribution (Gaussian).

### 3.2 Stocking area

The "Stocking area" subnet is also a subnet of the top level network ("Intermodal terminal layout", see 3.1). It represents the stocking area, with the assumptions that the handling operations take place in a central area and are guaranteed by 5 subnets (figure 4):

- 1) loaded trailer entry;
- 2) loader entry;
- 3) loader operation;
- 4) unloaded trailer exit;
- 5) loader exit.

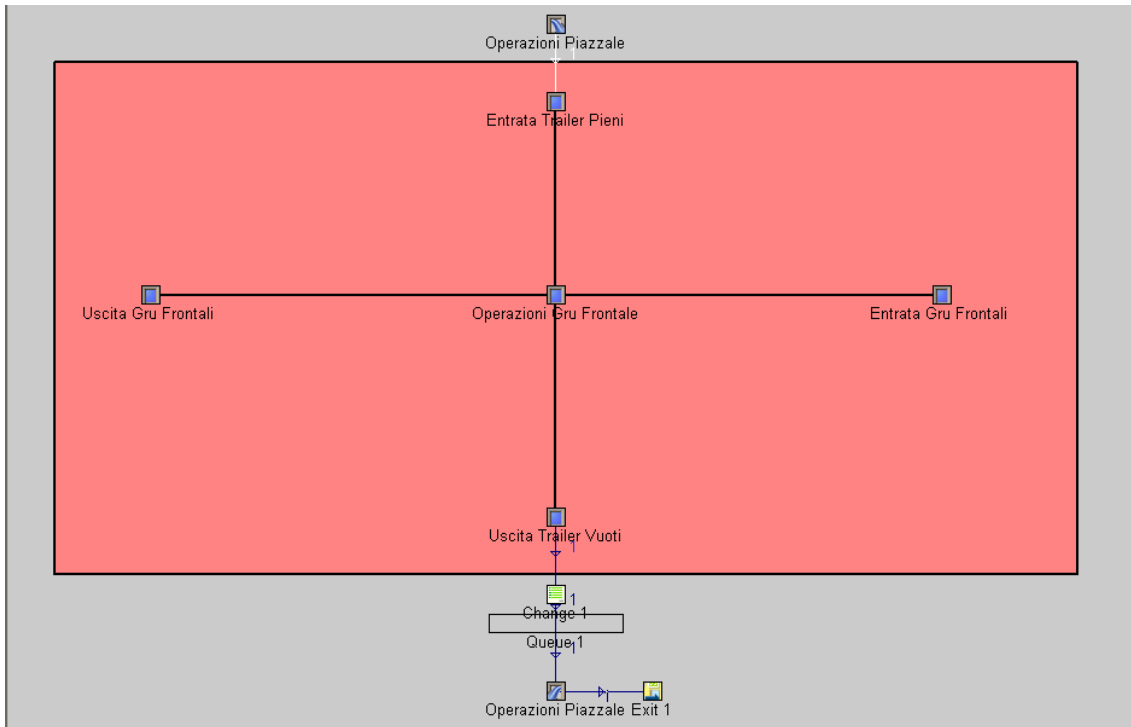


Figure 4: Stocking area layout.

This subnet represents the operations performed by the trailers and the reach stackers inside the stocking area.

The reach stackers pick up the container from the trailer, unload it on the stocking area and run back to a starting position, while the unloaded trailer leaves the stocking area following a path towards the ship crane.

A critical factor for simulated operations is the stocking area size, important for the calculation of travelling time of trailers and reach stackers inside this area.

### 3.2.1 Loaded trailer entry

The subnet "loaded trailer entry" simulates the entry in the stocking area of loaded trailers and the approach to the meeting point with the reach stackers (represented by the subnet "loader operation") situated in the centre of the stocking area.

The mean value of travelling time is calculated once the average speed of longitudinal movement of the trailer (about 20 km/h) and its average position in the middle of the stocking area are known.

### 3.2.2 Front crane entry

Similarly, in the "front crane entry" subnet the entry in the stocking area of the reach stackers and their approach to the meeting point with the trailers is reproduced.

### 3.2.3 Loader operation

The "loader operation" net (Figure 5) simulates the activities within the stocking area: it includes the interactions between the loaded trailer and the reach stacker.



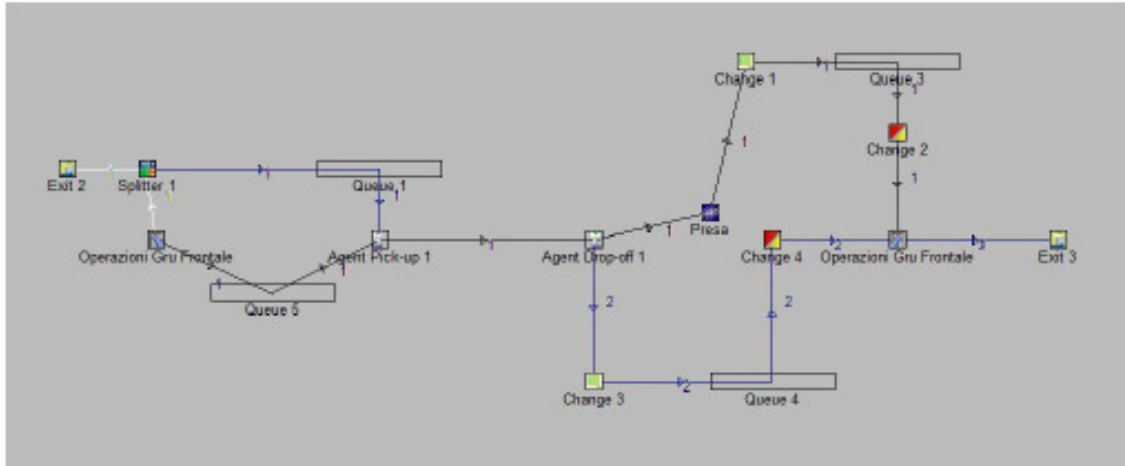


Figure 5: Loader operation subnet.

The loaded trailer waits within the stocking area for the arrival of the reach stacker assigned to it. Once unloaded the trailer moves towards the exit of the stocking area.

### 3.2.4 Unloaded trailer exit

In the "unloaded trailer exit" subnet the unloaded trailers are driven outside the stocking area and sent to the "trailer arrivals" subnet (terminal layout), so that the total number of working trailers is fixed.

### 3.2.5 Loader exit

Finally the "loader exit" subnet reproduces the unloading of the container by reach stackers, highlighted by the change of the icon from load to unload, and the link to the "loaders entry" for movements simulations.

The containers in the stocking areas will wait to be moved again towards their destination by a second transport system.

## 3.3 Simulated scenario

To improve the knowledge of the potential of the model and to optimise container unloading and handling operations three types of scenarios were simulated.

*Scenario 1 – TRY & FDC:* with operational traffic rules and fixed distribution of containers on the ship and quay cranes;

*Scenario 2 – TRN & RDC:* without operational traffic rules and random distribution of containers on the ship and quay cranes;

*Scenario 3 – TRY & RDC:* with operational traffic rules and random distribution of containers on the ship and quay cranes.

Moreover, for each scenario, the number of trailers and front cranes were changed to investigate the corresponding performances variations.

#### 4. Case study description and results

The container terminal located in the Italian harbour of Livorno (Darsena Toscana Terminal) (Figure 6) was chosen, as a case study, for the application of the model. It is a multipurpose terminal capable of handling all types of cargo ships and passenger traffic. Livorno harbour's basin extends over 1.600.000 square meters, while the surface on land is equal to 2.500.000 square meters, 800.000 inside the customs gates. It offers about 12.000 meters of quay with 90 dockings, with a depth of up to - 13 meters. The extension of the stocking area is 272.000 square meters, and the terminal is equipped with a total of 36 trailers, 16 loaders and 8 port cranes.

In addition to warehouses and equipped stocking areas, there are three rail yards inside the harbour with 60 km of tracks.



Figure 6: Darsena Toscana Terminal.

Livorno was selected due to its foreseen relevant increase of freight traffic and the continuous evolution of its harbour, with the creation of a new basin that will triple the current terminal activities, providing the opportunity to host last-generation ships.

The simulated unloading times are reported in Table 1, evaluated assuming the use of operational traffic rules and fixed distribution of containers on the ship. The columns indicate the values of time obtained with different simulations for variable fleets of trailers and reach stackers. In the last column the calculated average unloading time is shown.

A first analysis of the values obtained through the simulations (Table 1) shows that with the increase of the reach-stacker fleet, the variation of the unloading time allows to identify a dimension of the reach-stacker fleet (in our case 8 units) beyond with the decrease of the total unloading time becomes negligible.

In fact for a fixed number of 25 trailers, with the operation of 6 reach stackers the average unloading time is 11:27 hours, in comparison to 9:56 hours calculated with 8 reach stackers, with a reduction of 1:31 hours (-13%). The corresponding time reduction from 8 to 12 reach stackers is only 9 minutes (-1,5%).

Table 1: Unloading time with the operational traffic rules and fixed distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:29	11:35	11:20	11:29	11:26	11:26	11:27
	8	10:06	9:49	9:52	9:45	10:03	10:04	9:56
	12	9:50	9:40	10:00	10:03	9:35	9:36	9:47
15	6	11:36	11:12	11:37	11:25	11:41	11:40	11:31
	8	10:30	10:40	11:05	10:45	11:10	11:11	10:53
	12	10:50	10:40	10:48	10:45	11:01	11:00	10:50

Moreover Table 1 shows that the increase of trailer numbers, for a fixed number of reach stackers, produces a reduction of total unloading time of containers higher than the case in which the number of reach stackers is increased.

The simulation was also implemented with and without operational traffic rules and random distribution of containers.

The results are reported in Tables 2 and 3.

Table 2: Unloading time without operational traffic rules and random distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:41	11:33	11:37	11:35	11:39	11:40	11:37
	8	10:25	10:20	10:26	10:23	10:28	10:30	10:25
	12	10:15	10:22	10:20	10:19	10:18	10:18	10:18
15	6	11:51	11:44	11:49	11:47	11:46	11:46	11:47
	8	10:40	10:45	10:44	10:43	10:43	10:43	10:43
	12	10:29	10:40	10:39	10:33	10:32	10:32	10:34

Table 3: Unloading time with operational traffic rules and random distribution of containers.

Trailers	Reach stackers	Unloading time [hours]						
		#1	#2	#3	#4	#5	#6	Average
25	6	11:13	11:20	11:18	11:16	11:16	11:16	11:16
	8	10:15	10:18	10:17	10:12	10:12	10:12	10:14
	12	10:11	10:00	10:07	10:04	10:04	10:04	10:05
15	6	11:35	11:28	11:39	11:26	11:31	11:30	11:31
	8	10:39	10:32	10:36	10:30	10:35	10:34	10:34
	12	10:32	10:29	10:21	10:24	10:28	10:27	10:26

The results of the simulations represented in Tables 1, 2 and 3 confirm that the use of operational traffic rules provides benefits especially when the number of trailers is high.

The corresponding average unloading times are represented in Figure 7 and 8 respectively with 25 and 15 trailers.

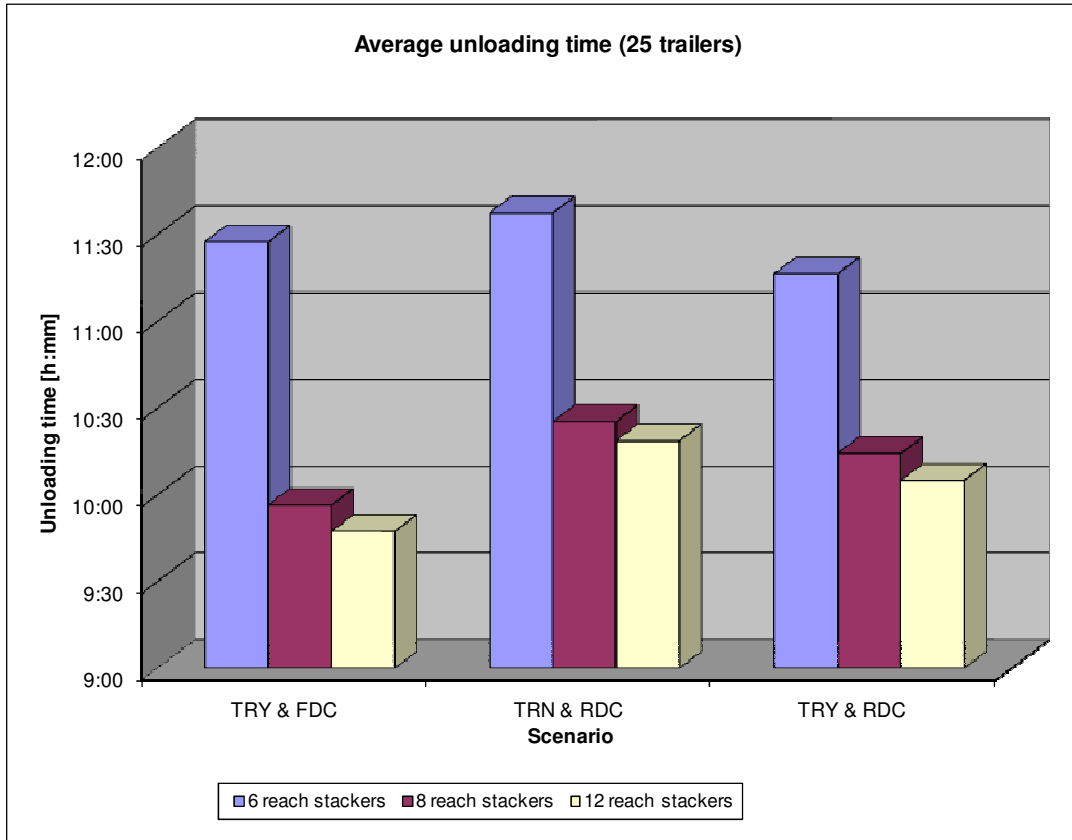


Figure 7: Average unloading time with 25 trailers.

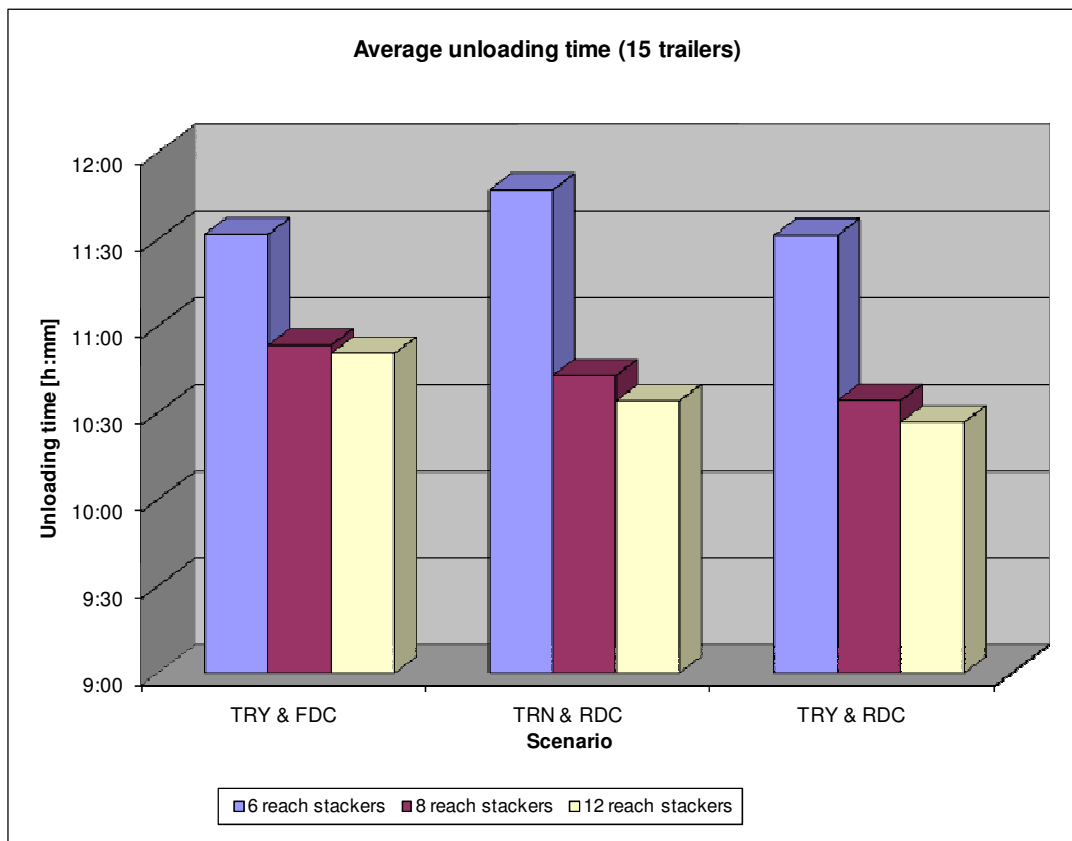


Figure 8: Average unloading time with 15 trailers.

## 5. Validation

The simulation results were compared for validation with data provided by the Port Authority of Livorno and with data obtained with an analytical model (Marinacci C., Quattrini A., Ricci S. - 2008).

Results of the comparison are shown in Table 4.

Table 4: Comparison results.

	CONTAINERS [n°]	PORT-CRANES [n°]	TRAILERS [n°]	REACH STACKERS [n°]	TOTAL TIME [hh.mm]	AVERAGE UNIT TIME [min]
LIVORNO PORT AUTHORITY	566	8 (available)	36 (available)	16 (available)	17:17	110
ANALYTIC MODEL	566	2	included in the average handling time	included in the average handling time	16:22	104
SIMULATION MODEL	566	3	15	6	11.31 ÷ 11.47	73 ÷ 75
			15	8	10.34 ÷ 10.53	67 ÷ 69
			15	12	10.26 ÷ 10.50	66 ÷ 69
			25	6	11.16 ÷ 11.37	72 ÷ 74
			25	8	9.56 ÷ 10.25	63 ÷ 66
			25	12	9.47 ÷ 10.18	62 ÷ 65

The mean value of the total time for unloading and handling of containers, calculated on the basis of data provided by Livorno Port Authority, is 17:17h.

With the analytic model, in which 2 port-cranes are used, the result is 16:22h, while the value obtained with the simulation model, in which 3 port-cranes are used, is variable between 9:47h and 11:47h.

Also in this case the deviations are limited because the total availability includes the reserve units for maintenance and additional services.

Total time, and single unit average times are lower by about 30%, but it is well justified by the use of 2 instead 3 port-cranes in the daily operation.

Therefore these data confirm the global response of simulation model results.

The fleets dimensions are comparable with those managed by the Livorno Port Authority (the analytical model does not calculate these parameters).

## 6. Conclusions

In coherence with the initial objective it has been built up and partially validated a simulation model based on the Planimate® software.

For the analysed case study the most relevant results are that:

- 1) over a certain reach stackers fleet dimension the decrease of the container unloading times becomes negligible;
- 2) the system is more sensible to the amount of working trailers than to the amount of reach stackers.

Moreover, the results of simulations confirm that the use of operational traffic rules provides benefits especially when are increased the number of trailers.

Further developments of the research will be devoted to identify the most effective application fields for the various model typologies.

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