INTERMODEL EU

Simulation using Building Information Modelling Methodology of Multimodal, Multipurpose and Multiproduct Freight Railway Terminal Infrastructures

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D5.4 Operational simulation. Simulation model of the second real-life case

Authors	**Ir. Paweł Kołodziejczyk (Macomi)** **Dr.ir. Cornelis Versteegt (Macomi)**
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Executive Summary

The INTERMODEL EU project aims at developing an integrated decision support platform to assess different pilot cases of multimodal, multiproduct and multipurpose freight rail terminals in terms of a wide range of Key Performance Indicators (KPIs) and Key Result Indicators (KRIs). By integrating simulation modules of the terminal operation and its relationship to the hinterland into a BIM design, both the throughput time and the quality of the decision-making will be improved.

The main objective of WP5 is to build a simulation based decision support environment that supports in optimizing the design process and the operational performance of intermodal freight terminals. To reach this objective a data model was developed, which describes all relevant data used in the simulation component library, see Deliverable 5.1 (Versteegt & Kołodziejczyk, 2017). Furthermore, an ontology and conceptual model were developed, describing the inner working of the library of simulation components, their hierarchy and interrelationships, see Deliverable 5.2 (Versteegt & Kołodziejczyk, 2017). This library is developed into an operational simulation that handles all sorts of freight terminals. The system is connected to integrated planning environment and demonstrated in two pilot case studies.

The goal of this document is to describe the activities connected to the Deliverable 5.4 – operational simulation of the La Spezia Container Terminal case, and is a written testimonial to the presented demonstrator for milestone MS10 (Second demonstration of the library of simulation components).

This document contains information on the design decisions made for simulation model components and their combination for the case study demonstrator, especially concentrating on the input data and delivered results, as well as validation efforts for the model, fulfilling the objectives for milestones MS12 (Results second case) and MS13 (Parameters of BIM virtual design of terminal checked against real terminal operational and maintenance performance).

We begin with an overview of the simulation model build-up, describing developed components and used methodology, consistent with the previously reported *D5.1 Data Model* and *D5.2 Ontology and Conceptual Modelling*, also basing the results on *D3.1 State of the art and description of KPI and KRI of Terminals, Hinterland Mobility and Rail*

Network. Then input structure is described, i.e. how the layout data from the BIM model is imported to the simulation, what parameter inputs are used for resources and other control logic, and how arrivals and volumes are created.

Then, a vital part is model validation. The joint efforts in that area are described, divided into validation of the provided data and expert validation of the modelling work. Following that, some details are given on the model run, the interface and the animation, as important factors of the simulation environment for the future integrated modelling tool prototype.

Finally, we go into details of the model results, describing the Key Performance Indicators (KPIs), logs, as well as result analysis and conclusions. The output data is divided into categories related to terminal itself and its resources, the stack, container handling equipment, and arriving vehicles. Some of the results, especially those of a confidential nature, have not been published in this report or have been altered.

On behalf of authors,

Paweł Kołodziejczyk
Macomi
The Netherlands

Table of contents

List of Figures

List of Tables

1. Introduction

1.1. Scope

There are many tasks needed to be performed before a terminal operational simulation model can be created, consolidated in an integrated planning tool, then validated and tested in a case study. This document concentrates on the efforts to bring it about, divided into functional areas of the investigation. In particular, it concerns the following milestones:

- MS10 – Second demonstration of the library simulation components
- MS12 – Results second case
- MS13 – Parameters of BIM virtual design checked against real terminal operational and maintenance performance

And the following deliverables:

- D5.4 – Operational simulation. Simulation model of the second real-life case – Demonstrator (public).

This document is complementary to one presented for the Deliverable 5.3 and Milestone 11, containing unique information on the La Spezia Container Terminal case. Yet, in order for the document to be a standalone entity, some information from D5.3 is repeated.

Due to the document's public nature, some sensitive data is not shared. This should in no case affect its understanding and usefulness.

1.2. Audience

This document is mainly written for the participants of the H2020 INTERMODEL EU project. Nonetheless, the authors deem the content useful for any party interested in integrated container terminal design and especially simulation of it. Hence a public nature of the document.

1.3. Glossary and Abbreviations

Table I. Definitions and abbreviations

Term	Abbrev.	Description
Actual time of arrival	ATA	The time a MoT actually arrives at a location.
Actual time of departure	ATD	The time a MoT actually departs from a location.
Anchorage point	AP	A place where vessels can anchor safely before the entry to a port.

Animation	-	A visualisation of the events that occur in the system that is being simulated over time.
Automated Guided Vehicle	**AGV**	Unmanned horizontal transporter controlled by the TOS or Equipment Control System.
Automated Rail Mounted Gantry	**ARMG**	See RMG / ASC.
Automated Stacking Crane	**ASC**	A cumulative name for automated, unmanned cranes servicing container stacks, typically an ARMG.
Baseline scenario	-	Also called Base Case. A scenario in which the analysis is done based on the current way of working in a place, without changes. This scenario serves as a comparison and starting point to other scenarios
Bayplan/stowage plan occupied and empty locations message	**BAPLIE**	Plan of exact positions of the cargo on board both for a situation at a given time and in a near future (i.e. after handling).
Beam	-	Width of a ship measured in either meters or TEU.
Barge	-	A flat-bottomed boat typically, though not always, without own propulsion used to transport heavy goods mainly on rivers and canals.
Barge crane	**BC**	Crane dedicated to servicing barges and small feeders.
Berth		A place alongside a quay in which a vessel is moored.
Berthing schedule		A schedule providing information on the estimated arrivals and departures of vessels per berth.
Bill of landing	-	A document that establishes the detailed list of vessels cargo between a shipper and a transportation company. It serves as a document of title, a confirmation of carriage, and a receipt for goods.
Capacity (handling)	-	The number of containers or goods that can be handled by equipment in a certain time window.
Capacity (storage)	-	The amount of goods that can be stored in a particular place (stack) or vehicle at a given moment. Can be expressed in volume, mass, units, etc.
Container Handling Equipment	**CHE**	Any equipment used for lifting, transporting and/or supporting the servicing of containers.
Control (layer)	-	All elements in the simulation tool that represent control over equipment, means of transport and infrastructure.
Corner casting	-	Part of a shipping container used together with twist-lock to secure cargo during transportation.
Customs	-	Customs in an authority responsible for collecting tariffs and controlling the flow of goods into and out of a country. Customs also inspects cargo in search for contraband.
Data	-	A set of values of qualitative and/or quantitative variables. Pieces of data are individual pieces of information.
Dashboard	-	A set of KPIs joined together in a single overview screen. This way a user gets the whole overview of the performance aspect in one view.

Data model	-	An abstract model that organizes elements of data and standardizes how they relate to one another and to properties of the real-world entities.
Distribution	-	Mathematical description of a random phenomenon in terms of the probabilities of events. The PSP platform contains many of the distribution used in simulation (normal, uniform, etc.).
Demurrage	-	A penalty fee for delaying the carrier's equipment beyond the allowed free time.
Deep sea	**DS**	Pertaining to areas or activities not in close proximity to a port, but farther out in the sea.
Draft	-	Or draught. Depth of a vessel remaining under water.
Dry bulk	-	Loose cargo transported in bulk carriers, e.g. coal, ores, fertilizers.
Dry port	-	Or inland port. Intermodal terminal directly connected by road or rail to a seaport and operating as a transhipment base for other hinterland destinations.
Dwell Time		The time goods (or containers) stay or are stored at the terminal.
Empty Container	**MT**	Container without any cargo in it.
Empty yard	-	Dedicated yard to store empty containers. Can be both internal at the terminal or external.
Empty handler	-	A large forklift for stacking empty containers.
Equipment Control System	**ECS**	Middleware that provides container handling equipment coordination and control as well as a single interface to TOS.
Estimated time of arrival	**ETA**	A measure of indication when an MoT is planned or scheduled to arrive at a particular place.
Estimated time of departure	**ETD**	Indication when an MoT is to depart from a location. Comparing estimated with actual times is a measure of scheduling performance.
Event	-	An instance when a state change in the system might occur.
Experiment	-	A number of simulation runs in which a single scenario is studied.
Forty-foot equivalent unit	**FEU**	Measure of container length equal to 2TEU, used less frequently.
Gateway	-	Point at which freight moving from one territory to another is interchanged between transportation lines.
Harbour master	-	Officer who is in charge of vessel movements, safety, security, and environmental issues within a port.
Infrastructure (layer)	-	All elements in the simulation tool that represent infrastructure (tracks, sidings, crossings, switches, areas, etc.). This will be an input from the BIM.
Inland waterway transport	**IWT**	Shipping of goods on rivers and canals, usually carried out on barges.
Inter-terminal transport	**ITT**	Inter-Terminal Transport to facilitate transport of containers between terminals in one port.

Intermodal	**-**	Movement of cargo containers interchangeably between transport modes where the equipment is compatible within the multiple systems.
Intermodal transport unit	**ITU**	Container, swap body or semi-trailer/goods road motor vehicle suitable for intermodal transport.
International Maritime Organisation	**IMO**	Specialised agency of the United Nations responsible for regulating shipping defines 9 classes of (dangerous) goods, which need special handling.
Jetty	**-**	Or pier. Structure that is perpendicular or at an angle to the shoreline to which a vessel is secured for the purpose of loading and unloading cargo.
Key performance indicator	**KPI**	Indicator that tells what to do to increase performance dramatically. They represent a set of measures focusing on those aspects of organizational performance that are the most critical for the current and future success of the organization. The KPI will be calculated on the results of the simulation model.
Knot	**kn**	Measure of ship speed, equal to one nautical mile (1,852 meters) per hour.
Land side	**LS**	Arbitrarily defined area for activities happening or areas located further away from the water. Typical land side areas/process are related to the gate (both for truck and train) and land side of the stack.
Lift-on lift off	**Lo/lo**	Cargo handling method by which vessels are loaded or unloaded by either ship or shore cranes.
Liquid bulk	**-**	Liquids that undergo commercial transportation in large volumes, ranging from petroleum products to vegetable oil or fruit juice.
Malacca-max	**-**	Maximum size of container and bulk vessels (in terms of draught) that can cross the Malacca Straits (25m). The Malacca-max reference is believed to be today the absolute maximum possible size for future container vessels (approximately 20,000 TEU).
Means of transport	**MoT**	Any vehicle that can travel or carry goods. Cumulative name for vessels, trains, vehicle and/or yard equipment
Mixed cargo	**-**	Or hybrid cargo. Two or more products carried on board one transporter.
Mobile crane	**-**	General purpose crane capable of moving on its own from one place to another.
Moor	**-**	To attach a ship to the shore.
Moves per hour	**Mph**	KPI for Container Handling Equipment that indicated the operational performance in moves per hours. A move can consist out of one or more container or boxes and is often viewed as a measure of terminal and CHE productivity.
Out of gauge	**OOG**	Cargo to be transported which does not fit in container slots (exceeds the internal dimensions of containers and needs to be loaded on an open top or flat rack.

Panamax	**-**	Maximum beam (32.3m) that allows vessels to pass through the locks of the Panama Canal (specifically used for dry bulk and container vessels). A limiting factor for ship sizes. Upon recent expansions a bigger classes of Post-Panamax and finally New-Panamax (49m) in 2016 are distinguished.
Pilotage	**-**	The act of assisting the master of a ship in navigation when entering or leaving a port or in confined water. Often superintended by a pilot from the port authority.
Port	**-**	Or seaport. Coastal location with a harbour where ships and dock and transfer goods to/from land.
Prescriptive Simulation Platform	**PSP**	Macomi's simulation platform software tool.
Quay	**-**	A structure built parallel to the bank of a waterway to allow for vessel moorings. Container terminal quays are strengthened to be able to withstand loads resulting from container handling.
Quay crane	**QC**	Collective name for any type of cranes located on a quay to service moored vessels.
Rail yard		The area for the rail side handling of terminals. Consists of a set of railroad tracks for storing, sorting or loading railroad vehicles, buffer positions and possible small stack.
Rail mounted gantry crane	**RMG**	A crane built atop a gantry, the movements of which are limited by rails.
Reach stacker	**RS**	CHE used at many terminals for handling containers.
Reefer container	**-**	Refrigerated or environment-controlled container designed for keeping its storage at specific temperature. Needs additional resources for storage like connection to electricity grid.
Relay	**-**	Transfer of containers from one ship to another.
Roll-on roll-off	**Ro/ro**	Ro/ro is a cargo handling method whereby vessels are loaded via one or more ramps that are lowered on the quay.
Rubber tyred gantry crane	**RTG**	A mobile gantry crane set on wheels with rubber tyres. Contrary to a RMG, a RTG can move to e.g. another stack if desired.
Safe working load	**SWL**	Force that a piece of lifting equipment, lifting device or accessory can safely use to lift, suspend or lower a mass without fear of breaking. Measured in tons.
Scenario	**-**	A situation that the user wants to study in the simulation tool. An experiment is the cross section of volume, control, equipment and infrastructure.
Ship-to-shore crane	**STS**	High capacity gantry QC.
Shunting yard		Or classification yard. A railroad yard with multiple tracks used for assembling freight trains.
Shuttle carrier	**ShC**	A horizontal transporter within a terminal, which can pick up containers from the ground.

Side loader	-	A lift truck fitted with lifting attachments operating to one side for handling containers.
Spreader	-	Piece of equipment to grab and lift containers by their corner castings. Attached to STS, RC and other CHE.
Stowage factor	-	The average cubic space occupied by one ton weight of cargo as stowed aboard a ship.
Stowage plan	-	Or bay plan. A plan and method by which container vessels are loaded with containers of specific sizes and destinations. Typically uses a bay-row-tier coordinate system.
Straddle carrier	**SC**	A type of container terminal equipment capable of lifting and stacking containers, as well as horizontal transportation.
Stripping	-	Or unstuffing. Unloading of a container.
Tank container	-	An intermodal container for the transport of liquids, gases and powders.
Tare weight	-	The weight of wrapping or packing (e.g. an empty container); added to the net weight of cargo to determine its gross weight.
Terminal operating system	**TOS**	Control system of a terminal responsible for issuing instructions to workers and equipment.
TEU factor	-	A measure of average size of container within certain population.
Transhipment	-	A distribution method whereby containers or cargo are transferred directly from one vessel to another to reach their final destination.
Turnaround time	**TAT**	The time it takes between the arrival of a vessel and its departure from port; frequently used as a measure of port efficiency.
Twenty-foot equivalent unit	**TEU**	Standard (but inaccurate) measure of a 20 foot container length. The capacity (handling and storage) of terminals, stacks, CHE and vessels is often measured in TEU.
Twist-lock	-	A standardised rotating connector for securing shipping containers. Used together with a corner casting.
Ultra large container vessel	**ULCV**	A class of large ships, whose size makes them too large to go through the Panama Canal.
Vessel manifest	-	Declarations made by international ocean carriers relating to the ship's crew and contents at both the port of departure and arrival. All bills of lading are registered on the manifest.
Water side	**WS**	Referring to areas or activities directly happening on or closely connected to water. Water side areas include e.g. apron and quay, and WS of stack.

1.4. Structure

The document is divided into two parts: generic description of the simulation model build-up and case study material, organized as below. The first 6 chapters are generic for the library of the simulation components as a decision support environment, leading to the deliverables D5.3 and D5.4 as well as milestones MS11 and MS12. These are followed by case-specific content.

Chapter 1: Introduction

Contains an overview of this document, providing its structure:

- **Section 1.1:** Scope
- **Section 1.2:** Audience
- **Section 1.3:** Glossary and abbreviations
- **Section 1.4:** Structure

Chapter 2: Generic model build-up and methodology

Describes the structure of the model and used methodologies:

- **Section 2.1:** Platform characteristics
- **Section 2.2:** Transported volumes
- **Section 2.3:** Control
- **Section 2.4:** Resources
- **Section 2.5:** Layout, infrastructure

Chapter 3: Input structure

Defines the structure of input data and its characteristics

- **Section 3.1:** Input data
- **Section 3.2:** Map editor and project architecture coupling
- **Section 3.3:** Stochastic variables

Chapter 4: Model validation

Describes the efforts to validate and calibrate the model

Chapter 5: Simulation execution

Characterizes how simulation experiments are configured and run

Chapter 6: Model outputs and key performance indicators

Outlines the outputs of the simulation model

Chapter 7: Case study La Spezia

Illustrates the case study for La Spezia container terminal

- **Section 7.1:** Volumes
- **Section 7.2:** Control
- **Section 7.3:** Resources
- **Section 7.4:** Layout & infrastructure
- **Section 7.5:** Model and experiment setup
- **Section 7.6:** Results and result analysis

Chapter 8: Conclusions

2. Generic model build-up and methodology

The operational terminal simulation model is created using the Discrete Event Simulation paradigm, using the Macomi's Prescriptive Simulation Platform (see Macomi's website http://macomi.nl/). These types of models are heavily reliant on the layout they are built upon. A systemic approach is used to assess terminal performance, comprising of four main components, as presented in Figure 1. The vital part is not only to define individual components well, but to exploit their interconnections in a meaningful manner. In Figure 1 we distinguish the following layers:

- Transported volumes
- Control
- Resources
- Layout, infrastructure

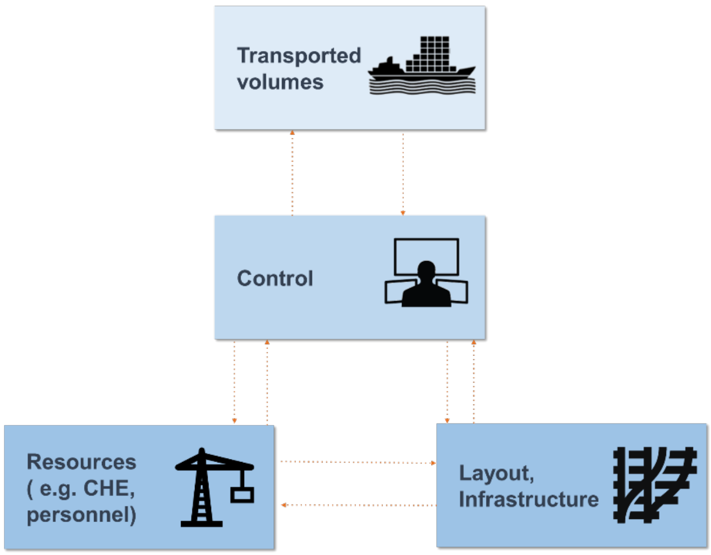


Figure 1. Main simulation components

Each of the components is discussed in detail in the following sections.

2.1. Platform characteristics

The four building blocks defined above are recorded in a database structure, which is then directly fed to the simulation engine. Figure 2 shows the places of the simulation components in the platform environment. All data is stored in a database and then sent to the simulation engine. After the model run, data is presented in dashboards as KPIs, charts and animation, all of which can also be exported for further processing.

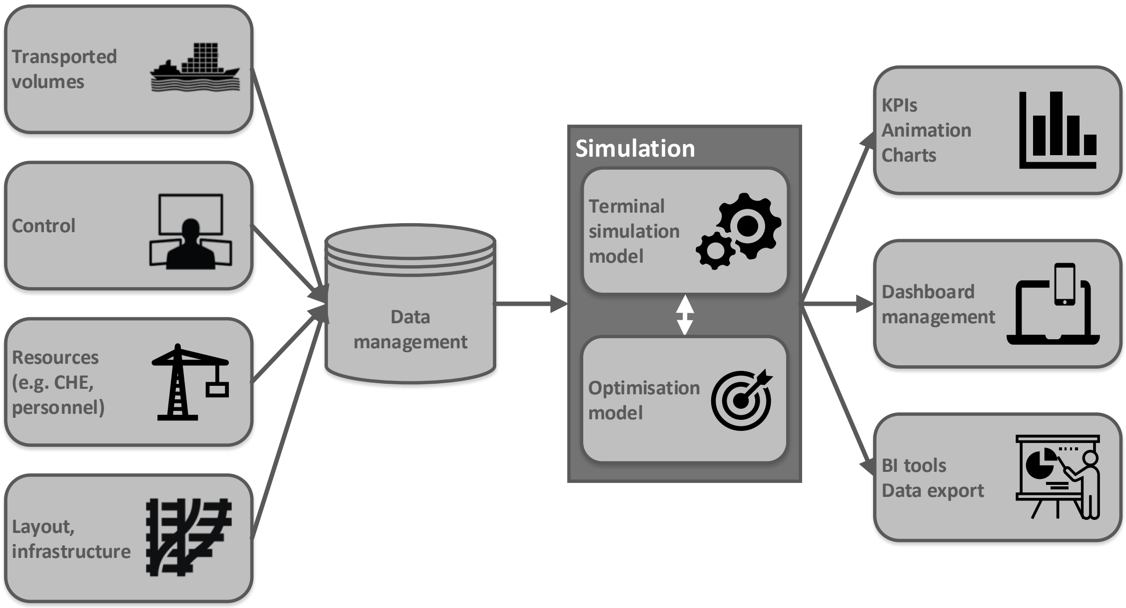


Figure 2. Schematic view of the Prescriptive Simulation Platform for terminal simulation

2.2. Transported volumes

Arrival list of vehicles and their cargo is prepared based on the historical data provided by the terminals and the agreed requirements for scenarios to investigate from the deliverable *D3.2 Pilot innovations and improvements*. Separate files are created for vessels, trains and trucks, as well as the initial containers in the stack for the start of the simulation. Per vehicles the following fields are necessary:

- ID
- arrival datetime
- vehicle type/capacity
- fill level (vessels only)
- containers to off-load (size, type and number)
- container to load (size, type and number)

Summing up the arrival and departure volume one can determine the total throughput for the terminal over the investigated period and extrapolate it for longer durations.

2.3. Control

Control logic is comprised of 3 elements, each governing a separate area.

I. High level control – TOS model

The TOS or Terminal Operating System is a software tool which essentially is the 'brain' of a container terminal, overseeing and making control decisions on the terminal. The TOS is responsible, among others, for:

- Determining where containers are to be stacked
- Choosing which resources to use to perform move operations

- Choosing parking positions for vehicles, including trains
- Keeping track of container inventory and their positions (database)

A simulated TOS is in charge of resources, prioritising and assigning jobs to them, as well as data exchange, and all supporting control, namely:

- Vehicle routing, trajectory assignment and queuing
- Collision avoidance among vehicles
- Management of level crossings
- Conflict resolution, when multiple objects want to claim the same resource
- Gate oversight

As such, the simulated TOS has a wider range of tasks than a traditional terminal control software, as it also needs to coordinate among vehicles, taking the roles of personnel (e.g. drivers).

II. Coordination control

The level of this control is limited to a single resource, usually a vehicle, and is responsible for performing tasks appointed by the TOS, especially:

- Monitoring the execution of the assigned job
- Realisation of the assigned trajectory
- Abiding physical limitations of the vehicle and layout

III. Arrival generation

Assigned vehicles and their cargo need to be created at the right time and appear in the right spot entering the investigated system. They also need to account for limitations like entry queues or blockages.

The features above exercise control over the physical layer, i.e. the actual vehicles and resources.

2.4. Resources

Next to the layout elements, defined in section 2.2, vehicles and other resources are defined for the simulation model, as describes in the deliverable D5.2 Ontology and Conceptual Modelling. These are listed below.

Cranes:

- Ship-to-shore (STS)
- Rail mounted gantry (RMG)
- Rubber tyred gantry (RTG)
- Reach stacker (RS)

Transporters:

- Terminal tractors (internal)

- External trucks
- Container ships
- Freight trains

Infrastructure resources:

- Road gates
- Parking lots
- Berths and anchor points
- Stack blocks
- Shunting and rail yards

Some of the elements of the defined resources overlap with the layout components, as they are both part of the infrastructure and vital conceptual elements of the model structure.

2.5. Layout, infrastructure

The first part of the model build-up is the layout, comprising infrastructure and other data related to it, necessary for the simulation model. These are all physical and fixed objects, which determine where containers are stored, and how vehicles can move, such as gate, container ground slots, driving lanes, etc.

Layout components are defined as simulation constructs, so that there is a direct mapping of imported elements to the simulation model objects. Below the categorised constructs of the simulation model are listed and described.

Road network has the following components:

- Source
- Sink
- Link and parking lanes
- Network element
- Nodes: gate, junction, level crossing
- Parking lot

The road network is used by the external trucks, internal transporters and reach stackers to reach containers and chosen parking positions. These vehicles can only move on the road network. Road network comprises mostly of road links and junction nodes, representing crossings. A road link can be unidirectional or bidirectional. In case of the latter vehicles can only go opposite directions when one stops at a parking lane and lets vehicles in the opposite direction through, before continuing. A road link can have parking lanes on the left, right or both sides of it to allow vehicles to park and exchange cargo.

A road link also has a maximum speed defined. Without additional speed limitations of the vehicles, they will try to accelerate to reach this speed. However, they are always forced to slow down before crossings, so that they are able to stop to let another vehicle through. In the animation, the acceleration to maximum speed is visible best on longer stretches of roads. Trucks have individual acceleration and deceleration curves sampled stochastically at the beginning of a run to vary their performance., since not all drivers accelerate and brake equally.

Road network intersects with rail network on level crossings, where there should not be any collisions between vehicles and trains. To avoid them, an interlocking system is used, the absolute priority is given to trains, and the vehicles can move only provided they will not interfere with any train movement. Vehicles cannot stop at level crossings at all.

Reach stackers and internal transporters are created at the beginning of the simulation run and stay within the boundaries of the terminal for the entire duration. Internal transporters if idle will go to a parking lot and stay there until a new job is assigned to them.

External trucks are created at one of the sources and then proceed to the gate, picking a lane with a shortest queue out of available entry lanes. Driver and cargo identification and the gate check-in procedure are carried out at a gate, and represented with a stochastic process, based on expert estimation.

Then they proceed to unload and load their cargo, i.e. to stop at a parking lane next to a designated spot of/for the container, where they wait to be serviced. Having finished the last load, they leave the terminal by one of the available exit lanes at the gate in a corresponding manner to entering, except the process is faster than on entry. Afterwards they proceed to the closest sink, an exit point from the system, where they disappear from the simulation.

Then, the rail network has the following components:

- Rail junction
- Rail track
- Rail location (grouping rails into e.g. shunting yard)
- Source
- Sink
- Rail node: end point, level crossing
- Buffer

The rail network is conceptualised in a different manner than the road network, as there are other characteristics and requirements for trains in comparison to road vehicles. The network mostly comprises of rail tracks and nodes, with special types of nodes in place of rail junctions. In order for trains to choose their routes, junctions have properties linking them to tracks connected in reality and restrictions, limiting the possible movements. The latter is especially important to avoid trains making a U turn, when e.g. a single track is splitting into two sidings. Signalling in junctions also enforces train priorities, keeping distance and collision avoidance. Finally, junctions determine the end points of a track.

Just as in case of trucks, the trains arrive in the network at a source and leave at a sink. Since all rail tracks are bidirectional, rail source can be in the same spot as a rail sink. Rail tracks comprise sidings if uninterrupted with a junction switch. Sidings are grouped into locations when a rail location polygon is drawn around them. This way sidings are grouped into rail yards and shunting yards, which are then referred to in logistics layer.

Level crossing nodes are the same as in case of the road network and a train cannot be stopped when on top of them.

A buffer is a special stack block, operated by a rail crane, which can be used as a temporary storage location for boxes coming from or going to a crane, without a need for an intermediate move with an internal transporter. Final configuration of gantry cranes is done based on the layout, so that the correct destinations can be reached from the gantry, including rail tracks, road parking lanes and buffer stack block.

Then the waterways are distinguished:

- Berth
- Anchor point
- STS rail: leading and secondary

The waterways are not drawn as a network in the BIM model and thus are simplified in the simulation model. Vessels can be either at anchor point, on their way to the reserved berth or moored at the berth. A berth is a logical division of a quay and can host up to two vessels. Ship-to-shore crane rails are drawn by the berth so that the cranes can be put on top of them, and able to reach moored vessels and transporters waiting for the cargo at the parking lanes.

Stack is comprised of the following elements:

- Stack block
- Stack spot (including ground spots)
- Crane rail: leading and secondary
- Crane node

Stack block is a distinguished area for a certain types of containers, usually forming a rectangle. Normally a block can host only a single type of container (e.g. general purpose or empty), but mixed stacks are also possible, depending on the terminal business processes and a type of CHE operating the stack block. Mixed ones are more frequent for RMG operation, while with reach stackers the containers tend to have type restrictions. Stack block height, which is the maximum number of container that can be put on top of each other is a property of the block.

Stack blocks are grouped into locations for two reasons:

- To pool chosen resources in certain locations – this applies to reach stackers, which are assigned to operate in certain areas, only accepting jobs that are close by, avoiding long horizontal movements to reach a job.
- To seamlessly control cargo flows within the terminal. Certain locations are more used by certain types of vehicles, and this must be recreated by the resulting cargo flows. For example, most use of the rail buffer will by the exchange of boxes between trains and the buffer. However, also external trucks drop off to and pick up cargo from the buffer to avoid double handling. On the other hand long direct moves from one rail yard to another are not desired, and should happen with an intermediate storage in a stack.

Allowed sizes of containers to be placed in the stack are defined by the ground spot sizes. These refer to the stack spots at the ground level. The order of stacking containers among adjacent spots is determined by the TOS algorithm. Obviously, a container can be placed on the ground or directly on top of another container. The employed stacking method tries to make the best use of available space in the stack, and at the same time allow to access as many containers without digging as possible.

Normally it is only allowed to place containers of the same size as the ground spot. These limitations can be lifted individually per stack block if desired. For example in the rail buffer it is often desired to be more flexible with ground spot usage to prepare for loading a train well. Thus, it is beneficial to lift the size restrictions. In any case, there might not be mixing of container sizes in the same pile (on top of each other) and in the same bay (adjoining longer side of the box).

Gantry cranes are placed on rails, which are separate from the main rail network and never intersect. Instead rail tracks are in between or right next to the crane rails. Crane rails are limited by crane rail nodes. There has to be an adjacent parking lane so that the cargo can be put on horizontal transporters.

Finally, there are other distinguished components:

- Superstructure element
- Area element

Superstructure comprises mostly buildings which are part of the layout, but are not directly used in the simulation, as they are not fundamental in the container transport chain.
Areas divide the terminal into pre-determined functional areas or any other regions, not directly used in the simulation. These can be wharfs, yards, terminals, etc.

3. Input structure

Data requirements are formulated in deliverable D5.1 Data model. That data is transformed and incorporated into the devised data structure. This chapter concentrates on the input data structure and values used for the case study.

3.1. Input data

There are three main areas to be distinguished for the input data:

a) Map and infrastructure data – containing information on the layout and physical aspects of the functional areas, including connections among them. This is the most extensive data for the model, the input of which is automated from external sources, i.e. the BIM model. Any changes to the infrastructure data require implementation effort as well as testing and validation, and should be done by an experienced user;
b) Equipment and configuration data – concerns terminal equipment and resources in general. These are all the container handling equipment: cranes, internal transporters and their parameters, including control logic, which together perform all the (un)loading and internal transport tasks. This information can be varied among scenarios to compare the added value of interventions (e.g. additional transporters);
c) Volume and arrival data – necessary parameters to allow for ITUs to arrive at a terminal via varying access methods, and the directions and amounts of ITUs leaving the terminal. Expressed in general terms for easier data gathering, as well as creating new scenarios. This data includes volumes, types and lengths of ITUs, their means of transport, general arrival patterns and dwell behaviour. It is possible to execute a historical schedule and compare performance.

3.2. Map editor and project architecture coupling

Simulation has been coupled to the layout coming from the BIM model, so that the same infrastructure information can be used both in WP4 and WP5. Firstly, a data structure was established, comprising necessary components for the simulation model layout, their properties and their way of representation in the drawing. Layout was organised into several layers to seamlessly import varying components, assigning them as correct objects (e.g. road link or rail track).

Layout drawings are based on the Building Information Modelling (BIM), which is adjusted to contain necessary information for the simulation model. Then, the relevant information is exported into .sqlite database format and can be imported to Macomi's PSP Drawing Editor, adjusted, and seamlessly converted to simulation model objects.

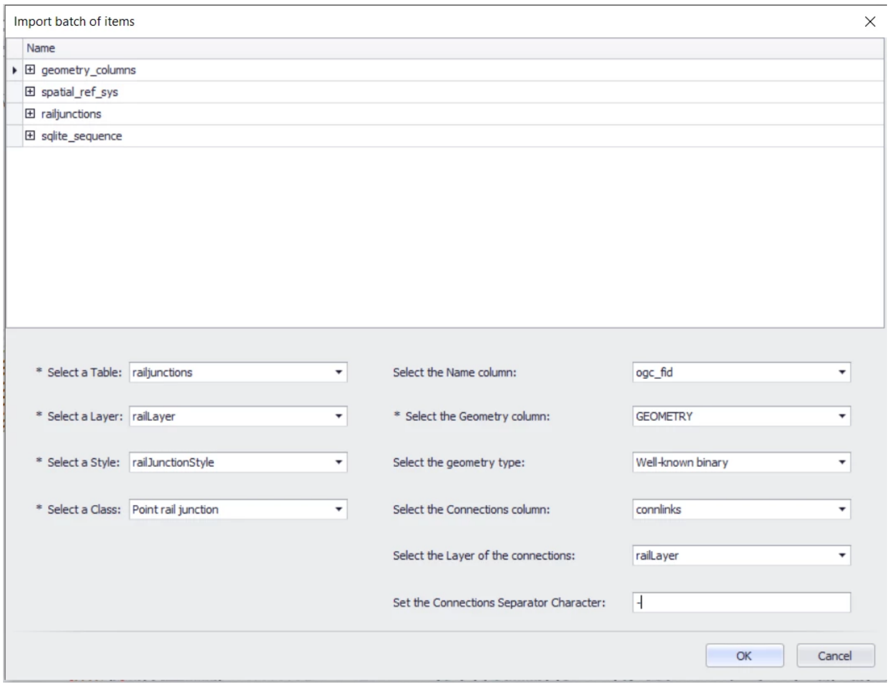


Figure 3. Example of layer import dialog box

In order to import object from external source "Import items" button needs to be clicked, which first ask to select the path to the file, and then starts the dialog window to get settings for the import. At first the user needs to select the table from the database from which the import is to happen, then choose the layer and style for the import, and select a class. Layout object classes are simulation model constructs allowing for seamless conversion from one to another. Then, the name column is for ID purposes, and the geometry column is usually pre-filled. Geometry type can be a well-known binary or well-known text, depending how information on the geometry is saved in the .sqlite file. Finally, it is possible to connect imported object to ones that are already in the drawing. For that one needs to choose the column for the imported table, where the information on the connected objects is and select the layer of objects to connect to. The last need is to fill in the separator character, which usually is a hyphen. It distinguishes individual object id's in the table's row.

An example of filled import parameters for rail junctions is shown in Figure 3. Having imported all the layers, a user has the ability to view the layout and to make changes to it, e.g. add properties or assign cranes. Since not all the necessary data for process logic is available in the BIM, some has to be added manually. A screenshot of the Map Editor interface is shown in Figure 4.

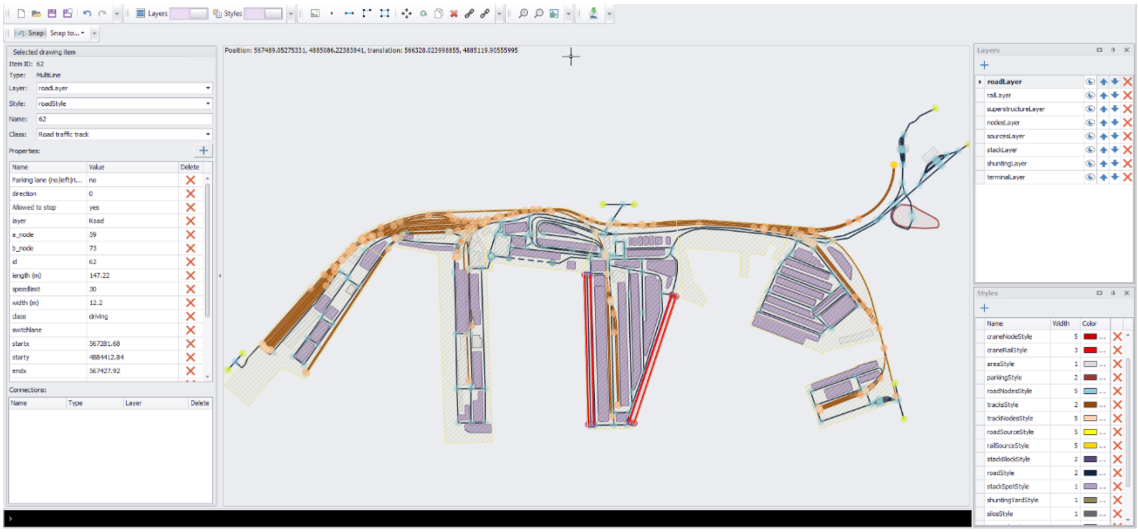


Figure 4. Map editor user interface with layout of La Spezia Container Terminal

Validation for the import functionality has been carried out in several stages, also taking into account the differences between requirements for Melzo and La Spezia terminals. Verification and validation efforts firstly included importing test to Macomi's map editor and visual inspections at the terminals. Then semi-automated test per logical groups of components, e.g. railway and road networks and stack blocks to see whether these are defined correctly and can be used in the simulation model and displayed in the simulation animation.

An export possibility from the map editor in the simulation component library to the BIM model is being developed as a complementary feature allowing to gather all layout information from various sources in one place easily, especially added logistics featured for the simulation. This will allow to combine expert knowledge from different sources in one. Functionality to export simulation output data (animation and KPI's) is being developed.

Finally, foundations for the simulation coupling to traffic microsimulation were established. The demarcation was fixed at the truck gate, so that all activities to happen on a terminal are part of the terminal simulation model and the truck transit beyond (as well as from on departure) is managed by the traffic microsimulation. Format and parameters exchanged were agreed upon and the connection was created.

3.3. Stochastic variables

Stochastic variables represent uncertainty, when the exact value differs and cannot be explicitly determined as constants. These are typically delays, like processing times, transport durations, but can also be connected to other uncertain values like amount of cargo on a MoT, ITU sizes or vehicle speed. Stochastic variables are sampled during the simulation run to determine their exact value for that given time. The deterministic variables, like the number of STS cranes remain constant. Stochastic variables are drawn from probabilistic distributions by a pseudo-random generator, responsible for achieving required probability density function by the processed utilising this value.

For example, a processing time at a road gate is given as a distribution, and every arriving truck has a different delay there, but so that together they form that given distribution. For another simulation run, a different set of random numbers is chosen, based on the chosen seed value for the pseudo-random, and each truck has a different than before processing delay. These together still form the same distribution. However, due to the causality in the model, a small delay on the gate can have consequences for a number of other arrivals, and significantly alter performance indicators for the terminal. Large changes to the outputs due to small changes in the values of parameters are called snowball effect.

4. Model validation

This section shortly summarizes the validation efforts for the model. For full description refer to a separate document related to validation and fulfilment of Milestone 13 (Versteegt & Kołodziejczyk, 2018)

The calibration and validation of the simulation library was executed in a number of steps:

- Compare the results of the simulation component library to earlier simulation studies that have been conducted by Macomi in 2015-2016. These include intermodal terminals and rail simulation studies in Europe, USA and Asia.
- Expert validation. The simulation component library to demonstrate to several experts from the field of designing intermodal terminals and operational experts working at intermodal terminals. Validation efforts included validation workshop

with experts involving model walkthrough, and statistical analysis of the outputs, comparing them with historical data.

- Validation of the results of the simulation component library to the results for the first real case (Melzo terminal).
- Validation of the results of the simulation component library to the results for the second real case (La Spezia terminal).

The parties to assist with the validation efforts:

- Intermodal terminal operator (APM Terminals Rotterdam, RSC Rotterdam, Contship Italia, etc.).
- Port authorities of Rotterdam.
- Universities with research on intermodal terminals (Delft University of Technology, Erasmus University Rotterdam and University of Groningen).

Simulation models for both cases were confronted with the operational performance data from the terminals in order to identify any discrepancies and counteract them. Calibration mostly relates to setting the correct values for abstract variables for vehicle arrivals, cargo split or equipment productivity, so that the correct delays and waiting times are represented. This is a data intensive process, which improves with the amount and quality of the data from the terminals. This activity mostly included comparison of KPI output data with historical performance. Model validation was performed with the problem owners, as well as other partners including container terminals to make sure the simulation library components closely represent reality. The results of the validation and calibration are described in deliverables D5.3 and D5.4, accomplishing MS13.

5. Simulation execution

Figure 5 depicts the structure of combining individual components into a simulation model, configuring experiments, then running them and eventually closing the loop via processing feedback from KPI's. It is divided into three stages of terminal design, simulation model and simulation run. The first step is terminal design. A design of the terminal is made based on customer requirements and specifications. The second step is creating the simulation model of the terminal design. In the third step, simulation run, experiments are conducted with the simulation model. In order to study the operational performance of the terminal. The results are presented in several KPIs and KRIs. Finally, the 'loop' is started again. Based on the KPIs the design of the terminal can be adjusted or fine-tuned and the 'loop' is iterated.

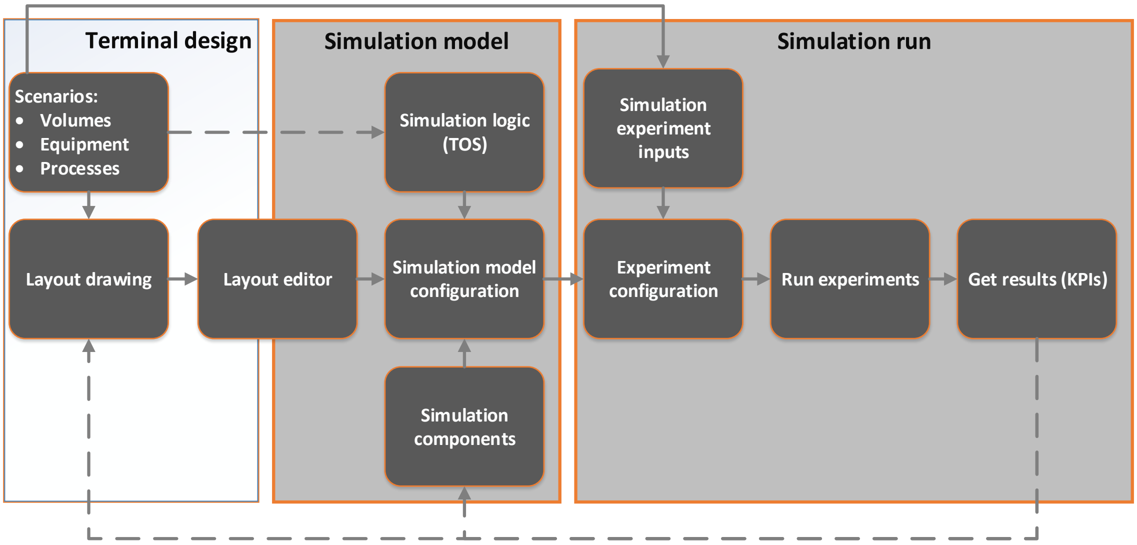


Figure 5. Schematic view of simulation run preparation and execution

Scenarios and layout data is obtained externally and imported into simulation via map editor and interfacing. A simulation model is comprised of a layout, control logic and resource components, as previously shown in Figure 1, but where the volume (arrival) data is arranged for particular experiments, not the model as a whole. Then the experiments are executed, after which animation can be previewed and KPIs determined. If needed, based on the results the input parameters can be revised to investigate (improve) other scenarios.

Experiment configuration and data input is done via Macomi's PSP GUI.

6. Model outputs and key performance indicators

Output data comprises of several key domains, which are then analysed to provide the user with useful information on the outcomes of the simulation run. The distinguished domains are:

- Result tables
- Logs
- Animation data

Result tables contain some chosen values that are recorded to convey important aspects of the model performance. In the design process, the aggregation level, i.e. the level of details to record is decided. Given the expected hundreds of thousands of ITUs a year to be handled on a terminal, displaying information on every single one of them to the users is rather redundant, as it could only confuse them. A more composite and meaningful results need to be conveyed. On the other hand, detailed information on individual MoTs might be desired, especially when looking into causes of varying performance among scenarios.

The result tables are further aggregated to obtain performance indicators and key performance indicators (KPI's), the source for which originates in the project deliverable D3.1 *State of the art and description of KPIs*. This is supplemented with a few additional measures, useful for the presentation of results and obtaining insight from the data. These are presented in Table II.

Table II. Terminal operational simulation KPI's from D3.1 with additions

No.	Name	Units	Frequency	Note
1	Terminal throughput	boxes, TEU	Yearly	Distinguishing import, export and transhipment. Add throughput per area
2	Equipment utilisation	percentage	simulation run	Including full state classification for CHE
3	Gate utilisation	percentage	simulation run	To be split for entry/exit lanes
5	Storage area utilisation	percentage	simulation run	Split per areas and stack blocks
6	Rail track utilisation	percentage	simulation run	Split per rail yard and shunting yards
7	Berth utilisation	percentage	simulation run	
8	Turnaround time	Time	per MoT	Split per vessel/truck/train
9	Waiting time	Time	per MoT	Split per vessel/truck/train
22	Delays produced (reliability) - Road	Time	Yearly, monthly	
23	Delays produced (reliability) - Railway	Time	Yearly, monthly	
28	Manoeuvring time	Time	Yearly, monthly, daily	Measure per MoT plus averages
29	Service time	Time	Yearly, monthly, daily	Measure per MoT plus averages
30	Berthing time	Time	Yearly, monthly, daily	Measure per vessel

31	Idle time (equipment)	Time	Yearly, monthly, daily	
36	Waiting time / Turnaround time	percentage	per MoT	
AD1	Container dwell time	Time	per ITU	Average time a container spends on a terminal
AD2	Gantry crane productivity	moves/h	per CHE	Measuring average number of productive moves a crane makes in an hour
AD3	Reach stacker productivity	moves/h	per CHE	Measuring average number of productive moves a reach stacker makes in an hour

Logging generally relates to storing values of chosen variables at a specific time, and recording that, so that a progression over time can be determined. Most often, a snapshot of a given situation (variable values) is taken in regular intervals, though it can also be recording time stamps of particular events for moving entities, like vehicles. A typical example is a current level of storage in a particular place. Logging is particularly important at the stage of verification and validation, to determine whether the behaviour of the model is as desired. This can hardly be done using result tables, and the verification is a crucial step of the model development.

Logs are used for all external vehicles (trucks, trains and vessels) to record their turnaround, processing or waiting times, among others. This is done per vehicle, and then intermediate indicators are calculated. After that aggregate statistics are computed.

Animation data is all the information necessary to display the model behaviour visually over time and can be accessed after the simulation run. Storing the simulation data and allowing for a separate animation requires a lot more data to be stored. Yet is has certain advantages, including saving experiments with animation runs, and investigating animation easier.

7. Case study La Spezia

La Spezia Container Terminal (LSCT) is located in the Port of La Spezia, and is just like Melzo a part of Contship Italia group. The maritime terminal has three available modes of transport, by vessel, rail and road. In general the Port of La Spezia is a major port in the Mediterranean, in the northern Italy, just 230km from Melzo. Its layout is shown in Figure 6. As can be seen, LSCT has a large area spread over multiple wharfs.

Next to quite large amount of import/export cargo via vessels, LSCT has a large modal share in rail, and a complicated rail network with relatively short production tracks. In Trans-European Transport Network framework, La Spezia is a part of the Scandinavian-Mediterranean corridor, another major rail transport channel like Rhine-Alpine corridor for Melzo.

La Spezia severs many customers in Italy and South/Central Europe and is closely connected to Melzo, to which a lot of cargo is sent by rail to sort it and transfer to international trains.

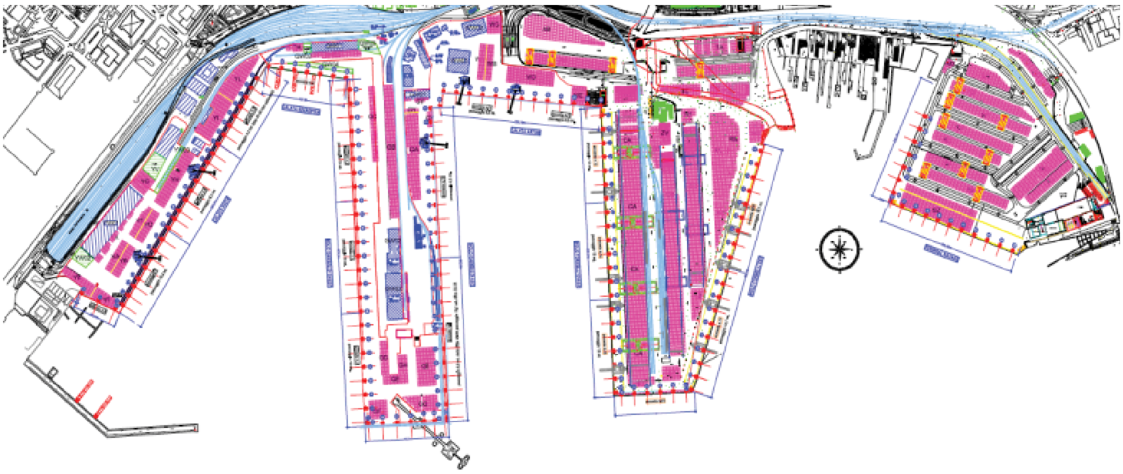


Figure 6. Layout of the La Spezia Container Terminal (Source: CSI)

LSCT in a very appropriate case study, mostly due to it being a medium-sized maritime terminal in an important port, for which most of the throughput is import/export based. Furthermore, a complex rail network and a lot of rail traffic make it challenging for operations, which is worth investigating.

LSCT is the second terminal modelled for a case study of the integrated decision support environment of the Intermodel EU project. At first the current (recent) situation on the terminal is to be represented, as this one can be validated most reliably. Then, more challenging scenarios will be investigated, which is not a part of this document. This is the second case to assess the value in reducing the design throughput time and in optimising operational performance. We aim to help the problem owner answer the following questions and more:

- Can the terminal handle the expected increase in volume?
- What are the bottlenecks in the terminals?
- Are the stacking choices (allocation of types and sizes) optimal?
- Is the container handling equipment allocated efficiently?
- What will be the impact of a new layout of the rail network?
    - Will the terminal have the capacity to handle more trains?
    - How should be the railway traffic be organised for smooth and efficient operations?

La Spezia case study is a part of the real pilot cases identified in deliverable D3.2 Pilot innovations and improvements (Dombriz, et al., 2017). In this deliverable a so called base case scenario is investigated and analysed. The base case entails the current demarcated situation at the LSCT container terminal, a starting point for further scrutiny, which can be thoroughly verified, validated and calibrated.

The results shown in this document are purposely limited, given the public nature of this document, and a sensitive character of the data involved. Some data is highly confidential and cannot be made public.

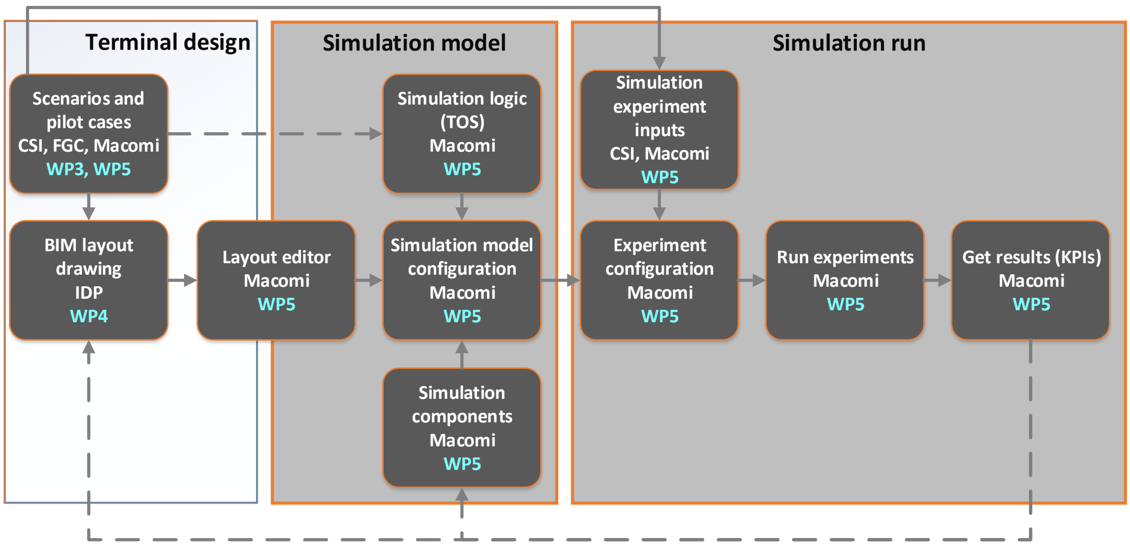


Figure 7. Simulation model in relation to Intermodel EU work division

In Figure 7 generic information on preparing and executing simulation runs is adopted from Figure 5. It includes the main beneficiary and the concerned work package of the Intermodel EU project. The terminal design is done in the WP4, scenarios mostly defined in WP3, and the simulation model developed and run in WP5 by Macomi.

The following sections describe model build-up for the specific characteristics of the La Spezia Container Terminal used for the terminal operational simulation model.

7.1. Volumes

This section summarizes some of the historical data for the La Spezia Container Terminal for 2016. Contrary to the Melzo case, much less data is available, which leads to limited conjecture. The available data mainly comes from various data summaries, and no raw data logs are available.

General data

In **Error! Reference source not found.** the total throughput of the berth is shown, together with breakdown into discharge and load and container sizes. Interestingly, the terminal TEU factor is low in comparison to other container terminals, and amounts to 1.51, meaning that on average there is almost as many 20 foot containers as there are 40 foot containers. In sea shipment in general, 40 foot containers constitute for a much larger share.

Table III. Yearly container throughputs in 2016.

Discharge				Load				
Full		Empty		Full		Empty		TEU Factor
20'	40'	20'	40'	20'	40'	20'	40'	
98,992	101,776	82,145	93,563	179,350	175,156	8,564	17,614	1.51

Due to fixed slots on container vessels, these almost never not carry 45 foot containers, and thus the boxes are either 20 or 40 foot long. Based on the available aggregations, the total volume per mode of transport are prepared in Table IV.

Table IV. Surmised volumes per mode of transport.

	IN [TEU]	OUT [TEU]	Total	% of total
Vessel	572,000	573,000	1145,000	51
Train	239,000	320,000	559,000	25
Truck	306,000	224,000	530,000	23

As in case of Melzo, the modal split to rail is significant. This is supported by the train and train wagons (railcars) aggregation from Table V, showing a throughput of 10 trains per day on average (arriving and departing). With 17 on average wagons in a train, and most common 4 TEU per wagon, the average train size is 68 TEU, about 440 metres.

Table V. Train and wagon throughputs in 2016

Export wagons	Export trains	Import wagons	Import trains	Wagons	Trains	Wagon s/day
60,478	3,552	60,478	3,550	120,956	7,102	331

Then, special containers can be distinguished, for LSCT these are reefers and containers with dangerous substances (IMO). They comprise an insignificant portion of the throughput, but due to their storage location might constitute a logistical challenge. Altogether, this is less than 4% of the total throughput.

Table VI. Special container throughput in 2016

Type	Import 20'	Import 40'	Export 20'	Export 40'	Transh. 20'	Transh. 40'	Total TEU	% total volume
Reefer	209	1039	1484	11169	26	471	27077	2.42%
IMO	1078	287	4383	5365	105	40	16950	1.52%

Contrary to the Melzo case, bulk cargo is not distinguished in the data and thus there are no vehicles arriving or departing with bulk. This is fair, as containerized bulk cargo is transported in open top containers, which are not suitable for a sea voyage and the terminal mostly facilitates import and export activities.

Dwell times

Aggregated dwell times are given separately for full, empty and all boxes, as summarized in Table VII, Table VIII and Table IX.

Table VII. Dwell times for full containers

Full Units average dwell (days)				
Exports	Imports	Transhipment	General	**TEU**
4.7	**4.1**	**5.4**	**4.5**	**825,646**

Full containers remain at the terminal for a relatively short time, which indicates short lead times and probable terminal efficiency. Furthermore, not much higher, except for the export, dwell times of empty containers as in Table VIII.

Table VIII. Dwell times for empty containers

Empty Units average dwell (days)				
Exports	Imports	Transhipment	General	**TEU**
2.4	**7.5**	**4.4**	**6.8**	**291,218**

Table IX. Average dwell times for all containers

All Units average dwell (days)				
Exports	Imports	Transhipment	General	**TEU**
4.6	**5.6**	**5.0**	**5.1**	**1,116,864**

Duration

Simulations are executed for a representative week of a year, starting from Monday midnight and ending on Sunday at midnight, 168 hours in total. Yearly volumes can be obtained by extrapolating arrivals.

Arrival volumes for simulation

Aggregated volume data for arrivals and departures split by the mode of transport is presented below in Table X and Table XI. The case on purpose presents an above-average weekly throughput to test the performance in a busier period. The volumes and their arrival patterns are generated based on the available aggregated data.

Table X. Arrival volumes in the weekly simulation per mode of transport

Mode of Transport	Arrival boxes	Arrival TEU	Departure boxes	Departure TEU
Truck	4022	6075	3025	4518
Train	3112	4712	4137	6281
Ship	7620	11649	7519	11481
Total	14754	22436	14681	22280
Yearly extrapolation	767208	1166672	763412	1158560

Types of containers summary:

Table XI. Arrival volumes in the weekly simulation per container type.

Type	Arrival	Departure	TEU factor
General Purpose (GP)	9229	9254	1.51
Empty (MT)	4892	4745	1.51
IMO	361	401	1.54
Reefer	250	267	2
Tank	22	14	1

7.2. Control

Control logic is based on the generic Terminal Operating System described earlier. The TOS identifies grouped locations within the terminal, stack blocks, rail yards and gates to control the flow of containers and mimic the actual usage of certain areas, which might differ significantly within the terminal.

As per initial schematic from Figure 7, model control logic and TOS are defined by Macomi based on the scenarios to investigate, and provided business rules by the terminal operator.

Table XII. Cargo flows within La Spezia Container Terminal

Locations	Gates		Berths		Rail yards		
	Main road gate	Special road gate	Berth west	Berth east	RS yard	RC yard west	RC yard east
Fornelli	32.00%	50.00%	60.00%	60.00%	15.00%	55.00%	55.00%
Paita	3.00%	0.00%	2.00%	2.00%	2.00%	2.00%	2.00%
Garibaldi	5.00%	1.00%	2.00%	2.00%	3.00%	5.00%	5.00%
Artom	40.00%	33.00%	15.00%	30.00%	15.00%	12.00%	17.00%
Ravano	20.00%	15.00%	20.00%	7.00%	64.00%	15.00%	10.00%
Malaspina	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%

7.3. Resources

Simulation experiment inputs are divided into duration setup and equipment (resource) data.

Duration

Simulations are executed for a representative week of a year, starting from Monday midnight and ending on Sunday at midnight, 168 hours in total. Yearly volumes can be obtained by extrapolating arrivals.

Equipment

The following equipment is used for the base case experiment:

Table XIII. Equipment numbers in the weekly simulation.

Type	Number	Max stacking Height	Notes
STS crane	6 + 5	N/A	Divided into western and eastern group
Reach stacker	22	5	
RTG crane	12	5	
RMG crane	8	5	
Internal transporter	52	1	

7.4. Layout, infrastructure

Specific layout for La Spezia is used, as shown previously in Figure 4. This section goes into more details about the characteristics of individual components and relationships among them. Layout and infrastructure data comes from the BIM model, as depicted in Figure 7, is then imported into Macomi's PSP map editor, and used for simulation experiments.

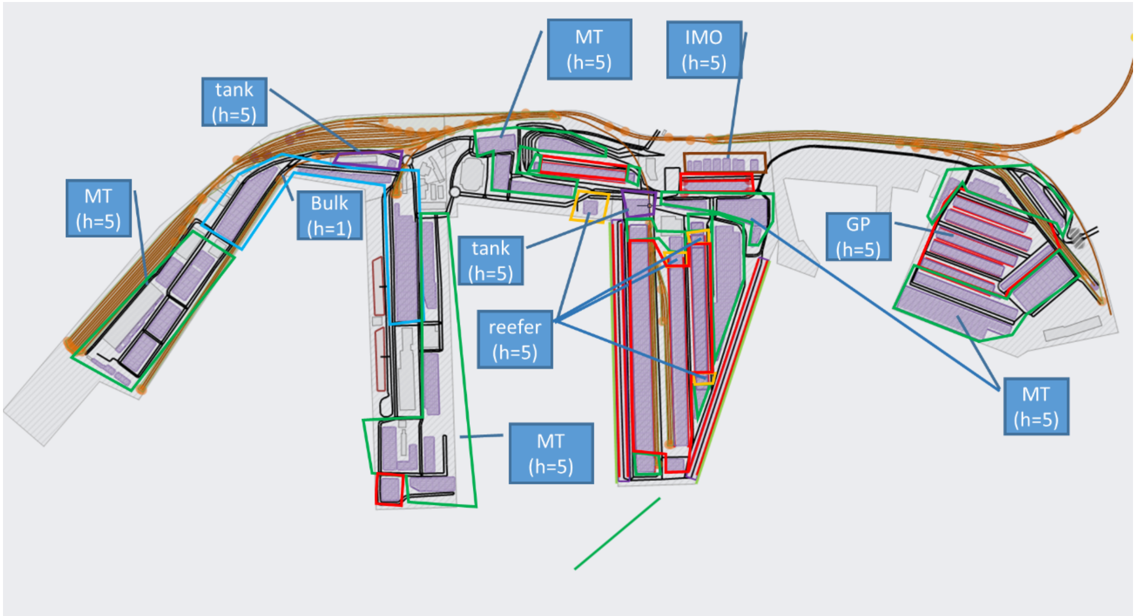


Figure 8. La Spezia Container Terminal layout with distinguished stack blocks, their types and heights.

In Figure 8 the division of stack per container types is given, assigning blocks for general purpose, empty, reefer, tank, bulk and IMO containers. It is assumed that blocks purpose is fixed and does not change over time. Stack blocks constitute the entirety of the container storage space on the terminal, which is constant.

In general terminals also have other storage space available, for example temporary buffer in between legs of STS cranes or other spots, without fixed ground spots. These are not considered in this model due to subjective nature of their usage by the operator and a lack of proper business rules.

The terminal is divided into six areas with the most busy Fornelli wharf and Artom as well as Ravano areas. Least used areas are Paita, Malaspina and Garibaldi pier. Thus general purpose containers are mostly stored within the busiest areas for quick access, and empty container blocks stretch all over the terminal. These blocks have the widest container bays, as empty containers are always placed and taken from the edge – there is no need to distinguish them by their contents, and thus a particular box is never needed, any will do provided it has the right size (and sometimes also logo). Empty blocks are serviced by reach stackers, while general purpose mixed blocks often have gantry cranes assigned to them.

Further blocks for special containers are also assigned. Refrigerated containers must be connected to the grid so that they can be kept at the right temperature. Thus the reefer block differs from the rest and has a limited number of slots. Tank containers and dangerous goods (IMO) also have their storage space, small in comparison to GP or MT types, but also with a very limited throughput.

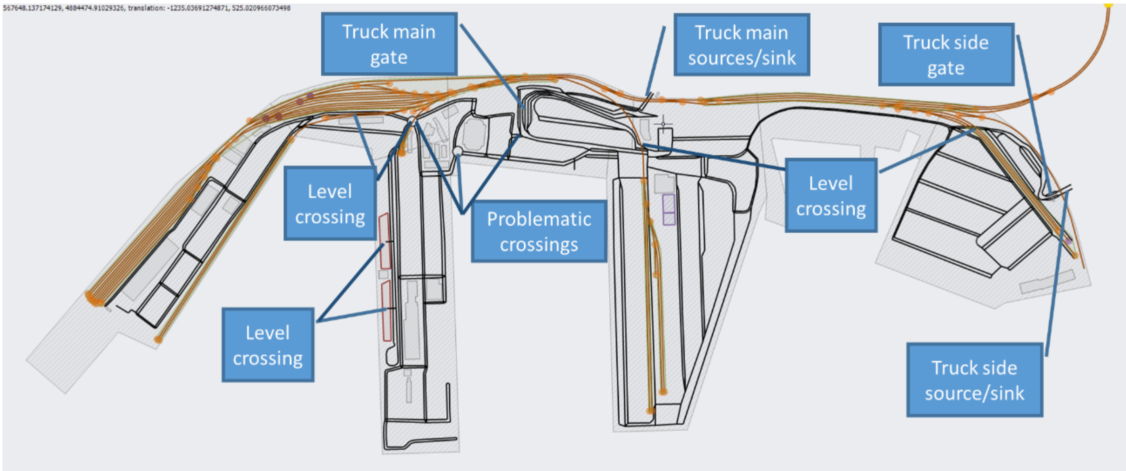


Figure 9. Road and rail networks of La Spezia Container Terminal.

In Figure 9 the road and rail network of the terminal are shown, where some other layers like the stack were removed to improve the visibility. External trucks are created at one of the three sources, then proceed to the available gate and from there to assigned parking lane positions where they wait to be processed. After all cargo has been handled they leave again through the same gate and proceed to the associated sink.

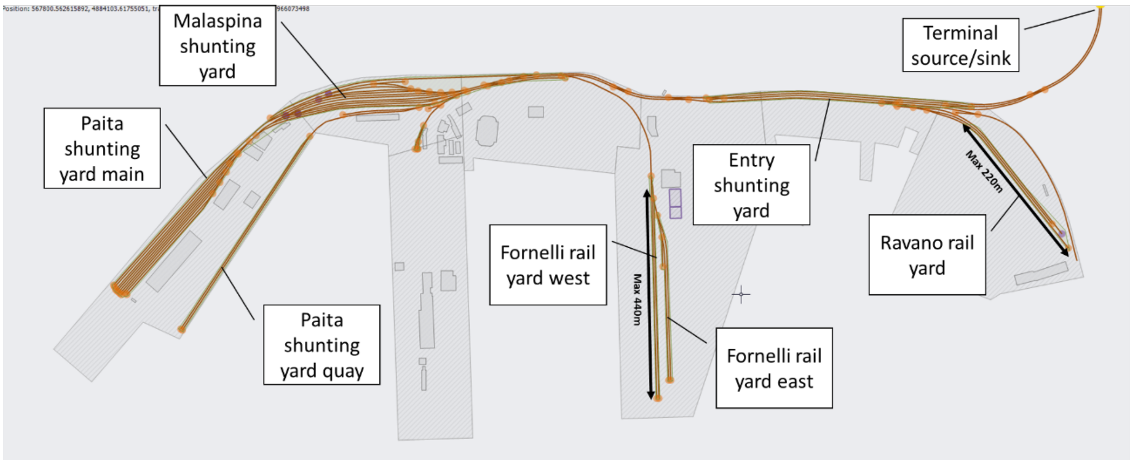


Figure 10. Rail network of the La Spezia Container Terminal.

Inside the terminal there are other vehicles using the network, reach stackers and internal transporters, which are created and remain within the premises over the entire duration of the run. Terminal transporters go to a parking lot if remain idle for a while and stay there until the TOS assigns them a new job.

The road network itself is comprised mainly of unidirectional links, where movement is only possible in one direction. There is also a limited number of bidirectional roads, where vehicles moving in opposite directions have to wait until they can cross each other. Moreover, there are two complicated roundabouts, one even with a level crossing, and a congested crossing inside the terminal, just next to the main gate.

Similarly as the road network, the rail network is shown in Figure 10, with three rail yards: two operated by rail cranes with longer production tracks in Fornelli pier, and the Ravano rail yard, with shorter production tracks and operated by reach stackers. Furthermore, there is apt shunting space for trains, provided these are not too long.

7.5. Model and experiment setup

The simulation experiment utilises parameter values and layout described in sections **Error! Reference source not found.** through **Error! Reference source not found.**. Furthermore, the terminal needs to be created with initial cargo on it, which is also based on historical throughput data and dwell time, so that the average number of containers on site per type can be determined. Once that is done, the containers are placed in stack according to the stacking rules.

Figure 11. Simulation map editor layout of La Spezia superimposed on Bing satellite map[1]

The layout can also be superimposed on publicly available satellite or infrastructure maps, to compare the layout drawing with the map. Despite some irregularities, both layouts fit well to each other. Superimposing is used both for verification/validation purposes, and to provide better reference to reality in the animation.

Figure 11 shows the layout from Macomi's PSP map editor overlaid on a satellite photo, while in Figure 12 the animation view is presented. Next to using different colours the animation view also has visualisations of equipment and arriving vehicles (although only the gantry cranes are barely visible in this view).

[1] Satellite images from: https://www.bing.com/maps ©2018 Microsoft Corporation

Figure 12. Simulation animation layout of La Spezia superimposed on Bing satellite map[1]

7.6. Results and result analysis

As described in chapter **Error! Reference source not found.**, there are a lot of outputs from the simulation model, for varying indicators. In the Macomi's PSP GUI we divide them into 3 categories:

- Terminal KPIs
- CHE KPIs
- Arrival KPIs

Only a limited set of the entire KPI/outputs from the simulation model are shown in this report.

Terminal KPIs

Terminal indicators comprise all those, which concern or affect areas in the terminal, especially throughputs, fill rates and utilisation. Below chosen KPIs are presented and discussed.

a) Throughput per stacking area

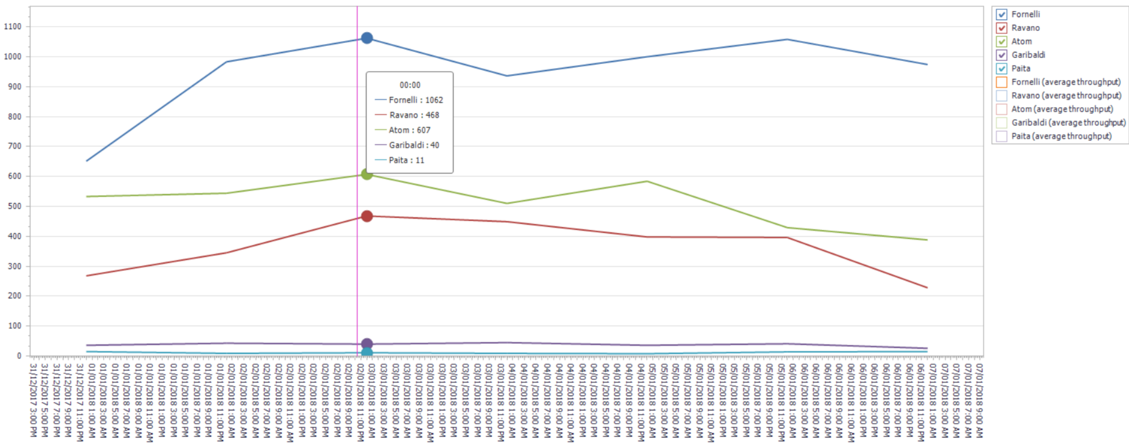
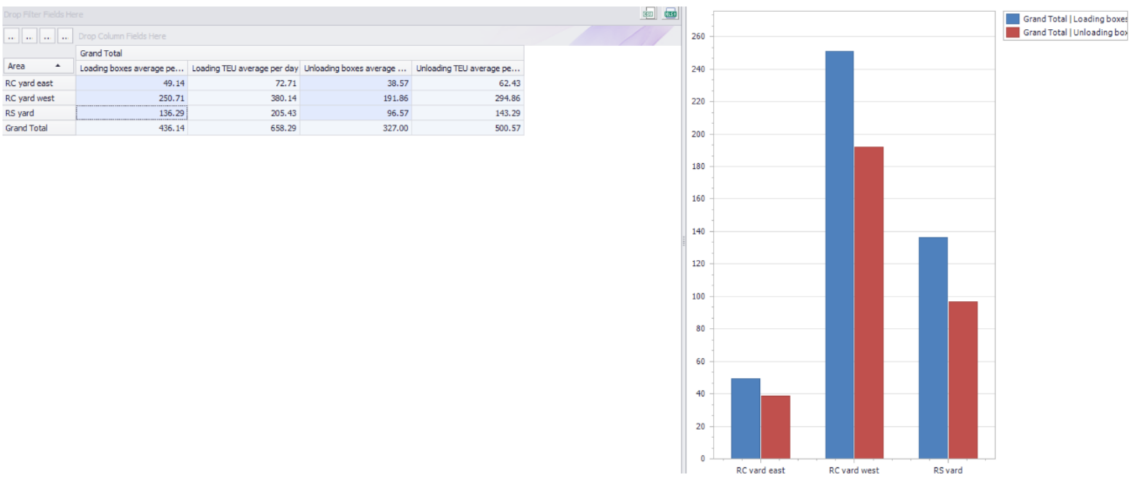


Figure 13. Daily throughputs per stacking area for La Spezia simulation

The total number of boxes (shown in Figure 13) and TEU processed through the terminal and split by functional area is calculated. This indicates which areas are busier than others and how many containers and TEU actually used them. As the run period entails a 7-day period starting on Monday just after midnight, the lines in Figure 13 show higher throughput in the first five measurement points, after which it drops slightly. This is an expected behaviour, as the number of truck arrivals at the terminal during weekends is lower, and the train arrivals are also reduced. The vessels call the port normally during weekends as well.

b) Throughput per rail yards

Rail yards are of particular interest for throughput, for which the total number of handled boxes in a period of time is calculated. Figure 14 shows a pivot table with column chart for the average number of processed containers and TEU per rail yards, additionally split per loaded to and unloaded from the trains.



Area	Grand Total Loading boxes average pe...	Loading TEU average per day	Unloading boxes average ...	Unloading TEU average pe...
RC yard east	49.14	72.71	38.57	62.43
RC yard west	250.71	380.14	191.86	294.86
RS yard	136.29	205.43	96.57	143.29
Grand Total	436.14	658.29	327.00	500.57

Figure 14. Average throughput per rail yards in La Spezia simulation

As expected the highest throughput is obtained at the rail gantry operated rail yard with the longest tracks (rail yard west). This is because the yard is least limited in accepting arrivals, and many incoming trains can only fit there.

c) Fill rates

Fill rates relate to the percentage of available cargo space, that is used at the moment. The more yard space that is utilised, the bigger the chance that digging will be necessary and the longer the digging (more containers to move). On the other hand, low stack utilisation indicates that travel distances might be unnecessarily long. Weekly fill rates with hourly intervals per six distinguished container yards in LSCT are shown in Figure 15.

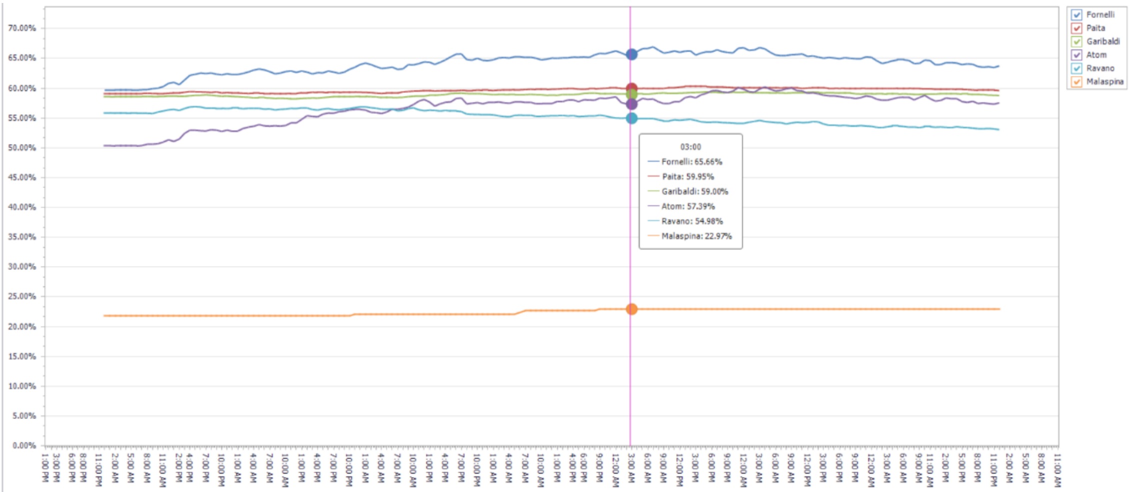


Figure 15. Stack fill rates in La Spezia per container yard (area)

The fill rates in LSCT oscillate insignificantly, mostly between 50% and 67%. No significant variations can be seen, despite large call sizes for arriving vessels.

d) Gate utilisation

The percentage of time each gate is busy or idle split per entry and exit lanes is also recorded. These are aggregate numbers for the only gate in LSCT, which is open 24/7 over the entire week.

Table XIV. La Spezia gate utilisation

Gate	Direction	State	Total Time [%]
Main	Entry	Busy	40.17
		Idle	59.83
	Exit	Busy	38.37
		Idle	61.63
Special	Entry	Busy	27.44
		Idle	72.56
	Exit	Busy	14.71
		Idle	85.29

More detailed indicators for the gate are shown as part of the Arrival KPIs

CHE KPIs

Container handling equipment key performance indicators mostly comprise state classification and productivity of various cranes and horizontal transporters. Here, it is divided per gantry cranes, reach stackers and internal transporters.

Gantry cranes

Percentage of time container handling equipment spends performing various activities is recorded. That is how much time percentagewise each crane spends idle, productive or digging.

Figure 16 shows that crane utilisation differs per area, most utilised are rail gantry cranes at the Fornelli pier, operating on trains there, especially on the longest tracks, reaching as much as 75% utilisation.

Total time (h)

Ratio

Area	Crane	Digging	Idle	Productive	Grand Total
Crane yard 1	Crane (1 - Default rail crane type)	1.6%	92.2%	6.3%	100.0%
Crane yard 10	Crane (28 - Default rail crane type)	4.1%	80.3%	15.6%	100.0%
Crane yard 11	Crane (29 - Default rail crane type)	2.7%	83.0%	14.2%	100.0%
Crane yard 12	Crane (31 - Default rail crane type)	3.8%	81.6%	14.7%	100.0%
	Crane (30 - Default rail crane type)	5.8%	68.1%	26.1%	100.0%
Crane yard 12 Total		9.5%	149.7%	40.8%	200.0%
Crane yard 2	Crane (8 - Default rail crane type)	0.0%	70.3%	29.7%	100.0%
	Crane (7 - Default rail crane type)	0.0%	71.9%	28.1%	100.0%
	Crane (6 - Default rail crane type)	0.0%	77.9%	22.1%	100.0%
	Crane (5 - Default rail crane type)	0.0%	71.1%	28.9%	100.0%
	Crane (4 - Default rail crane type)	0.0%	74.0%	26.0%	100.0%
Crane yard 2 Total		0.0%	365.2%	134.8%	500.0%
Crane yard 3	Crane (9 - Default rail crane type)	0.0%	76.2%	23.8%	100.0%
	Crane (13 - Default rail crane type)	0.0%	84.8%	15.2%	100.0%
	Crane (12 - Default rail crane type)	0.0%	80.5%	19.5%	100.0%
	Crane (11 - Default rail crane type)	0.0%	73.2%	26.8%	100.0%
	Crane (10 - Default rail crane type)	0.0%	74.6%	25.4%	100.0%
Crane yard 3 Total		0.0%	389.4%	110.6%	500.0%
Crane yard 4	Crane (16 - Default rail crane type)	7.2%	26.8%	66.0%	100.0%
	Crane (15 - Default rail crane type)	15.3%	9.7%	75.0%	100.0%
	Crane (14 - Default rail crane type)	7.5%	24.6%	67.9%	100.0%
Crane yard 4 Total		29.9%	61.2%	208.9%	300.0%
Crane yard 5	Crane (19 - Default rail crane type)	3.1%	76.2%	20.7%	100.0%
	Crane (18 - Default rail crane type)	7.4%	55.1%	37.5%	100.0%
	Crane (17 - Default rail crane type)	3.9%	74.0%	22.0%	100.0%
Crane yard 5 Total		14.5%	205.2%	80.3%	300.0%
Crane yard 6	Crane (21 - Default rail crane type)	6.4%	65.6%	28.0%	100.0%
	Crane (20 - Default rail crane type)	6.2%	64.4%	29.4%	100.0%
Crane yard 6 Total		12.6%	130.1%	57.4%	200.0%

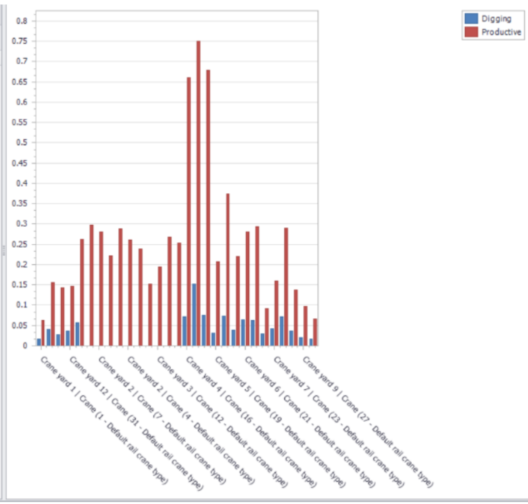


Figure 16. Gantry crane (RMG and RTG) utilisation for LSCT counting digging

For other stack yards, there are fewer jobs assigned to them by the TOS, and as a result they are not as productive on average.

STS cranes

Ship-to-shore cranes operate on vessels and do not dig. Their classification is shown in Figure 17, where the STS cranes are divided into western berth (6 cranes) and eastern one (5). Their utilisation is relatively low due to waiting times in between vessels and for vehicles, but consistent and not varying much.

Total time (h)

Ratio | State

Area	Crane	Digging	Idle	Productive	Grand Total
Crane yard 2	Crane (8 - Default rail crane type)	0.0%	70.3%	29.7%	100.0%
	Crane (7 - Default rail crane type)	0.0%	71.9%	28.1%	100.0%
	Crane (6 - Default rail crane type)	0.0%	77.9%	22.1%	100.0%
	Crane (5 - Default rail crane type)	0.0%	71.1%	28.9%	100.0%
	Crane (4 - Default rail crane type)	0.0%	74.0%	26.0%	100.0%
	Crane (3 - Default rail crane type)	0.0%	78.5%	21.5%	100.0%
Crane yard 2 Total		0.0%	443.7%	156.3%	600.0%
Crane yard 3	Crane (9 - Default rail crane type)	0.0%	76.2%	23.8%	100.0%
	Crane (13 - Default rail crane type)	0.0%	84.8%	15.2%	100.0%
	Crane (12 - Default rail crane type)	0.0%	80.5%	19.5%	100.0%
	Crane (11 - Default rail crane type)	0.0%	73.2%	26.8%	100.0%
	Crane (10 - Default rail crane type)	0.0%	74.6%	25.4%	100.0%
Crane yard 3 Total		0.0%	389.4%	110.6%	500.0%
Grand Total		0.0%	833.1%	266.9%	1,100.0%

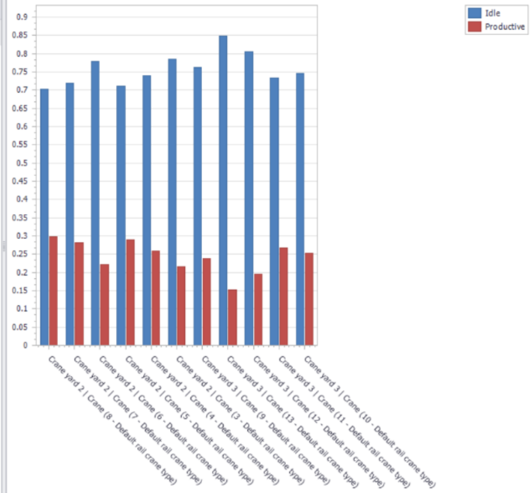


Figure 17. STS cranes utilisation for LSCT

Reach stackers

There are 22 reach stackers used in the simulation, on shift 24/7. They operate all of the areas where there are no gantry cranes, including servicing of the domestic rail yard.

a) Reach stacker classification

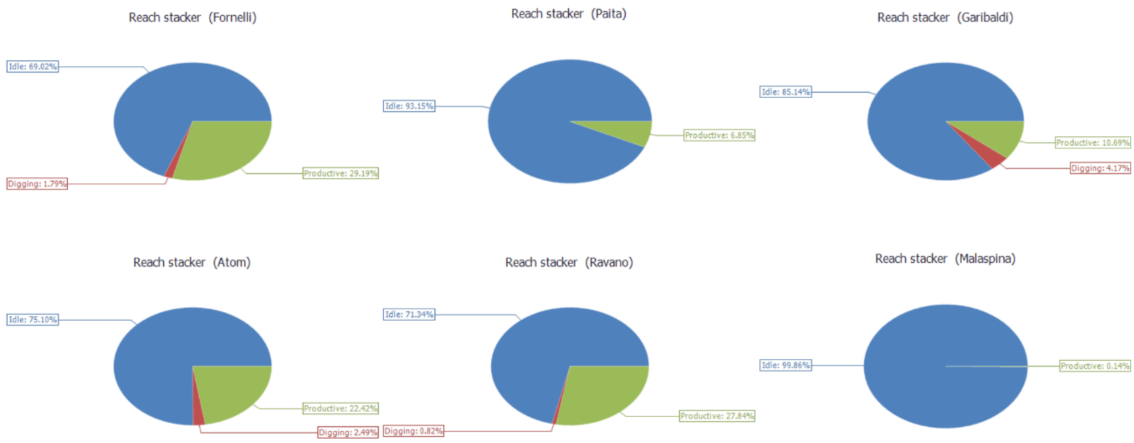


Figure 18. Reach stacker state percentage classification in LSCT per location

How much time percentagewise all reach stackers in an area on average spend in different states is shown in Figure 18. The busiest are RS in Fornelli and Ravano areas, where the most container throughput is. The farther areas are less used.

Internal transporters

Internal transporters in LSCT move containers all around the terminal, and there is abundance of such vehicles (52 in total). Moves performed by them are not distinguished to productive and unproductive as all of them are intermediate to and from a CHE.

a) Internal transporter classification aggregated

In Figure 19 an aggregated state classification for all internal transporters in LSCT is shown, dividing the states into waiting, idle, loaded transporting cargo to location, empty going to pick up cargo and empty going to park.

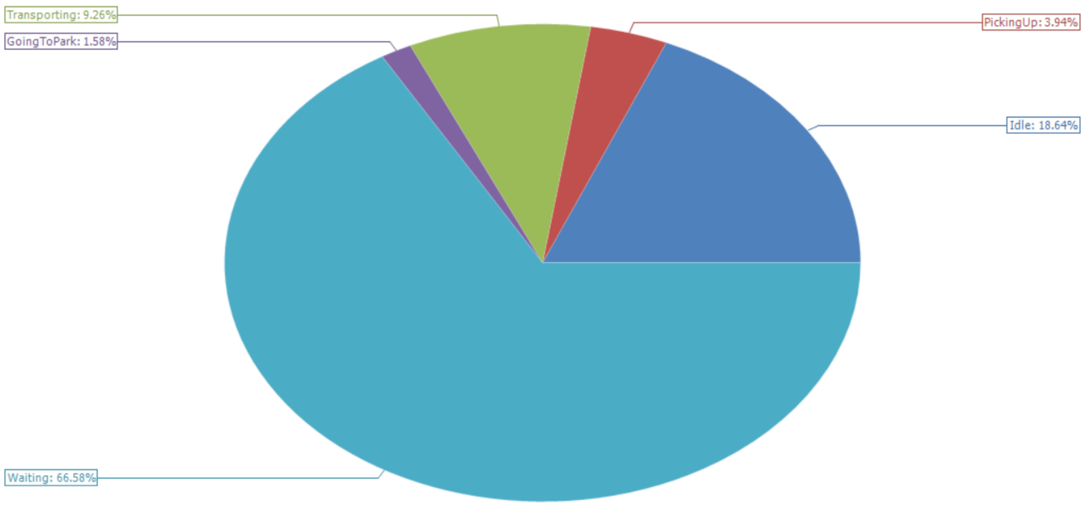
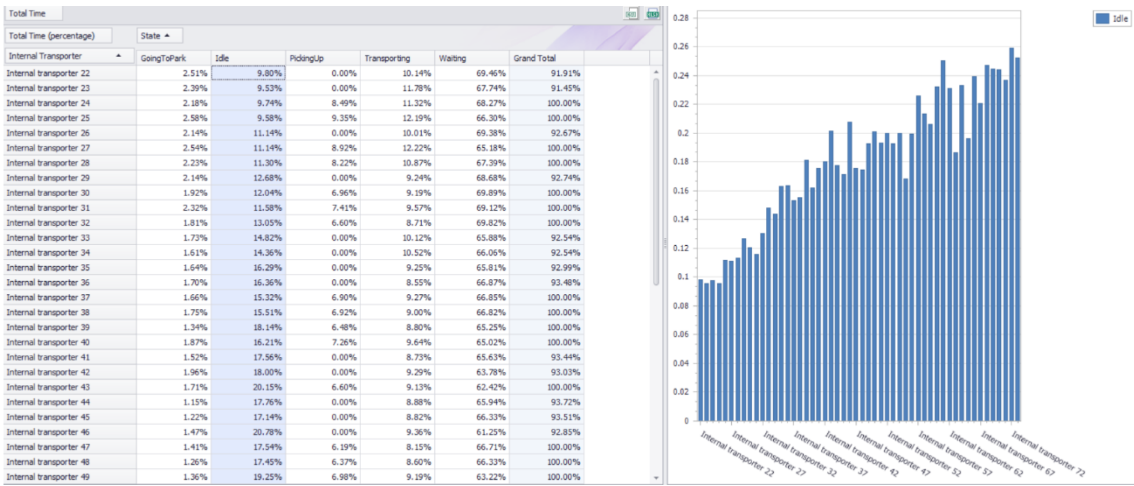


Figure 19. Aggregated internal transporter state classification percentage

It is clearly visible, that the ratio the transporters are in motion is very low. This is because internal transporters are not considered precious resource, and they need to be ready in place to perform a job before a job is crated for any CHE. Thus, most of the time, almost three quarters of their time the transporters spend waiting to be loaded or unloaded.



Total Time

Total Time (percentage) | State

Internal Transporter	GoingToPark	Idle	PickingUp	Transporting	Waiting	Grand Total
Internal transporter 22	2.51%	9.80%	0.00%	10.14%	69.46%	91.91%
Internal transporter 23	2.39%	9.53%	0.00%	11.78%	67.74%	91.45%
Internal transporter 24	2.18%	9.74%	8.49%	11.32%	68.27%	100.00%
Internal transporter 25	2.58%	9.58%	9.35%	12.19%	66.30%	100.00%
Internal transporter 26	2.14%	11.14%	0.00%	10.01%	69.38%	92.67%
Internal transporter 27	2.54%	11.14%	8.92%	12.22%	65.18%	100.00%
Internal transporter 28	2.23%	11.30%	8.22%	10.87%	67.39%	100.00%
Internal transporter 29	2.14%	12.68%	0.00%	9.24%	68.68%	92.74%
Internal transporter 30	1.92%	12.04%	6.96%	9.19%	69.89%	100.00%
Internal transporter 31	2.32%	11.58%	7.41%	9.57%	69.12%	100.00%
Internal transporter 32	1.81%	13.05%	6.60%	8.71%	69.82%	100.00%
Internal transporter 33	1.73%	14.82%	0.00%	10.12%	65.88%	92.54%
Internal transporter 34	1.61%	14.36%	0.00%	10.52%	66.06%	92.54%
Internal transporter 35	1.64%	16.29%	0.00%	9.25%	65.81%	92.99%
Internal transporter 36	1.70%	16.36%	0.00%	8.55%	66.87%	93.48%
Internal transporter 37	1.66%	15.32%	6.90%	9.27%	66.85%	100.00%
Internal transporter 38	1.75%	15.51%	6.92%	9.00%	66.82%	100.00%
Internal transporter 39	1.34%	18.14%	6.48%	8.80%	65.25%	100.00%
Internal transporter 40	1.87%	16.21%	7.26%	9.64%	65.02%	100.00%
Internal transporter 41	1.52%	17.56%	0.00%	8.73%	65.63%	93.44%
Internal transporter 42	1.96%	18.00%	0.00%	9.29%	63.78%	93.03%
Internal transporter 43	1.71%	20.15%	6.60%	9.13%	62.42%	100.00%
Internal transporter 44	1.15%	17.76%	0.00%	8.88%	65.94%	93.72%
Internal transporter 45	1.22%	17.14%	0.00%	8.82%	66.33%	93.51%
Internal transporter 46	1.47%	20.78%	0.00%	9.36%	61.25%	92.85%
Internal transporter 47	1.41%	17.54%	6.19%	8.15%	66.71%	100.00%
Internal transporter 48	1.26%	17.45%	6.37%	8.60%	66.33%	100.00%
Internal transporter 49	1.36%	19.25%	6.98%	9.19%	63.22%	100.00%

Figure 20. Pivot table for internal transporter percentage state showing idle times

The usage of internal transporters, as shown in Figure 20 is not exactly even, i.e. there are some with significantly less idle time than others. Since no restrictions are imposed on the internal transporters, it can indicate that their overall number might be too high for a long term. That does not mean that they are not all needed in peak situation.

Arrival KPIs

Arrival KPIs are all indicators regarding the arrival of vehicles to and their departure from the terminal. For La Spezia, there are three available modes of transport: sea, rail and road. For external trucks, their arrival pattern is closely connected to the performance and queuing at the terminal gate.

For all arrivals detailed logs are recorded to obtain values like turnaround time or waiting times. These are not included in the document as combine they would create a table of almost six thousand records. Only the more meaningful aggregated numbers are given in this document.

Truck KPIs

In La Spezia, contrary to Melzo, trucks can during a single terminal visit both unload containers and then load other.

Table XV shows the aggregate numbers for truck arrivals, displaying their number, total number of unloaded and loaded boxes as well as TEU, call size and two time-based KPIs: turnaround time and percentage of waiting time. There is significantly more cargo picked up from La Spezia by trucks, than dropped-off.

Table XV. Aggregate values for truck arrivals

Arrivals	Loaded boxes	Unloaded boxes	Loaded TEU	Unloaded TEU	Call size total	Turnaround time average [h]	Percentage of waiting time average [%]
5633	3025	4022	4518	6075	10593	0.68	70

As suspected, the biggest part of truck terminal visit is waiting to both be processed and at the gate. Yet, with average time spent at the terminal of below an hour, the operation seems very efficient.

To further investigate the waiting time at the gates, Figure 21 and Figure 22 are created, the first showing the number of arrivals and departures in each hour split for the main and the special side gate. The biggest number of arrivals occur on Monday after the weekend, where almost 50% more trucks in comparison to any other day are processed. Trucks for the remainder of the working week are spread evenly, and during the weekend there are only a few arrivals on Saturday.

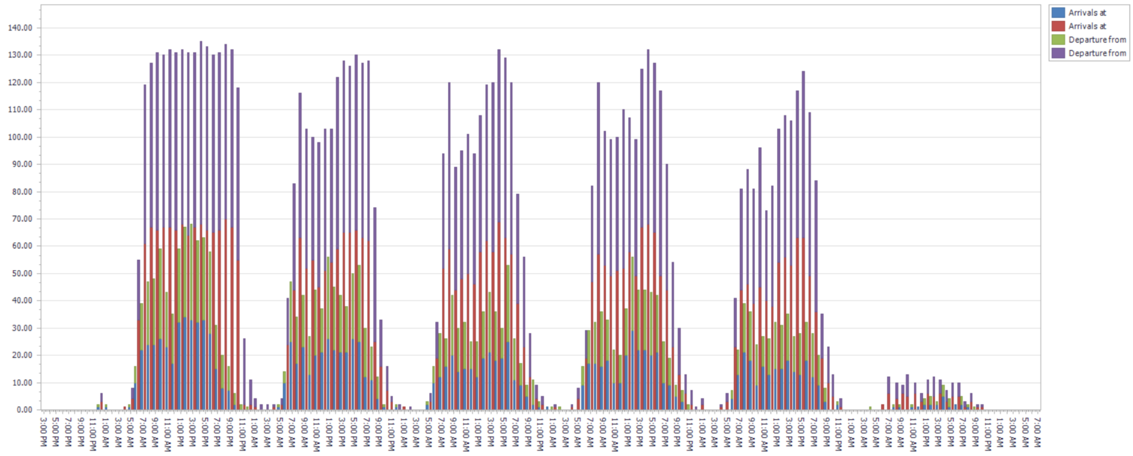


Figure 21. Number of arrivals and departures of trucks per gate per hour in LSCT

In Figure 22 the size of entry and exit queues for the terminal per each gate are shown.

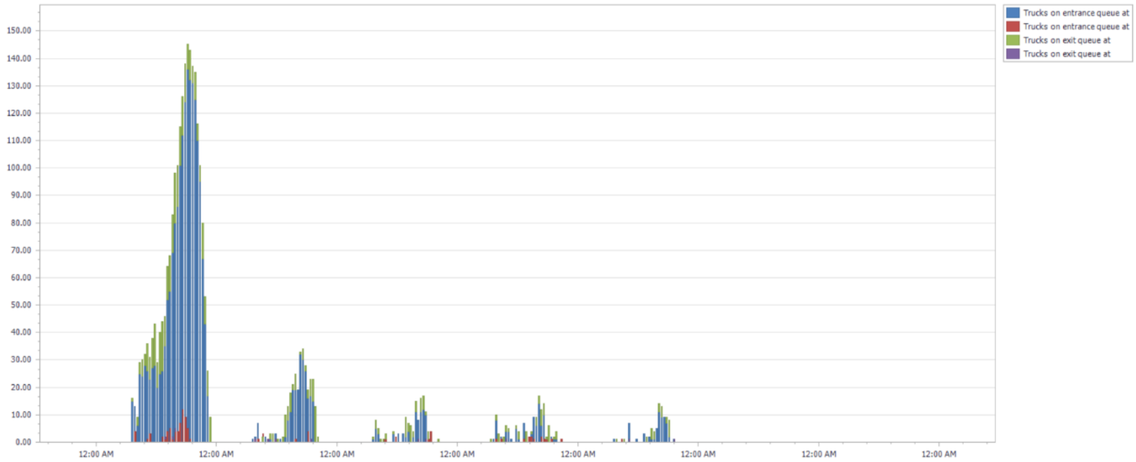


Figure 22. Size of arrival and departure queues at the gates in LSCT

The congestion arising from significantly higher number of arrivals on Monday is clearly visible at the gate and resulting queue, which reaches over 120 waiting vehicles, the number not occurring even closely on other days.

Train KPIs

it. Typically train arrivals are planned in an efficient manner, so that the amount of queueing is minimised. Yet, for operational reasons trains might get delayed.

Table XVI. Aggregate values for train arrivals

Arrivals	Loaded boxes	Unloaded boxes	Loaded TEU	Unloaded TEU	Call size total	Turnaround time average [h]
133	4137	3112	6281	4712	10993	15.59

Table XVI shows a summary for the train arrivals, in the period, averaging just almost twenty trains per day (arrival and departure). Due to large volume at the terminal and significant number of trains, their turnaround time is also long, almost 16 hours on average.

Vessel KPIs

In the investigated period there are 15 vessels scheduled to arrive, and 13 of them managed to be processed, except for two arriving on the seventh day. For aggregate numbers regarding arrivals, see Table XVII and for average processing and waiting times Table XVIII.

Table XVII. Aggregate volumes for vessel arrivals

Arrivals	Departures	Loaded boxes	Unloaded boxes	Loaded TEU	Unloaded TEU	Call size total [TEU]
15	13	7108	7310	10819	11137	21956

The total berth throughput (loaded and unloaded) in the investigated period can be extrapolated to 1.14 million TEU a year, a figure consistent with terminal performance in 2016. The amount of cargo unloaded from and loaded to vessels is almost the same.

Table XVIII. Aggregate processing times for vessel arrivals

Average turnaround time [h]	Average berthing time [h]	Average processing time [h]	Average waiting time [h]
35.27	29.8	28.8	4.47

According to Table XVIII the average turnaround time per vessel took almost 1.5 days, with 5h waiting time for berthing spot and just above a day of actual processing time. That would indicate the waterside operations are not that efficient and could be improved.

7. Conclusions and future work

7.1. Conclusions

The goal of the WP5 is to build a simulation-based decision support environment that assists in optimizing the design, planning as well as the operational performance of intermodal freight terminals. A prototype of such tool has is being created, and its part relating to simulating the operations of these terminals is described in this document. First of all, the design and development of a terminal simulation model, based on a library of simulation components, and coupling it to the integrated tool, was successfully carried out. Then the verification, validation, calibration and finally testing based on two case studies was performed. We especially support the following aspects (of EC interest):

- Development of whole system planning environments (based e.g. on virtual design concepts such as BIM – Building Information Modeling) to support the streamlined delivery of infrastructure projects from concept to deployment, with particular attention to the rail sector;
- Solutions for advanced infrastructure capacity planning and modeling for all transport modes.

The La Spezia intermodal terminal was chosen as case study in this written testimony. It is a representative example of a relatively large container terminal in a port, with varying terminal equipment, and a large volume transported by rail. This is the second, next to Melzo test of the integrated tool, complementing the inland terminal with a seaside one. The results of the case study are consistent with expectations and the historical data provided by the terminal operator. The simulation-based decision support environment was successfully applied to the La Spezia intermodal terminal.

- Based on the library of simulation components the creation of a simulation model of the La Spezia terminals was relatively short, compared to traditional simulation studies. Moreover, it was comparable to the Melzo case, which had smaller and less complicated layout. The time it took to create the simulation model (especially the infrastructure) and the testing limited, as unit tests for individual components took less time and effort. In this part, the solution as a whole was also faster to verify and validate. The throughput time of the design with simulation was strongly reduced. This was mainly achieved by strongly reducing the time it takes to create the layout of the infrastructure in the simulation model.

- Traditionally, the layout needs to be entered manually in the simulation software, which is a time consuming and error-prone activity. In the project we have be a connection between the BIM (WP4) and simulation environment. This strongly reduced the time. Moreover, we are confident that further development of the integrated ICT environment prototype will additionally reduce throughput time of similar cases, as the library of simulation components grows along with the experience of using the tool. Integrated tool allows to gather performance indicators from multiple sources and combine them in a coherent and cohesive form. Terminal operational simulation provides a considerable part of the KPIs, related to the terminal performance, equipment usage and processed volumes. Development and integration of Macomi's PSP map editor relates to the biggest gain in time, as it allows to both quickly import the infrastructure layout, as well as easily inspect and test it for the logistics layer. Such solution enables detecting mistakes and inefficiencies quickly, leading to fewer mistakes in simulation testing, which further reduces the time for study, requiring less experimentation time.

Based on the La Spezia case study we can conclude that the simulation-based decision support environment

- Reduces the throughput time of the decision-making process
- Improves the quality of the decision-making process by reducing the number errors that can be made in error-prone processes.

7.2. Future work

The collection of data took longer than expected. Not all data that was required was available, especially regarding detailed historical volumes at the terminal. Furthermore, the quality of the data was lacking is some instances (missing data, wrong values, etc.). In the future, more effort should be spend on collecting data and improving the quality of the collected data in order to obtain more reliable results, more effort should be paid towards collecting data well.

The simulation model of La Spezia will be used in the remaining of the project to test different changes to the La Spezia terminal (virtual cases), also including a new layout for the rail network. We will be able to investigate how additional equipment, changes to infrastructure and perhaps business processes impact the performance in the terminal. Especially, to quickly determine whether envisioned changes prove beneficial in comparison to the base case, presented in this document. Based on this the simulation environmental will be further developed and improved in M18-M28.

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