INTERMODEL EU

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

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D5.1 – Data Model

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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 Performance Indicators (PIs). By integrating simulation modules of the terminal operation and its relationship to the hinterland into a BIM design, both the quickness and the quality of the decision-making will be improved.

The main objective of WP5 is to build a decision support environment that supports in optimizing the design and the operational performance of freight terminals. To reach this objective it is considered a data model that describes all relevant data used in the simulation component library. 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 pilot case studies.

This document shows the results from the T5.1 Data collection. The data model describes how data will be used in the operation simulation models. In order to use a data model, the required input needs to be collected, cleaned and often aggregated, depending on the source. Typically, there has to be a lot of flexibility with regards to input data, especially volume one. Data requirements describes also the necessary information on port and terminal layout, its operations and used equipment. Yet, uncertain or false information might skew the results, resulting in wrong conclusions. That is why data and process validation is of high importance.

The defined data model represents connections varying objects have among each other. Due to the size of domain, their properties and more detailed characteristics are removed from diagrams and put in text or tables. Data model is divided into functional groups, and analysed separately, concentrating especially on infrastructure, network elements, resources and relations among them. Data model supports two types of terminals: container and dry bulk, yet additional terminals can be added if need arose.

As the data model is not useful in seclusion, the last chapter puts it in framework of simulation models and their characteristics, describing certain functional requirements for the data model. It also describes which data is considered input and which output from the model perspective, and how some of the data is handled or generated.

This is a final version updated based on the course of the project, also supplemented with bulk terminals and cold chain depiction for document resubmission.

On behalf of authors,

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1 Introduction

1.1 Scope

To build intermodal terminal simulation models a lot of input data is required from the terminals or terminal designs. The exact data requirements differ from project to project. This document provides a general overview of what data is required to make valid terminal simulation models. There may be additional data requirements for specific projects. Then, it gives a general overview of the data modelling activities, and supporting measures vital in establishing a structure of data for the terminal simulation model. It describes the data architecture, relations between entities, as well as names, types and units of defined variables. Data model also formulates which entries are required, what are possible values of certain fields, and how do they relate to other items.

A data model is a necessary intermediate step to create a conceptual simulation model of a freight terminal hub, and finally to build a simulation tool based on it. The document governs the extent and structure of data in the simulation tool, which builds upon the data from a BIM model. It mostly comprises operational structures and indicators, so that the KPIs defined in D3.1 for terminal simulation can be obtained. For example, it complements the CAPEX figures from the BIM with equipment OPEX values obtained in the simulation. Nonetheless, the data model can be extended with additional indicators, depending on the data availability.

The goal is to create a logical data model, and not a database design, to facilitate the integration of data, disseminate data requirements, expedite communication of data aspects among project participants, and to avoid redundancy in data. It needs to make sure that all identified functional objects are completely and accurately represented. Moreover, a data model allows for easier and better identification of important aspects, addition of new features, and possible correction of mistakes.

Although independent from a physical database, a data model needs to be sufficient to allow creating one. Moreover, a data diagram is completely process independent, and does not describe data transformation. As such, it only deals with data, its structure including relations, but not with how it is obtained, processed or physically stored. These are defined as a part of a conceptual model in deliverable D5.2.

1.2 Audience

This document is written for the participants of the H2020 INTERMODEL EU project.

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.
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: data requirements and data modelling, organized as follows:

Chapter 1: Introduction

Contains an overview of this document, providing its

- **Section 1.1:** Scope
- **Section 1.2:** Audience
- **Section 1.3:** Glossary and abbreviations
- **Section 1.4:** Structure
- **Section 1.5:** Model scope and assumptions
- **Section 1.6:** Port layout depiction

Chapter 2: Data requirements

- **Section 2.1**: contains all data requirements regarding the areas in the terminals and the general layout of the terminal.
- **Section 2.2**: contains all data requirements regarding the volumes that need to be handled and volume composition.
- **Section 2.3**: contains all data requirements regarding the quay, berths and vessels that need to be served.
- **Section 2.4**: contains all data requirements regarding the Container Handling Equipment that is used at the terminal.
- **Section 2.5**: contains all data requirements regarding the stack were the containers are stored.
- **Section 2.6**: contains all data requirements regarding the terminal operations and labour situation.
- **Section 2.7**: contains all data requirements regarding the rail terminal and rail operations.
- **Section 2.8**: contains all data requirements regarding the gate for trucks and the gate operations.

Chapter 3: Data modelling

- **Section 3.1:** contains the model for port and terminal areas and elements, including container terminals as well as bulk ones
- **Section 3.2:** depicts the waterside resources and vessel characteristics
- **Section 3.3:** describes the intermodal transport unit and its division
- **Section 3.4:** contains information on cold chain elements
- **Section 3.4:** models the rail network elements
- **Section 3.5:** models the road network elements
- **Section 3.6:** describes the truck instances and their cargo
- **Section 3.7:** describes the train instances and their cargo
- **Section 3.8:** lists terminal rail yard elements

Chapter 4: Terminal simulation input and output data

- **Section 4.1:** describes how scenarios are created and executed
- **Section 4.2:** informs about replications and their relevance
- **Section 4.3:** describes input data to the terminal operational simulation
- **Section 4.4:** mentions automatic generation of arrival patterns based on historical data
- **Section 4.5:** contains information on the types of output data

1.5 Model scope and Assumptions

Creating a simulation model requires a clear formulation of its scope and made assumptions, as a model is only a simplified version of the actual investigated system. Furthermore, a good practice is to concentrate on modelling the problem, i.e. intermodal transport, so that it is useful to help in answering a set of questions, and not on modelling the complete system as it is. Reducing the complexity of unnecessary aspects or exceptional cases to a valuable framework necessitates careful consideration of which features are requisite, and which are not. This requires certain simplifications and concise boundaries, so that the simulation model is kept clear, manageable and easy to use. Although this needs to be fully formulated at a conceptual model stage, a certain number of them is necessary for the data model as well. This data modelling activity concerns WP5 and depicts only the elements relevant for the terminal operational simulations. Thus, the following are to be included in scope:

- Processes necessary to devise intermodal transport hub, starting with generation and arrivals of the Means of transport (MoTs), their access restrictions to a port or a terminal, handling the MoTs (including loading and unloading), horizontal transport within terminals, stacking of containers in a yard, some special handling processes, and finally departures of the MoTs
- Common processes and equipment in dry bulk terminals;
- Cold chain freight characteristics;
- At least a single freight terminal in a (dry) port;
- Control by simplified Terminal Operating System, mainly related to routing logic and task selection strategies, in accordance with dispatching rules principle.

Out of scope is:

- Anything happening outside of the port, i.e. once the MoTs leave the PBS, port road network or port rail access node[1];

[1] In the WP5 we look at terminals in isolation. WP7 extends the analysis with network connections between terminals. Also WP6 looks into road vehicle arrival and departure from the port and terminals.

- Other terminals, not included in the Intermodel project scope and case studies
- Simulation of individual people and their tasks;
- Incorporation of a full-fledged control system, both for a Terminal Operating System and an Equipment Control System;
- Other traffic than defined MoTs in a terminal or port;
- Handling items that are not intermodal transport units or bulk cargo.

The following design choices and assumptions are made within the simulation model:

- Terminals can always be accessed by road trucks and trains, but not necessarily by vessels, when there is no physical access channel;
- Any box that does not fit ISO container sizes and/or fit within cargo bay container slot is an OOG item;
- MoTs do not break down or require maintenance. Yet, maintenance effects can still be taken into account in the simulation model;
- There are no accidents or any other occurrences disrupting operations of the MoTs, other than the MoTs themselves (like blocking other MoTs due to their location or dependency);
- External MoTs always wait until all of their planned cargo has been unloaded and/or loaded. This way containers are not left behind;
- There are no changes to available CHE or infrastructure during the simulation run;
- Containers do not get damaged or lost, though might require special handling like customs check;
- Containers do not need to be repositioned on a vessel to allow for stripping other containers;
- Sufficient workforce is always available and their activities done in a manner that does not delay operations of modelled equipment;
- Trains are always so called block trains, which arrive and depart from the terminal in the same configuration. During shunting on a terminal however, they can be split or reconfigured for processing purposes;
- Equipment utilised on a terminal is consistent in type. There is no mixing of operations of vastly different types of equipment, i.e. AGVs are not employed at the same terminal area with terminal tractors or straddle carriers;
- Model checks for feasibility of some of the input data and stops giving an error if that is violated, in cases of e.g. vessels not fitting their assigned berth, too small STS cranes to service a vessel, etc.;

- Weather conditions do not disrupt terminal operations. Possible downtime due to e.g. strong wind is incorporated in average number of operational days in a year.

1.6 Port Layout

A schematic overview of a port with two container terminals is shown in Figure 1. It is an explanatory figure to visually represent functional areas in a port, and not a design of any particular port. Especially that some areas are disproportional to typical designs, to emphasise critical places. It needs to be noted that a division of quayside into berths as well as terminal handling area into water side and land side is arbitrary, done during the design process, to facilitate specific needs of a terminal.

As shown in Figure 1, there are three ways to access a terminal within a port:

- By a vessel
- By rail
- By a truck

For the purpose of the project it is assumed that connections by rail and road trucks are always available. In case of a dry port in a hinterland, vessel access might not be possible, even for barges via river.

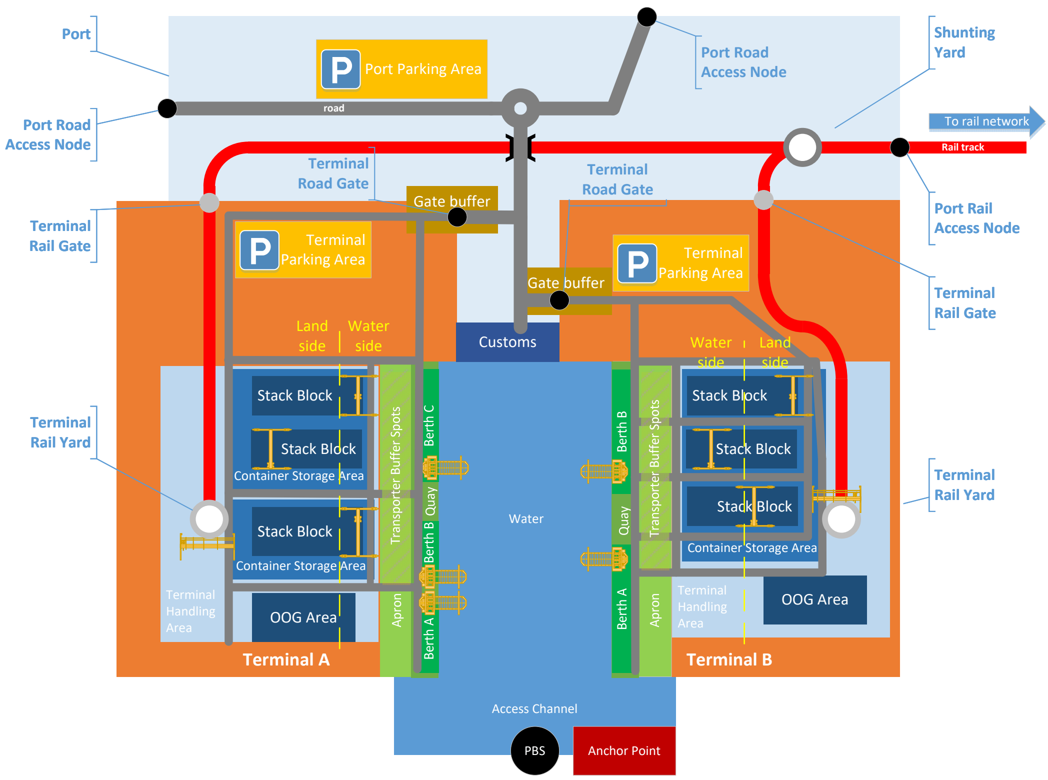

Figure 1. Functional outline of a port with 2 container terminals

2. Data requirements

2.1. Terminal layout, areas and access to the terminal

2.1.1. Layout of terminal and areas

A general specification of the layout of the terminal. The areas that are used and their function and dimensions of:

- Total terminal
  - General dimensions of terminal
  - Dimensions and description of the area (stack, apron, rail yard, etc.)
  - Driving routes within terminal (for both internal vehicles and road vehicles)
- Waterside / berth
  - Quay / berth dimensions
  - Apron dimensions
  - Possible separate area for barge handling
- Stack
  - Stack dimensions (length, width and height in TEU)
  - Number of ground spots and stack positions
  - Special stacks for reefers
- Rail facilities / terminal
  - Dimensions of rail facilities
  - Number of tracks (sidings and process tracks)
- Truck gate
  - Dimensions of gate area
  - Number of gates (in/out)
  - Description of gate process
  - Scanners (nuclear and/or x-ray)
- Empty depot / yard
  - Capacity (storage)
- Inter-terminal facilities (ITT)
  - Dimensions of areas

Drawings and/or designs of the terminal layout as detailed as possible. Preferable in

- CAD format (DWG, SFX, etc.)
- Industry standard formats, such as Land XML, RailML
- PDF

2.1.2. Access to terminal

There are different types of access to/from the terminal:

- Deep sea access terminal
- River access terminal
- Rail access terminal
- Road access terminal

Required information

- A map of the port area with access routes
- Rough capacity of access (e.g. #vehicles-vessels-trains/hr or number of lanes)
- Possible restrictions or limitations (such as nautical depth restrictions/tides)

2.2. Terminal volumes and flows

The volume that is, or expected to be, handled by the terminal. The volume is divided into containers and other cargo.

2.2.1. Container volume data

Table II. Container volume

Data required	To be filled in by terminal
Total quay volume containers • Yearly basis (In TEU)	
TEU factor • General boxes	
Built-up of volume • Import (%) • Export (%) • Transhipment (%)	
Box types distribution • Normal boxes (%) • Reefers (%)	

• Tank containers (%)	
Dwell times • General or average (days) • Import/export (days) • Transhipment (days)	
Peak factors monthly • Waterside (#) • Gate (#) • Rail terminal (#)	
Peak factors daily • Waterside (#) • Gate (#) • Rail terminal (#)	

2.2.2. Other cargo volumes data

Other such as ore, (liquid) bulk, oil, etc.

Table III. Other cargo volumes

Data required	To be filled in by terminal
Total quay volume other cargo • Type • Amount (tons) • Yearly lifts for OOG (#)	

2.2.3. Targets

The aimed performance for which the terminal is designed.

Table IV. Performance targets

Data required	To be filled in by terminal
Throughput per quay • TEU/m	

Throughput per area • TEU/ha	
STS/BC productivity • Mph • Lifts/year	
Vessel / berth productivity • Mph	

2.3. Berth and vessels

2.3.1. Berth data

A description of the berths that are used.

Table V. Berth data

Data required	To be filled in by terminal
Deep sea quay/berth • Length • Number of berths (starting points and length) • Depth of apron	
Hatch cover handling • Location	
Twist-lock handling • Location	
Barge berth • Length • Depth of apron	(in case of dedicated berth)

If available a drawing or sketch of the berth and its dimensions.

2.3.2. Vessel data

Table VI. Vessel data

Data required	To be filled in by terminal
Vessel types • Vessel type/class • Length (m and TEU) • Width ((TEU) • Height (TEU) • Call size (bx) • Required productivity (bx/hr)	
Arrival pattern of vessels • Weekly basis	
Berthing schedule • Arrival (ETA) • Location (berth) • Number of STS	

2.4. Terminal equipment

All data related to the terminal equipment or Container Handling Equipment that is used at the terminal for the handling of containers/cargo and secondary processes.

Table VII. Terminal equipment data

Data required	To be filled in by terminal
Ship-to-Shore cranes • Type of crane (with or without platform, working between legs, etc.) • Number of cranes • Productivity (mph) • Types of possible lifts (twin, tandem, dual cycle) • Supplier and type • Width/ span (TEU or m)	

• Lift height • Outreach • Maximum hoist load (tons)	
Barge / feeder cranes • Number of cranes • Productivity (mph) • Supplier and type	
Stacking equipment (Strads, RTG, ARMG, etc.) • Number of cranes • Productivity (mph) • Supplier and type • Operational height (e.g. 1 over 3 or 1 over 4, etc.)) • Stacking span (width of a stack)	
Horizontal transport (WS-stack) • Type of transport (Terminal Tractor / AGV / shuttles) • Numbers of transporters • Speed (km/h) • Capacity (TEU / bx)	
Horizontal transport (stack – rail terminal) • Type of transport (Terminal Tractor / AGV / shuttles) • Numbers of transporters • Speed (km/h) Capacity (TEU / bx)	
Rail cranes • Number of cranes • Productivity (mph) • Supplier and type	

2.5. Stack

Table VIII. Stack data

Data required	To be filled in by terminal
General orientation • Parallel or Perpendicular	
General size • Total number of ground spots (TEU) • Total storage space (TEU) • Average utilisation / filling rate (%)	
Stack blocks • Number of blocks (#) • Length (TEU) • Width (TEU) • Height (TEU)	
Transfer zones • Dedicated lanes (#) • Number of spots (#)	
Reefer stack • Total number of ground spots for reefers (TEU) • Total storage space reefers (TEU)	
Empty containers • Total number of ground spots (TEU) Total storage space (TEU)	(in case of dedicated empty yard)
Stack Container Handling Equipment (RTG, straddle carriers, ARMG) • Productivity (mph) • Working height (1 over 4, 1 over 5, etc.) • Width/span (TEU)	

Table IX. OOG handling

Data required	To be filled in by terminal
Description of OOG handling process	
Container handling equipment used for OOG • Type • Number • Dedicated (or pooled with other CHE)	

2.6. Terminal operations and staffing

Table X. Terminal operations and staffing

Data required	To be filled in by terminal
Overview of the shift- structure • Number of shifts (#) • STS / QC pool (# of employees) • CHE pool (# of employees)	
Opening days of terminal per year • Berths /WS (#) • Gate(#) • Rail terminal (#)	
Opening hours berth /WS	
Opening hours gate	
Opening hours rail terminal	

2.7. Rail Terminal and operations

This section focusses on the specifics of the rail operations of the terminal.

Table XI. Rail terminal and operations

Data required	To be filled in by terminal
Layout of rail terminal • Number of tracks (#) • Length of tracks • Driving routes stack – rail • Buffer positions (#)	
Horizontal transport stack-rail • Type • Number of vehicles • Decoupling?	
Trains • Type • Length (m) • Number of wagons (#) • Number of TEU • Call size (TEU)	
Train process • General description of the rail process • Process times	(for example: train arrival, decoupling locomotive, (un)loading, etc.)
Weekly arrival pattern trains • Type of train • Arrival time • Length of train • Call size (boxes) • Origin • Destination	

2.8. Gate and operations

Table XII. Gate and gate operations

Data required	To be filled in by terminal		
Yearly gate volume (TEU)			
Containers to be handled	Delivery	Pickup	%
	0	1	
	0	2	
	1	0	
	1	1	
	1	2	
	2	0	
	2	1	
	2	2	
3 TEU trucks	(if applicable)		
Peak hour performance (TEU/hr)			
Weekly pattern	day	%	
	Monday		
	Tuesday		
	Wednesday		
	Thursday		
	Friday		
	Saturday		
	Sunday		

<table>
<tr><td>Data required</td><td colspan="2">To be filled in by terminal</td></tr>
<tr><td rowspan="13">Daily pattern</td><td>Hours</td><td>%</td></tr>
<tr><td>0-2</td><td></td></tr>
<tr><td>2-4</td><td></td></tr>
<tr><td>4-6</td><td></td></tr>
<tr><td>6-8</td><td></td></tr>
<tr><td>8-10</td><td></td></tr>
<tr><td>10-12</td><td></td></tr>
<tr><td>12-14</td><td></td></tr>
<tr><td>14-16</td><td></td></tr>
<tr><td>16-18</td><td></td></tr>
<tr><td>18-20</td><td></td></tr>
<tr><td>20-22</td><td></td></tr>
<tr><td>22-24</td><td></td></tr>
<tr><td>High gate process description
Steps (name/description)
Process times (s)</td><td colspan="2">(for example: security gate in – visual gate – administrative gate)</td></tr>
<tr><td>Overflow for trucks
Number of parking spots</td><td colspan="2"></td></tr>
<tr><td>Number of lanes
In (#)
Out (#)
Combined (#)</td><td colspan="2"></td></tr>
</table>

If available a drawing or sketch of the gate and its dimensions.

3. Data Modelling

A relational approach to describing a data model, i.e. an abstract organisation and standardisation of distinguished aspects, is chosen. Characterising it as a collection of predicates has many advantages, ranging from storing the data only once to allowing for future expansion. As a method, an entity-relationship (ER) model using the Crow's foot notation (Coronel & Morris, 2014) is selected for documentation purposes, as one of the most commonly used forms.

Microsoft Visio 2013 is used to create a logical model in the Crow's foot notation (Microsoft, 2016). Due to considerable size, not all relations are drawn in the diagram, the attributes and data types are also omitted. Moreover, generation of MoT arrivals as well as data output is treated separately. A simplified diagram without attributes is shown in Figure 14 in the Appendix, due to its considerable size. Detailed tables describing the attributes, units, requisite values, are included further on.

3.1. Port infrastructure

A port is defined as a location on a coast with at least a single terminal, at which a ship can moor and transfer cargo or passengers. In this project a starting point is a port with a single container terminal, which is to be extended to multiple terminals in the future. For example, Port of Rotterdam has 13 container terminals (Port of Rotterdam Authority, 2016), though some of them are rather small. In the middle of Figure 2 this basic relation is shown, among other connections to, mostly infrastructural, elements of a port.

Only a seaport has components connected to water. A vessel arrives at a pilot boarding station (PBS) according to its schedule. This location is a boundary (access point) for the model. If an entry is impossible at a given time, a vessel has to wait at an anchor point (AP), until it can gain access to a berth. Travel from the PBS to a berth happens via an access channel or river. Depending on the location of a terminal, the duration of the sailing differs. Crossing the access channel can be further limited by access restrictions, due to e.g. changing water depth (tides), storms, ice or even safety regulations (like daylight requirements), and locks. As the weather conditions change over time, they have a direct link to access restrictions, and sailing time durations. Ships moor at a particular terminal, which has a quay, divided into berths. A berth is a functional division of a quayside, often varying in length and water depth. Because of that, sometimes more than a single vessel can be moored to a berth at given time, provided there is space for that. As such a berth determines the maximum length of a ship it can accommodate.

Berths can further be categorised into deep sea and short sea/inland, with appropriate equipment always at hand. A quay is encompassed by an apron, an area supporting handling of ships, and not storing containers. Naturally, a dry port has neither a quay, nor an apron.

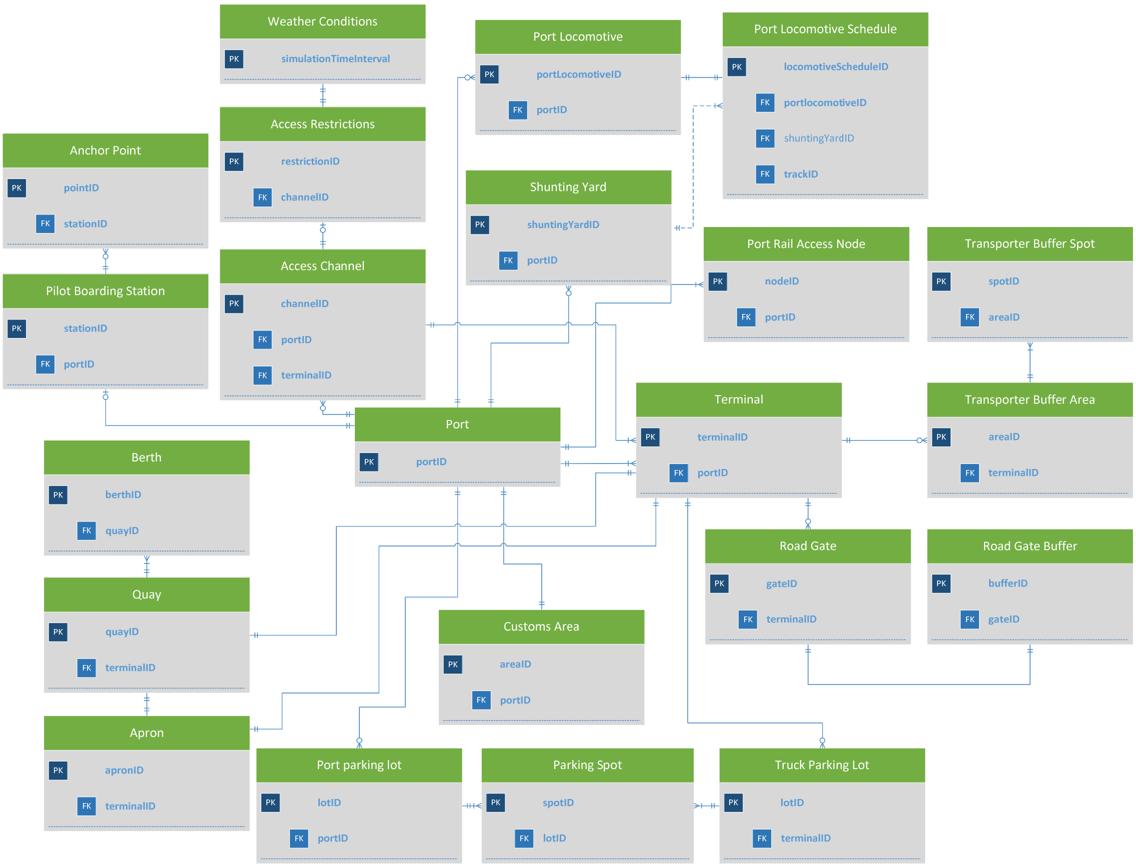

Figure 2. Port infrastructure elements

A port might have a parking lot for incoming external trucks, which for some reason do not enter their destination terminal, but have to wait. Such car parks have a certain capacity and are built up of parking spots, where a spot is a place for a single truck or trailer. Similarly, terminals have parking lots for external trucks to wait, but also for internal transporters. If desired the spots can be limited to a particular type of transport. External trucks enter a terminal via a road gate, where several processes, including identification or inspection are carried out. In case of irregularities there is a road gate buffer, where special handling can be done. Then, just for internal transporters there can be buffer areas, consisting of buffer spots for a single transporter, where they are gathered expecting to be soon required to process a ship.

Trains access the port via a port rail access node to normally arrive at a shunting yard, where they are processed and sent to terminals. A port can have a few shunting yards to assemble trains, wait, perform inspections, etc. Each of them is comprised of several siding tracks, where the trains can be parked in a manner not disrupting other trains. Often at a shunting yard, external electric locomotives are swapped with internal diesel ones, as the tracks are not always electrified. Port locomotives are thus a resource of a port, enabling trains to enter the terminals. Moreover, some terminals, especially liquid bulk terminals, employ additional shunting locomotives for manoeuvring within terminals like assembling trains, moving detached railcars or servicing loading stations. Some trains need to access multiple terminals, according to their schedule, and might wait at a terminal or a shunting yard. Port locomotive's schedule defines then at which point a port locomotive needs to be at a shunting yard to be attached to a train, and then executes the schedule of the train. Small ports might not have a shunting yard, in the case of which a train proceeds directly to a terminal's rail yard via a rail gate.

A port also has other functional areas on land, the most important of which for the project is customs area. Customs officials can call in containers for inspection, which requires additional handling.

3.1.1. Container terminal elements

A terminal, or container terminal in this case, has a few functional areas and some equipment characteristic to its operations. It is assumed that a terminal has a single terminal handling area (shown in top left corner in Figure 3), which is a part of a terminal, where operations on ITUs are carried out. It is an arbitrary modelling decision to distinguish one, and it does not limit multiple separate stacks, OOG or empties areas.

Although there are other functional areas within the terminal handling area the data structure distinguished two: out of gauge (OOG) and container storage areas, which are used for storing out of gauge items and containers respectively. In an OOG area items are placed on the ground and not stacked. Container storage area consists of typically several stack blocks, i.e. separated segments of containers. Stack blocks can be regular (mixed) or for empty containers, and they are defined by their ground spots and height.

A set of ground spots comprise a plan, called a stack map, on where what type and length of container is placed in a stack block, so that the TOS can make planning based on that, which includes the standardised width and height considerations as well. It is not common that a stack map configuration is changed or that different types of container are placed on not-corresponding spots. A stack spot is a location in a bay-row-tier nomenclature of where a single container can be placed. Every stack spot has a corresponding ground spot, and for stack spots in tier 1, they are equivalent to their ground spots.

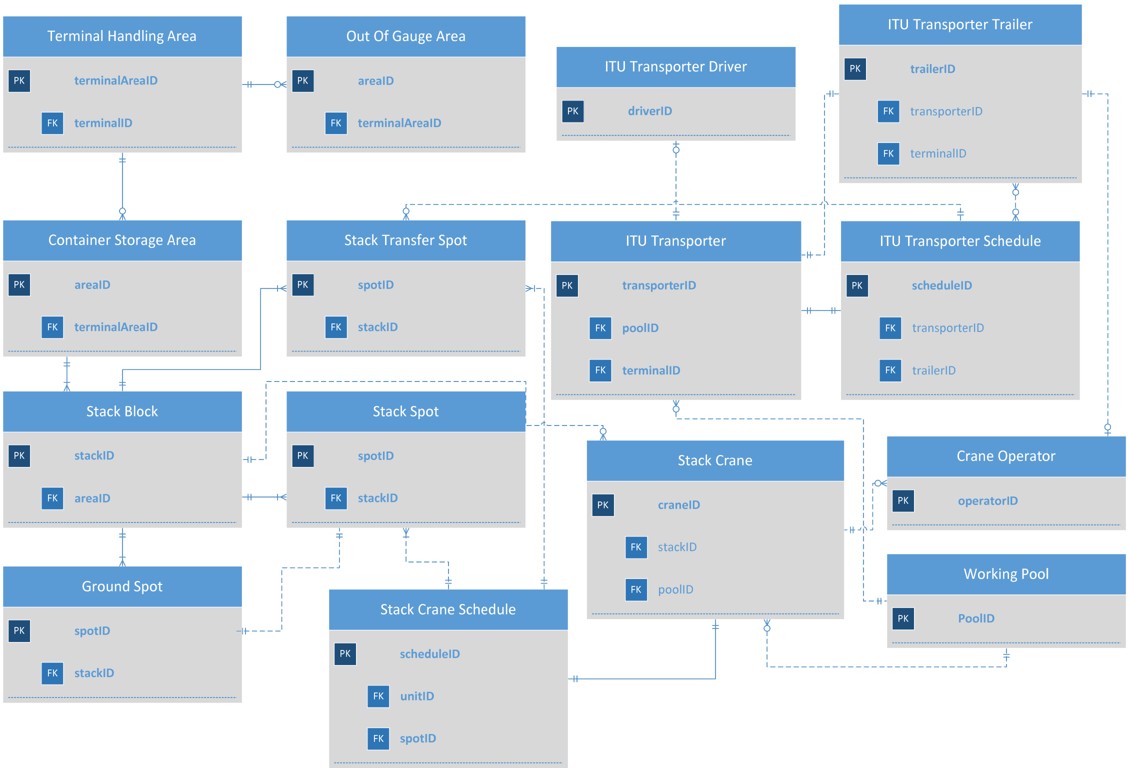

Figure 3. Container terminal elements depiction

A stack block can be serviced by a single, or multiple stack cranes, especially when the terminal utilises RTG cranes or straddle carriers. A crane picks a top container from the stack and moves it to one of the stack's transfer spots, where an internal transporter or external truck is already waiting, and places it on top of a trailer. If the desired container is not on top, a so called digging needs to be done, which is moving other containers from above the desired one to other places in the stack, before grabbing the right container. Picking containers and placing them in the stack is done in a similar manner. To limit the amount of unproductive moves and the time loss when digging for containers, a process called housekeeping is executed during less busy periods. It is generally known when containers will be removed from a stack, and preparations can be made to shift their positions in the stack to more efficient ones. As it is a complex process that needs to accommodate sudden changes and incoming containers to the stack, its control is carried out by the TOS.

A stack crane abides a schedule, that defines which containers need to be moved and where. It can also contain movements characteristic to more complex stack blocks with multiple cranes, defining container handovers or avoiding conflicts and deadlocks. A crane might have and operator, controlling its behaviour, and some support workers, handling locks, plugging reefers etc.

An ITU transporter is a horizontal transporter, transferring ITUs between areas within a terminal. It can be a terminal tractor, an AGV (both with a fixed or detachable trailer), or a shuttle carrier. In some cases, where straddle carriers are used, horizontal transport and stacking is done by the same vehicle. In case trailers for ITU transporters are detachable, a trailer can be decoupled at a parking or buffer spot to be serviced, while the transporter goes to perform further tasks. This obviously introduces and additional layer of scheduling complexity. However, while transporters must have their own schedule to know when and where to go, additional schedule is not required by a trailer, even though it influences the main transporters movements. This is because a trailer does not have a propulsion and is completely dependent on the ITU transporter. Then, terminal tractors and possible shuttle carriers require a driver to operate.

Cranes or transporters can be in a pool, which is a distinguished group of resources working together. Sometimes several internal transporters are bundled to a particular crane and service only it. Such approach significantly reduces scheduling complexity, but is a less efficient way of resource utilisation.

3.1.2. Dry bulk terminal elements

Dry bulk cargo differs from containers most of all in granulation. As containers only come in full boxes, bulk is measured with tonnage or volume. For simulation purposes, bulk cargo is typically discretised into equal batches, each holding e.g. a metric tonne of material. All storage compartments must be then multiplications of this batch.

Figure 4 depicts typical elements present in dry bulk terminals. A terminal can have multiple handling areas, each holding some piles, silos and possibly hoppers. Some might have conveyors to transport cargo without intermediate moveable equipment. In general, only one type of bulk cargo can be stored in individual piles, silos, hoppers, or within a vehicle. Piles are open-air heaps of material taking certain area and with limited, though high, capacity. Silos can hold certain volume of cargo, and are mostly used in order not to contaminate it during storage (for e.g. crops or powders). Silos might have conveying systems of certain capacity attached to load and unload. Then hoppers allow gravity unloading to holders put underneath them.

Bulk cargo can be transported on bulk carrier vessels, or tip-cart trucks, as well as in bulk railcars (mostly open top or hoppers) or separate bulk containers. All have certain capacities, and properties similar to their class of vehicles: vessels, trucks, railcars and containers respectively.

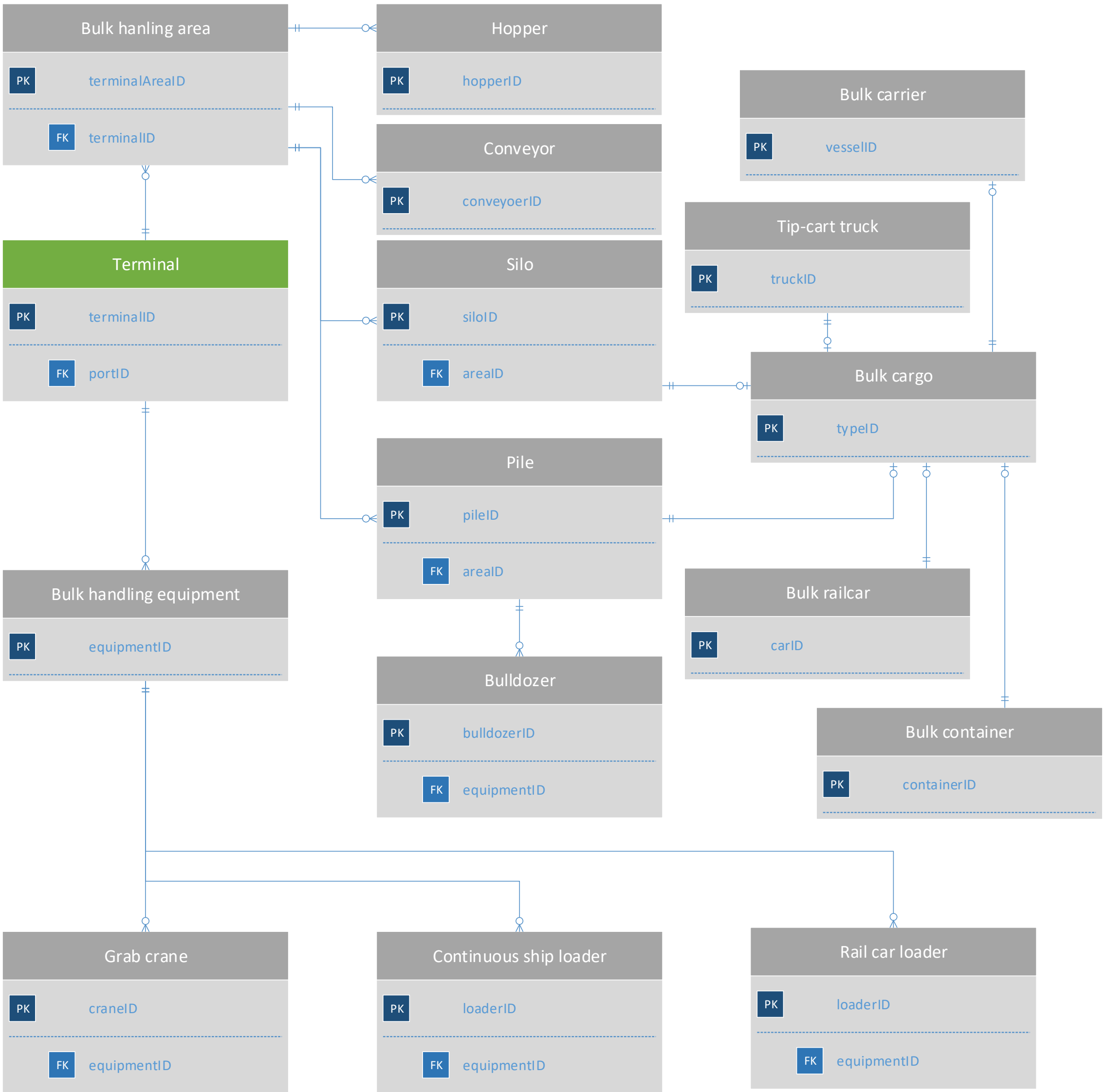

Figure 4. Dry bulk and related resources ERD

Large piles can be also serviced by bulldozers, which typically serve as auxiliary equipment. The loading is done by grab cranes with hoist and bulk material bucket attached. For medium and large terminals continuous ship loaders can be used, which do not grab small portions of materials in buckets, but rather suck up material continuously, with higher capacity. These can be divided into ship and rail loaders.

3.2. Waterside resources and vessels

A diagram for waterside resources and vessels is distinguished in Figure 5.

A container vessel is the central entity in the diagram. A vessel, as any other entity is identified by its ID, which can be e.g. its name. A container vessel typically is a deep sea ship but can also be a coastal feeder or inland barge. Every container vessel has exactly one bay plan, which is a description of slots for containers on the ship. Thus, it can be known which types of containers can be placed where, and what is their exact place.

A container vessel also has exactly one mooring schedule, i.e. a plan for arrivals at its destinations at a particular time. Estimated time of arrival is given for its reaching assigned berth. In some ports or for some vessels it is necessary to use a tugboat to help manoeuvre the container vessel, due to e.g. physical limitations of the access channel. A vessel type also has indirect influence on access restrictions, mainly due to its length or draft.

Moreover, many ports require a pilot to assist in leading a vessel from the pilot boarding station (PBS) to the berth, mainly for safety reasons. Tugboats and pilots are resources of a port, and not a particular terminal. Neither tugboats nor pilots are required for an inland waterway transport.

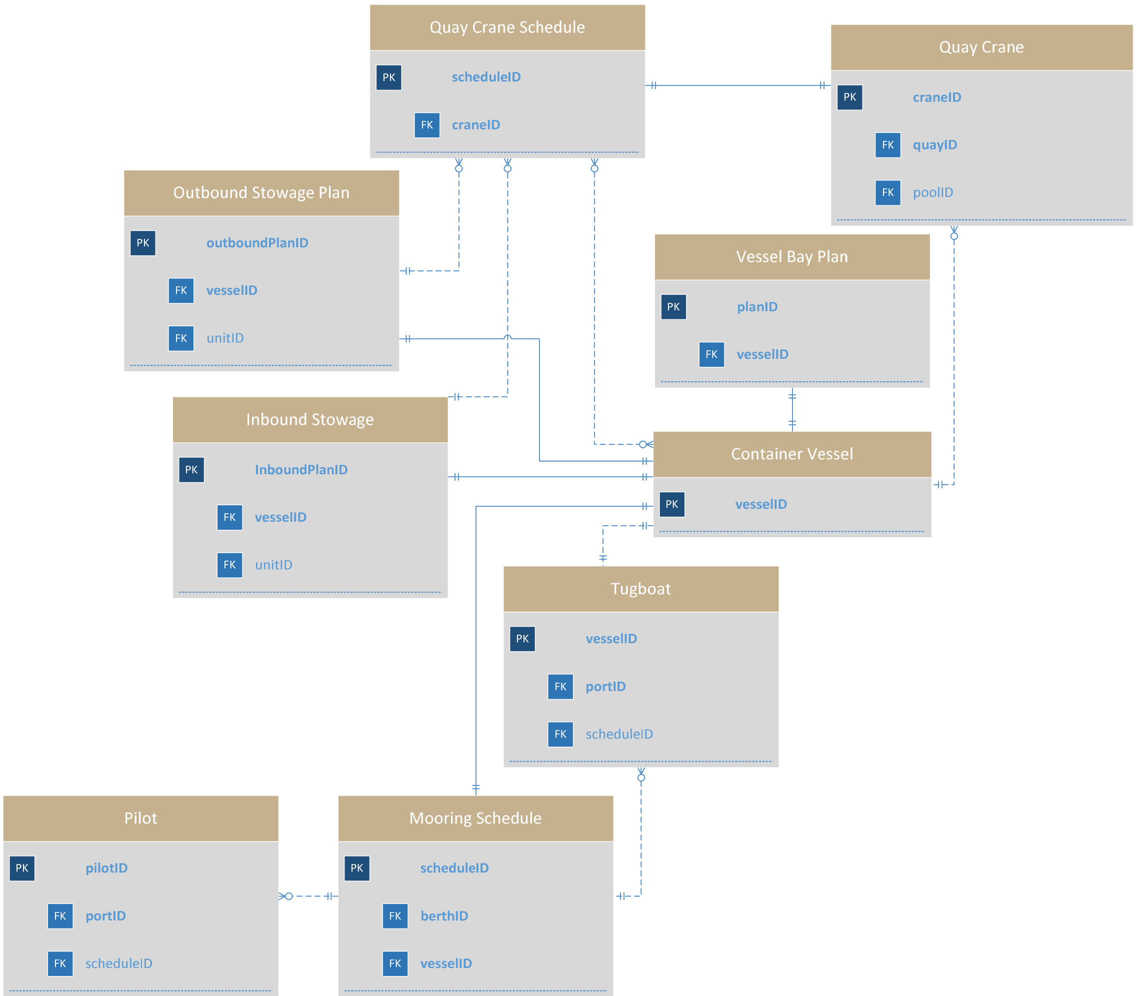

Figure 5. ERD part displaying waterside resources and vessels

When it comes to cargo, a vessel is generated at a Pilot Boarding Station (PBS) and comes to the terminal with a certain cargo on board, called inbound stowage. This describes which slots are occupied, and what sizes the containers have (The German Insurance Association, 2017). Similarly, there is a plan for outbound stowage, which is the cargo with which the vessel should leave. The difference between inbound and outbound stowage is the handling done at the terminal, thus a similar approach as BAPLIE. The order in which the containers are stripped or loaded to a vessel is not a concern for a vessel, as it is moored just waiting to be serviced.

Inbound and outbound stowages have an impact on the schedules for quay cranes. Each quay crane has a single schedule (or dispatching rules), defining where to be when, how to service a vessel and how to interact with other cranes as well as internal transporters. Typically a quay crane has an operator and a few supporting workers for handling e.g. twist-locks, visual container inspection etc.

3.3. Intermodal Transport Unit

An intermodal transport unit (ITU) is not a name of a single type of object, but rather a collective name for several, different types of standardised transportation units suitable for multimodal transport including containers, semi-trailers and swap bodies. For the purpose of the simulation model two types of ITUs are distinguished: containers and out of gauge items, as shown in Figure 6. Intermodal transport unit (ITU) split

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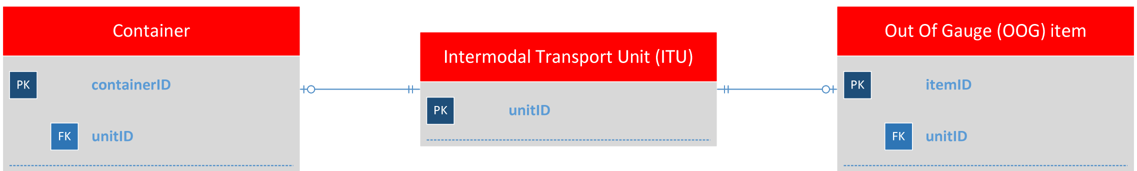

Figure 6. Intermodal transport unit (ITU) split

A container is a box with sizes in accordance to ISO norms, which can be stacked, and placed and secured in pre-constructed slots, especially on a ship. A container also can be easily handled by an STS crane, and is distinguished by its length and type. Container types include general purpose, refrigerated (reefers), tanks, among others. Standard container lengths, expressed in feet, are 20’, 40’, 45’ and 53’.

Out of gauge item describes a unit, which is not stackable in the regular stacking blocks. There are several reasons why their stacking is not possible, including lack of upper corner fittings. Their width and height also prevents them from fitting into standard container slots. Although swap bodies are typically sized in accordance to ISO container dimensions, their use is limited to rail and truck transport within Europe. OOG items are stored in a separate area on the ground, with a certain packing density.

3.4. Cold chain elements

The term cold chain refers to temperature-controlled supply chain, the main purpose of which is transporting refrigerated goods in an unbroken chain, at a specified low-temperature range. Data connections and structure for cold chain are depicted in Figure 7. In general, cold chain goods are shipped over long distances using three different types of boxes: reefers (refrigerated containers) with their own cooling equipment, insulated containers able to sustain low temperature for some time, and refrigerated swap-bodies, that connect to truck power supply to maintain low temperature.

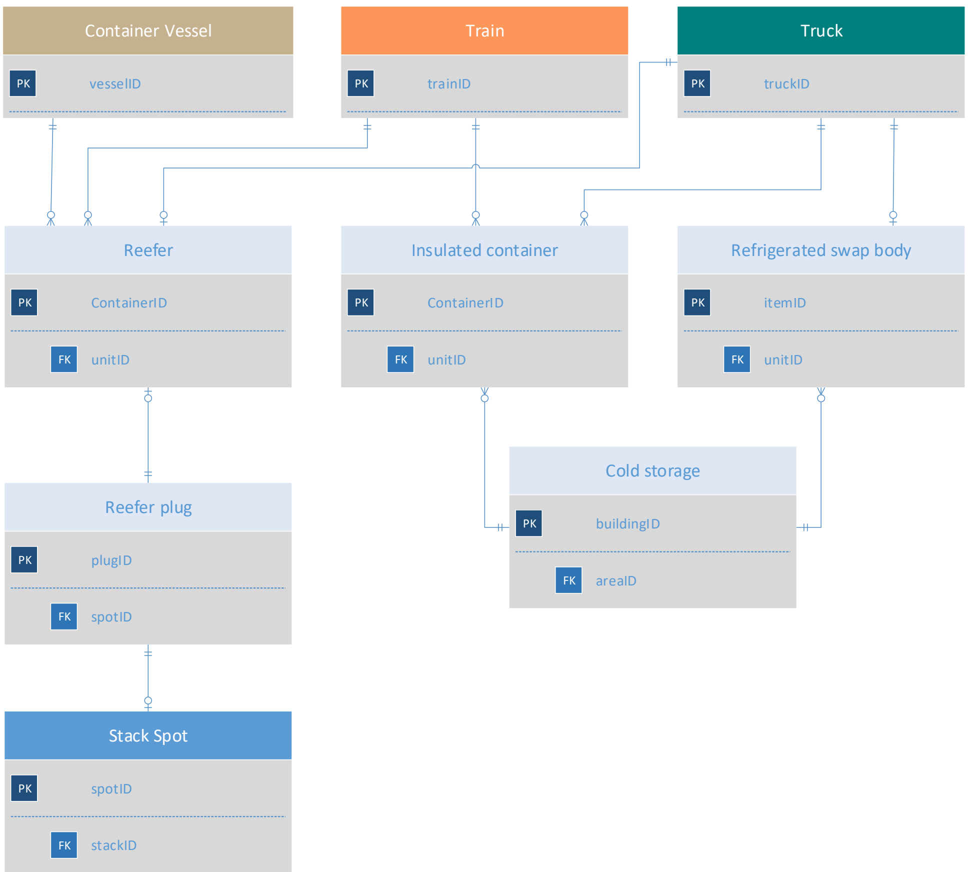

Figure 7. Cold chain data structure

Reefers are most popular and can be loaded on container ships or kept in stack, connected to power supply of the terminal. They can be disconnected from power only for short periods, like for transportation within container terminal, which can be done by a regular equipment, as for other containers. Insulated containers and refrigerated swap bodies are usually put or connected to cold storage warehouses on a terminal.

3.5. Rail network elements

A rail network enables train movements to terminals and other destinations, describes the available connections and rail infrastructure. Rail network elements encompass the model and connect areas, especially rail yards within terminals. Network consists of multiple rail tracks connected to each other. Sets of continuous tracks can be grouped into corridors, when joining distant locations. Moreover, a track consists of several speed points that are demarcations on allowable speed for a train.

Structurally a track is built of track points, connected in lines, which define its shape. They have spatial coordinates defined and together determine the length of a track. Since tracks need to start and end with a track point, a single track point can be part of more than one track. A track configuration determines the sequence of track points within a track, so that it is exactly known how the connections are built. On the other hand, a rail junction might separate three or more tracks and enable connections among them. A junction has a certain type, which defines its necessary parameters. Since the tracks usually go in pairs for movements in opposite directions (which is just a routing choice as tracks are always bidirectional), junctions can be complex, and thus sometimes some movements and connections might need to be structurally limited. A rail junction limitation might define from which tracks to which movement is not possible and whether it is bidirectional.

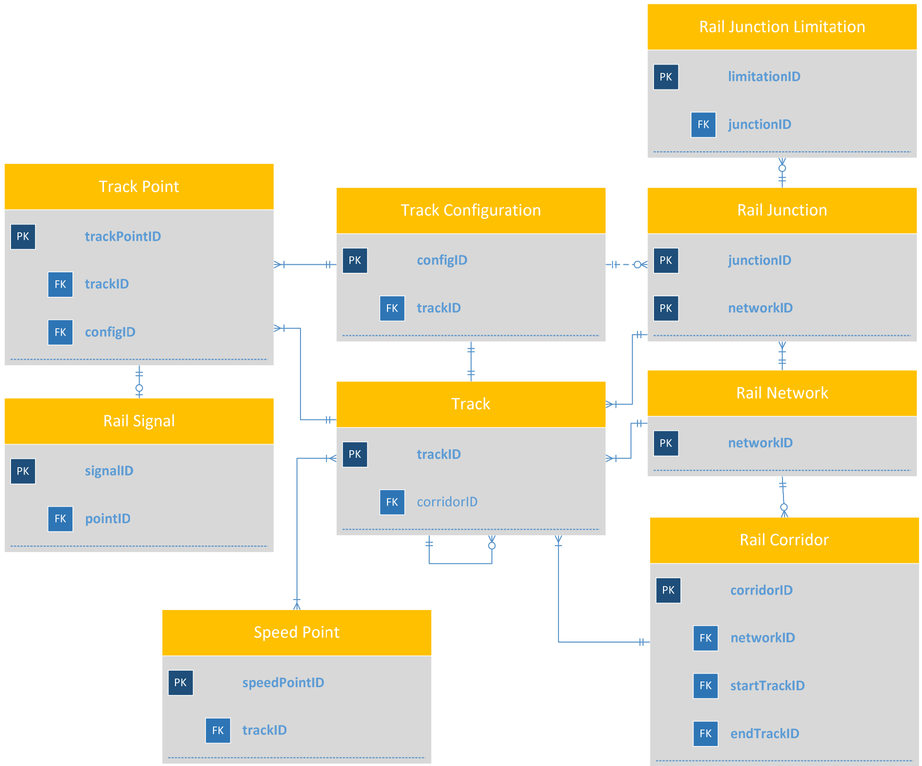

Figure 8. Rail network elements structure

Finally, a track point might have a rail signal for managing traffic, which works similarly to a traffic light, forcing the trains to stop. For a rail signal it is important to know about its direction.

3.6. Road network elements

Road network is built differently than rail network. Due to the scope, a road network is modelled only within a port, and ranges from the road gates to terminal aprons. All external trucks and internal transporters use road network exclusively. A port road network has a set of network routing rules, defining the allowable behaviour of vehicles, including priority rules or road crossing conduct. Terminal internal transporters use only part of the network, and are prevented from crossing a road gate. Moreover, terminals internally can have limitations on using their internal road network by certain types of vehicles. These can be set for individual roads.

A road network consists of roads and connecting them intersections. A road, typically unidirectional, has a start and an end node and a single node can be a part of many roads. If two, then it is a simple road connection, and if more then there is an intersection at that node. In the model intersections are simple, do not include spatial complexities, and the traffic on them is governed by the network routing rules.

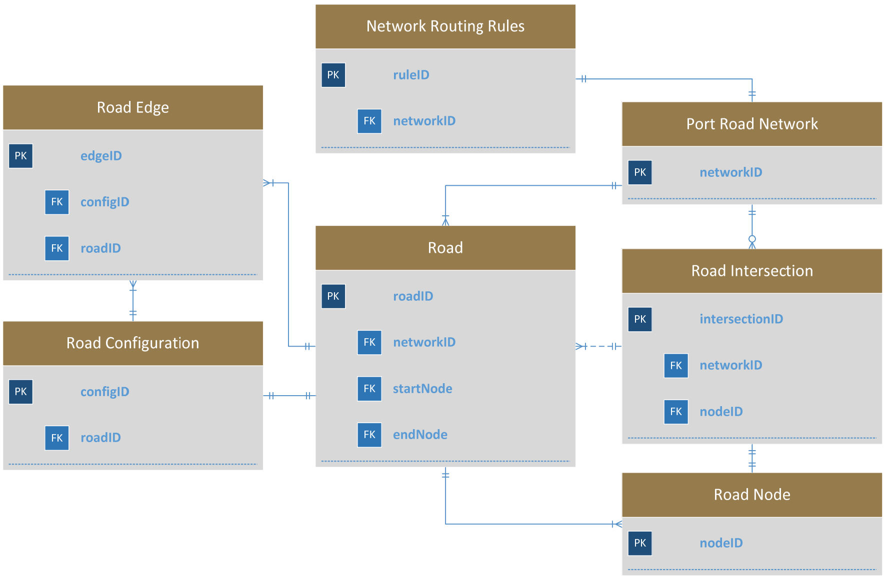

Figure 9. Road network elements structure

A road consists of road edges, with a particular geometry and length. This way various road shapes can be modelled, without defining multiple roads. Sequence of edges is defined in the road configuration, specific for every road.

Finally, as a road is usually unidirectional, two-way traffic is modelled with two separate roads. Unidirectional roads do not necessarily restrict obstacle avoidance, overtaking, or in general using the opposite direction lane in some cases.

3.7. Truck instance elements

A truck or external truck is a vehicle that brings ITUs to the terminal and/or takes them away to deliver to their destination. Arrival and departure of an external trucks are their boundary processes, meaning they are created on arrival and removed from the road network as soon as they leave. No outside processes are modelled. Truck generation is subjected to truck's arrival schedule, containing data on when to arrive at a terminal and the planned departure. All processes within the terminal, including required cargo and destinations, are governed by the truck's inter-terminal schedule.

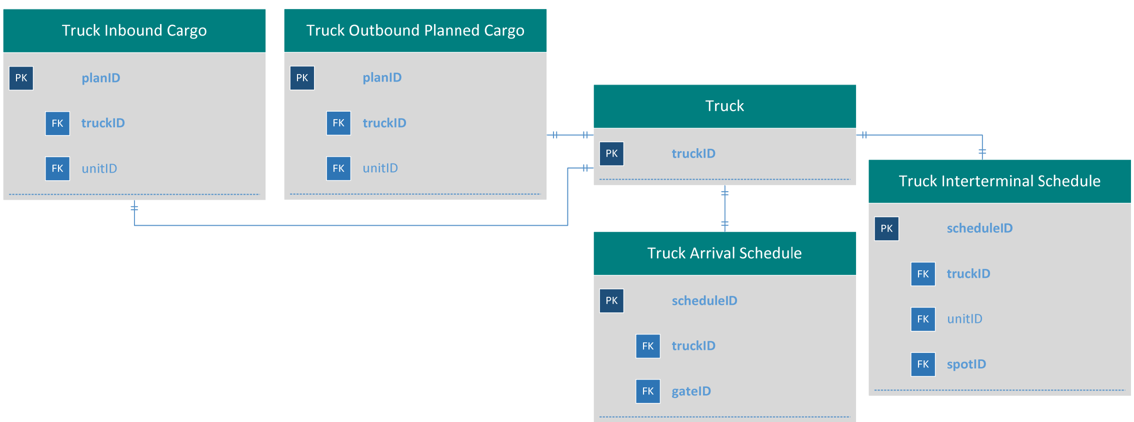

Figure 10. Track instance element depiction

A truck arrives with a certain amount of inbound cargo, which can be up to three ITU's, though usually it is zero or one. Every truck also has a planned outbound cargo, and the difference between the inbound and outbound cargo is the amount of work that has to be carried out on a truck, just as in case of a ship, but in smaller scale. Trucks typically drop or pickup cargo at a stack, though in some rare cases, especially with valuable or dangerous goods, trucks can also proceed directly to a quay crane or rail yard transfer spot.

3.8. Train instance elements

A train is a combination of a locomotive and railcars, which travels on tracks. From a conceptual standpoint, a set of railcars or a single locomotive can also be a train. Certainly, a train arrives with an external locomotive and a set of railcars, the sequence of which is defined in the train configuration element, as shown in Figure 11.

Train configuration also describes any required changes of the locomotive. A locomotive must always have a driver. Railcars on arrival might carry ITUs to be dropped off. Rail workers service trains throughout their stay in the port and at the terminals.

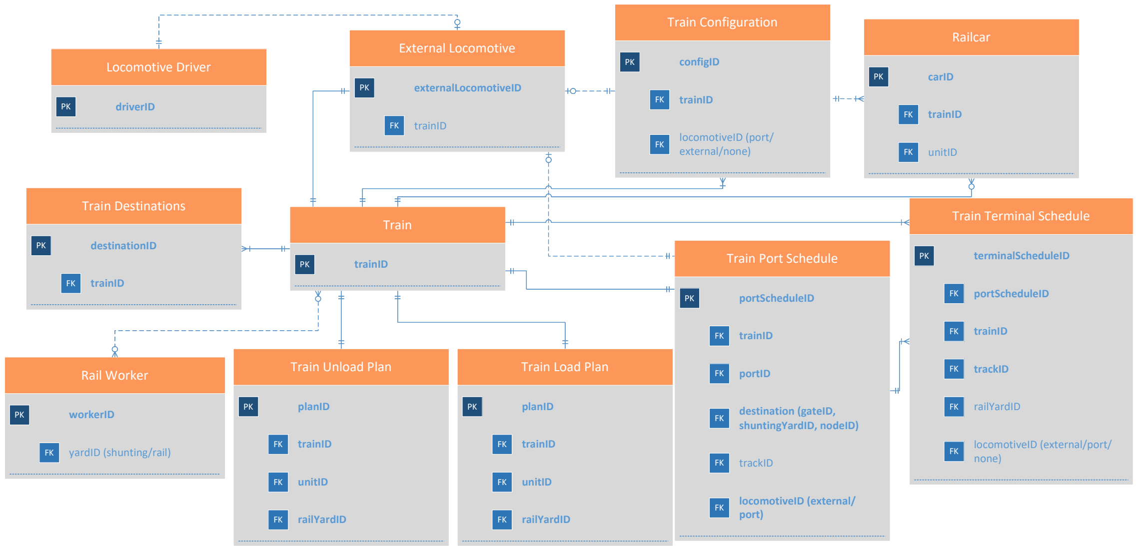

Figure 11. Train instance element depiction

Similarly, to vessels and external trucks trains have unload and load plans, the only difference being that the plans for the trains accommodate stopping at multiple terminals. That is why these are called plans and not stowages. Terminals to visit are recorded in the train port schedule, together with estimated times of arrivals there. A train has a single port terminal schedule, which also describes when locomotive changes are done. Within each visited terminal, there are different schedules. They describe which track at the rail yard to go to, and how long are the activities to take. Moreover, port locomotives are often decoupled from a train when before loading activities start, and go to service other trains. This information is also included in the train terminal schedule. Finally, a train has a set of destinations outside of the port to be reached at a specified planned time.

3.9. Terminal rail yard resources

Terminal rail yard is a location where trains are loaded and unloaded. A train enters a terminal via a terminal rail gate, where first inspections are performed, and stops at one of the tracks on the terminal rail yard. Rail workers described in the previous section also work at a rail yard, or at a shunting yard.

Figure 12 shows the terminal rail yard data components. A terminal rail yard uses rail cranes to transfer cargo between the trains and horizontal transporters. Rail yard crane is of a certain type, typically and RMG, and has a span (width) to be able to handle the tracks on the yard. The handover happens in one of the rail yard transfer spots, a special places where vehicles can stop and where cranes can reach. Rail yard crane abides its schedule to move containers from one place to another. Rail yard cranes can also move an ITU from one train directly onto another train or a vehicle (both external truck and internal transporter).

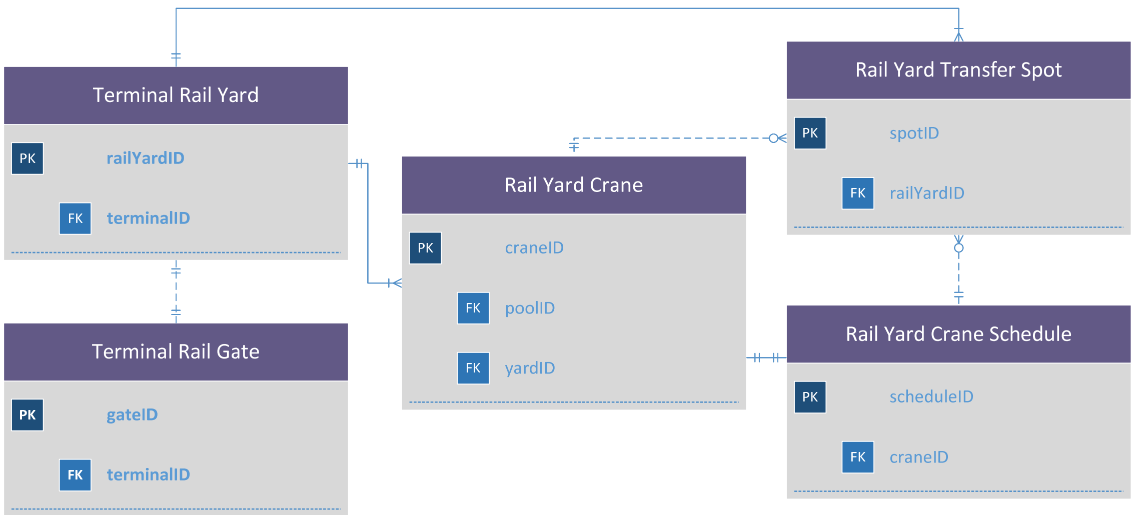

Figure 12. Terminal rail yard elements depiction

4. Terminal model input and output data

Data requirements are formulated in chapter 2. That data needs to be transformed and incorporated into the devised data structure. This chapter concentrates on some specific aspects of input and output data.

4.1. Scenario handling

An important aspect of simulation studies is the ability to be able to accommodate multiple scenarios, sometimes called experiments, which require significantly more storage space. Most typical approaches consist of defining a default Baseline scenario, which is then duplicated, together with entire model I/O data structure, i.e. user configurable input settings and gathered model outputs: logs, result tables, performance indicators, etc.

Moreover, in order to run a scenario, a starting point and investigated duration are also necessary. For this case of either a terminating or non-terminating simulation, where for the former there is no precedent goal to reach by the model and stop the run thereof, the simulation run is carried out for a set time after the model behaviour reaches a steady-state. A terminating simulation runs until a certain goal has been reached, e.g. until certain amount of cargo has been processed, or simply for a pre-defined time. Starting point is required as a reference for time-indexed data like arrivals or schedules.

A typical simulation run begins with a system in a certain configuration, based on historical data from a terminal. The stock in the yards changes during the run, to account for. Then, without extensive data on the initial situation (actual positions of all containers), the containers in the stack are handled, and after the initial warm-up period, their positions are similar to what should be actually expected. The time it takes to reach a steady-state is called a warm-up period, which is another typical parameter in a simulation model.

After the warm-up period, all necessary statistics are cleared so that the performance indicators are reported only on the steady-state of the system. There are analytical methods to help establish the duration of a warm-up period, complemented with the experience of the modeller and scenario analyst.

Finally, an important aspect is to prevent the user from changing input parameters once a scenario has been simulated. It is a measure to avoid making unnecessary mistakes, especially when comparing multiple scenarios. When changing input parameters of a completed scenario is nevertheless desired, the results need to be deleted before this can be done. Commonly platforms distinguish scenario states for a better user experience, these states are:

- Design – when a scenario is prepared and can be edited freely. There are no results;
- Queued – a scenario waiting to be run by the simulation engine with prepared inputs that cannot be edited;
- Running – a scenario currently being executed by the simulation engine;
- Completed – a simulated scenario with the results, the input parameters of which cannot be edited
- Error – a completed scenario that was interrupted due to an internal error.

4.2. Replications

Every experiment consists of a set of simulation runs, called replications, executed by the simulation engine. These runs use the exact same input parameters, but obtain varying result due to different sampled values of the stochastic variables. Stochastic variables represent uncertainty, when the exact value differs and cannot be explicitly determined. 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. 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, if a processing time at a road gate is given as a distribution, then every arriving truck has a different delay there, and together they roughly form that given distribution. For another simulation run, a different set of random numbers is chosen, based on so called random seed 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. Often during validation of the model, its sensitivity to varying inputs is measured and assessed.

Nevertheless, utilising multiple replications is useful to determine the robustness of the model, and to fully assess the impact of stochastic variables. With more, and better model results, output analysis can be used to more accurately establish the expected performance of the real system.

In general, the more replications the better, yet at some point the added value diminishes, and is not worth the resources committed, especially the time required to run the simulation, which might be considerable. There number of replication needed to achieve good enough results, can be determined based on the model outputs with some analytical techniques, as well as modeller experience.

Finally, with multiple replications in an experiment, the results should be assessed collectively and analysed with descriptive statistics. Only then the likely range of outputs can be assessed, and the model results are most useful, even though it requires additional effort, sometimes significant.

One must not select a single replication to draw conclusions from and discard the rest, or simply take the average of the results. Hypothesis testing and interval estimates are often used statistical methods to determine population parameters from the achieved samples (model outputs).

4.3. Input data

Precise information on the input data is included in the chapter 2 of this document. The data requirements need to be accommodated by the data structure defined in this document. Moreover, some of it needs to be easily altered to enable experimentation. There are three main areas to be distinguished from that standpoint:

a) Map and infrastructure data – containing information on the 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. The exact means of importing data from e.g. BIM have not yet been determined, and they might require some alterations to the proposed data structure. Then, because of complexity in applying changes, the user will not be able to alter map and infrastructure information for experimentation. This does not mean that changes are altogether impossible, they rather require implementation effort as well as testing and validation;
b) Equipment and configuration data – concerns terminal equipment in general. These are all the cranes, internal transporters and their parameters, including control logic, which together perform all the (un)loading and internal transport tasks. All the equipment characteristics need to fit into the defined data

structure. Moreover, a lot of this information is to 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. General data needs to be transformed into useful schedules, that govern inflow and cargo flows to and from the terminal. 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. This is however not convenient to alter and create scenarios for analysis. It is also not attainable for non-existing terminals.

4.4. Volumes split for arrival generation

There are two general types of scenarios for investigation: peak performance and long-term planning, with slightly varying requirements. Peak performance is a short-term inquiry into system performance under strenuous conditions, i.e. large volumes of cargo to be processed. Peak performance scenarios can be used to determine the system's capacity as well. Long-term scenarios also might include peaks (and valleys) in cargo volume, but the general goal is to explore performance under normal operations. Both scenario types require slightly different generation of arrivals.

Nevertheless, Figure 13 shows the general steps in creating cargo split from the total volume per year, to actual arrivals and departures during a day. In order to reach that, the total volume needs to be split per MoT, incoming and outgoing volumes, accounting for box size and type, peak factors and arrival patterns.

The approach is to create a schedule from a limited number of parameters, one that can be generated over and over, if any of the inputs are to be changed. Manually inputting information for hundreds of arrivals or reusing historical schedules is in the long term too labour intensive and too prone to human error. Although generated schedules are not perfect, they are better for assessing general performance for an uncertain future situation. Generated schedules can also be optimised, while it is difficult to assess the quality of imported schedules, which do have tremendous impact on the system's performance.

The general approach in generating arrivals is to go top down, from large time span to smaller ones, categorizing the amount of cargo further, until reaching individual MoTs and their cargo.

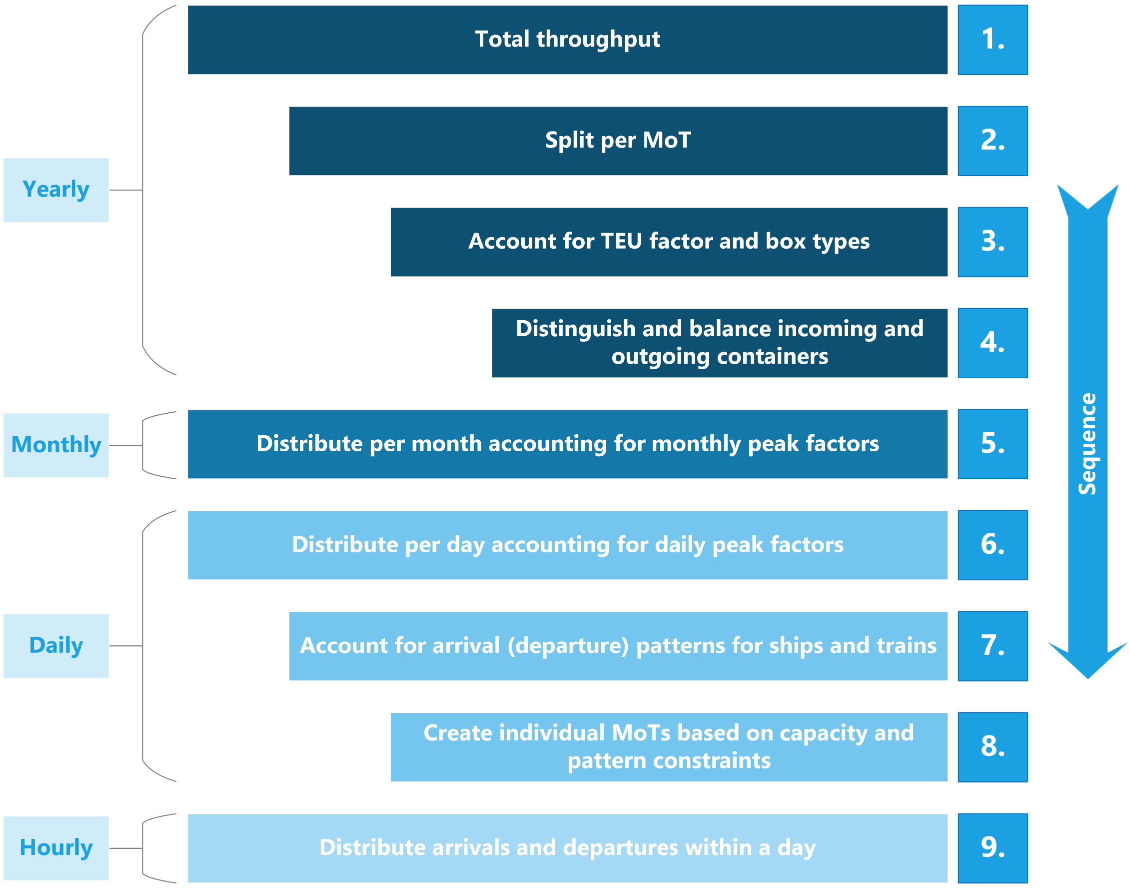

Figure 13. Sequence of generating arrivals processes

Note that for larger MoTs like ships and trains as per step 7., vessels and trains might have pre-specified arrival days that need to be taken into account. Moreover, based on the vessel fleet mix and call size, ships need to be generated every couple of days, so daily volume split might be counterintuitive. Individual MoTs are created in step 8.

4.5. Output data

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. Any simulation generates massive amounts of data, only some of which, deemed useful by the designers, is kept and stored after the run has been completed. 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 tens 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 (PI's) 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 . For example, from a set of results on crane operations information on different levels can be given. On one hand the cranes can be grouped into crane types, engine type, control type, etc., and statistics can be given per group, while they can also be used to show figures per particular area, terminal. This all basing on the same result tables, but transformed differently.

Table XIII. Terminal operational simulation KPI's from D3.1

No.	Name	Units	Frequency	Reference	Note
1	Terminal throughput	boxes, TEU	Yearly	Table XLII. Simulation overview results Table XLVI. Terminal throughput log	Distinguishing import, export and transhipment
2	Equipment utilisation	percentage	simulation run	Table XLIII. Equipment utilisation result table	
3	Gate utilisation	percentage	simulation run	Table XLIV. Gate utilisation result table	To be split for entry/exit lanes
5	Storage area utilisation	percentage	simulation run	Table XLVII. Storage area utilisation log	Split per areas and stack blocks
6	Rail track utilisation	percentage	simulation run		Split per rail yard and shunting yards

				Table LI. Rail track occupation log	
7	Berth utilisation	percentage	simulation run	Table XLV. Berth utilisation result table	
8	Turnaround time	Time	per MoT	Table XLVIII. Vessel times log Table XLIX. Train times log Table L. Truck times log	Split per vessel/truck/train
9	Waiting time	Time	per MoT	Table XLVIII. Vessel times log Table XLIX. Train times log Table L. Truck times log	Split per vessel/truck/train
22	Delays produced (reliability) - Road	Time	Yearly, monthly	Table XLIII. Equipment utilisation result table	
23	Delays produced (reliability) - Railway	Time	Yearly, monthly	Table XLIII. Equipment utilisation result table	
28	Manoeuvring time	Time	Yearly, monthly, daily	Table XLVIII. Vessel times log Table XLIX. Train times log	Measure per MoT plus averages
29	Service time	Time	Yearly, monthly, daily	Table XLVIII. Vessel times log Table XLIX. Train times log	Measure per MoT plus averages

				Table L. Truck times log	
30	Berthing time	Time	Yearly, monthly, daily	Table XLVIII. Vessel times log	Measure per vessel
31	Idle time (equipment)	Time	Yearly, monthly, daily	Table XLIII. Equipment utilisation result table	
36	Waiting time / Turnaround time	percentage	per MoT	Table XLVIII. Vessel times log Table XLIX. Train times log Table L. Truck times log	

Logging is raw data storage with regards to time. 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.

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. Its exact structure has not been determined yet, though despite the data requirements it has a lot of advantages. These include decoupling animation from the simulation run, ability to rewind and go back in time or smooth animation not depending on simulation execution speed. On the other hand, one must wait until the simulation run has been completed before viewing the animation.

Bibliography

Coronel, C., & Morris, S. (2014). *Database Systems: Design, Implementation, & Management* (11 ed.). Cengage Learning.

Microsoft. (2016). *Create crow's foot notation.* Retrieved from Microsoft Office help and training: https://support.office.com/en-us/article/Create-crow-s-foot-notation-1ec22af9-3bd3-4354-b2b5-ed5752af6769

Port of Rotterdam Authority. (2016, https://www.portofrotterdam.com/en/cargo-industry/containers/container-terminals). *Container terminals.* Retrieved from Port of Rotterdam Web Site.

The German Insurance Association. (2017). *Container stowage plans.* Retrieved from Container Handbook: https://www.containerhandbuch.de/chb_e/stra/index.html?/chb_e/stra/stra_01_03_03.html

Appendix

Stochastic distributions

Some of the parameters in tables of the data model utilise a random distribution, meaning that the actual value during the simulation run is sampled from it. Table XIV contains some selected random distributions that need to be possible to use, including one fixed for deterministic runs.

Table XIV. Supported distributions table

Name	Paremeter_1	Parameter_2	Parameter_3
Fixed	Deterministic	-	-
Normal	Mean	Standard Deviation	-
Triangular	Minimum	Mode	Maximum
Exponential	Mean	-	-
Binomial	Probability of Success	Number of Trials	-
Uniform	Minimum	Maximum	-
Weibull	Shape	Scale	-

Distributions vary in number of relevant parameters, thus their number and order is presented. Presented distributions are continuous. If discrete values are required, they are obtained by rounding.


edule
Quay Crane
PK craneID
FK quayID
FK poolID
Vessel Bay Plan
PK planID
FK vesselID
Container Vessel
PK vesselID
Tugboat
vesselID
FK portID
FK scheduleID
Shunting Yard
PK shuntingYardID
FK portID
Weather Conditions
PK simulationTimeInterval
Access Restrictions
PK restrictionID
FK channelID
Access Channel
PK channelID
FK portID
FK terminalID
Port
PK portID
Quay
PK quayID
FK terminalID
Apron
PK apronID
FK terminalID
Rules
Customs Area
PK areaID
FK portID
Port Road Network
PK networkID
Port parking lot
PK lotID
FK portID
Road Intersection
PK intersectionID
FK networkID
FK nodeID
Truck Parking Lot
PK lotID
FK terminalID
Parking Spot
PK spotID
FK lotID
Road Node
PK nodeID
ed Cargo
Truck
PK truckID
Truck Interterminal Schedule
PK scheduleID
Working Pool
PK PoolID
PK driverID
Port Locomotive
PK portLocomotiveID
FK portID
Port Locomotive Schedule
PK locomotiveScheduleID
FK portlocomotiveID
FK shuntingYardID
FK trackID
Terminal Rail Gate
PK gateID
FK terminalID
Port Rail Access Node
PK nodeID
FK portID
Terminal
PK terminalID
FK portID
Road Gate
PK gateID
FK terminalID
Road Gate Buffer
PK bufferID
FK gateID
Stack Crane
PK craneID
FK stackID
FK poolID
Crane Operator
PK operatorID
Stack Crane Schedule
PK scheduleID
External Locomotive
PK externalLocomotiveID
FK trainID
Train Destinations
PK destinationID
FK trainID
Terminal Rail Yard
PK railYardID
FK terminalID
Transporter Buffer Area
PK areaID
FK terminalID
Transporter Buffer Spot
PK spotID
FK areaID
Terminal Handling Area
PK terminalAreaID
FK terminalID
Container Storage Area
PK areaID
FK terminalAreaID
Stack Block
PK stackID
FK areaID
Ground Spot
PK spotID
FK stackID
Train Configuration
PK configID
FK trainID
FK locomotiveID (port/ external/none)
Train
PK trainID
Train Port Schedule
PK portScheduleID
FK trainID
FK portID
FK destination (gateID, shuntingYardID, nodeID)
FK trackID
FK locomotiveID (external/ port)
Railcar
PK carID
FK trainID
FK unitID
Train Terminal Schedule
PK terminalScheduleID
FK portScheduleID
FK trainID
FK terminalID
FK trackID
FK railYardID
FK locomotiveID (external/port/ none)
Rail Worker
PK workerID
FK yardID (shunting/rail)
Out Of Gauge Area
PK areaID
FK terminalAreaID
FK itemID
ITU Transporter
PK transporterID
FK poolID
FK terminalID
Stack Transfer Spot
PK spotID
FK stackID
Stack Spot
PK spotID
FK stackID
Container
PK containerID
FK unitID
FK spotID
ITU Transporter Driver
PK driverID
Out Of Gauge (OOG) item
PK itemID
FK unitID
Intermodal Transport Unit (ITU)
PK unitID
PK trackPointID
FK trackID
FK configID
Track Configuration
PK configID
FK trackID
Track
PK trackID
FK corridorID
Speed Point
PK speedPointID
FK trackID
Rail Yard Crane
PK craneID
FK poolID
FK yardID
Train Unload Plan
PK planID
FK trainID
FK unitID
FK railYardID
ITU Transporter Trailer
PK trailerID
FK transporterID
FK terminalID
ITU Transporter Schedule
PK scheduleID
FK transporterID
FK trailerID
Rail Junction Limitation
PK limitationID
FK junctionID
Rail Junction
PK junctionID
PK networkID
Rail Network
PK networkID
Rail Corridor
PK corridorID
FK networkID
FK startTrackID
FK endTrackID
Train Load Plan
PK planID
FK trainID
FK unitID
FK railYardID
Rail Yard Crane Schedule
PK scheduleID
FK craneID
Rail Yard Transfer Spot
PK spotID
FK railYardID

External MoTs

Vessel tables

Table XV. Vessel type definitions

Column	Type	Unit	Required	Remarks
typeName	string	-	Y	Primary Key. Name for a type of a vessel, e.g. Panamax
capacityMax	integer	TEU	Y	Maximum number of TEU's on board
length	real	m	Y	
maxDraft	real	m	Y	
beam	real	m	Y	
bayNumber	integer	TEU	Y	
rowNumber	integer	TEU	Y	
tiersAboveDeck	integer	TEU	Y	
tiersBelowDeck	integer	TEU	Y	
maxServicingCranes	Integer	-	N	Maximum number of cranes that can service given vessel at the same time
requiredProductivity	real	bx/h	N	

Table XVI. Vessel generation properties

Column	Type	Unit	Required	Remarks
typeName	integer	-	Y	
callSize	distribution	TEU	Y	0-100%. Part of cargo that is moved
callSizeVariation	real	%	Y	How much can CallSize differ over particular transporters
utilisationRate	real	%	Y	0-100%. How full arriving vessels are

Table XVII. Vessel entity properties

Column	Type	Unit	Required	Remarks
vesselID	integer	-	Y	
vesselName	string	-	Y	
typeName	string	-	Y	Foreign Key from vessel generation table
owner	string	-	Y	
currentDraft	real	m	Y	
callSize	real	TEU	Y	

Train tables

Trains in the model are assumed to be block trains, i.e. there is no detachment of railcars from the trains or configuration changes except for changing locomotives.

Table XVIII. Train definitions table

Column	Type	Unit	Required	Remarks
trainID	integer	-	Y	Primary Key
destinationsScheduleID	Integer	-	Y	External destinations and time for planned visits
portScheduleID	integer	-	Y	Foreign Key, schedule within the port
locomotiveID	integer	-	Y	Foreign Key, external locomotive (on arrival)
configID	integer	-	Y	Foreign Key, train configuration
railCompanyName	string	-	N	owner
serviceType	string (list)	-	Y	Type of behaviour in the port (e.g. direct shuttle, hopper)
length	real	m	Y	
railcarNumber	integer	-	Y	
cargoCapacity	integer	TEU	Y	
callSize	integer	TEU	Y	
globalOrigin	string	-	N	Origin of the train
totalRailCarNumber	integer	-	Y	Number of attached railcars
totalLength	real	m	Y	Total length of the train
maxSpeed	real	m/s	Y	Maximum allowed speed for the train

Table XIX. Railcar definitions table

Column	Type	Unit	Required	Remarks
carID	integer	-	Y	Primary Key
trainID	Integer	-	Y	Foreign Key
type	list	-	Y	container/tank/bulk…
cargo	vector	-	Y	list of unitID, can be empty
capacityTEU	integer	TEU	N	only for containers
capacityCargo	real	tonne	Y	
width	real	m	N	
length	real	m	N	
emptyWeight	real	tonne		

Table XX. External locomotive definitions table

Column	Type	Unit	Required	Remarks
portLocomotiveID	Integer	-	Y	Primary key
trainID	Integer	-	Y	Foreign key

Column	Type	Unit	Required	Remarks
railCompanyName	String	-	N	owner
type	String (list)	-	Y	Diesel, electric or hybrid
length	Real	m	Y	
weight	Real	kg	N	
maxSpeedFree	Real	m/s	Y	
maxShuntingSpeed	Real	m/s	Y	
couplingTime	distribution	s	Y	
decouplingTime	distribution	s	Y	

Table XXI. Port locomotive definition table

Column	Type	Unit	Required	Remarks
portLocomotiveID	Integer	-	Y	Primary key
type	String (list)	-	Y	Diesel, electric or hybrid
length	Real	m	Y	
weight	Real	kg	N	
maxSpeedFree	Real	m/s	Y	
maxShuntingSpeed	Real	m/s	Y	
couplingTime	distribution	s	Y	
decouplingTime	distribution	s	Y	

Truck tables

Table XXII. Truck parameters

Column	Type	Unit	Required	Remarks
truckID	integer	-	Y	Primary Key
inboundCargoID	integer	-	Y	Foreign Key
outboundCargoID	integer	-	Y	Foreign Key
arrivalScheduleID	integer	-	Y	Foreign Key
interterminalScheduleID	integer	-	Y	Foreign Key
owner	string	-	Y	
capacity	integer	TEU	Y	
globalOrigin	string	-	Y	
globalDestination	string	-	Y	
avgSpeed	real	m/s	Y	
length	real	m	Y	
width	real	m	Y	

Matrix tables

The following matrix tables are used to translate the periodical volumes of cargo into specific ship quantities. As they express percentage composition, the values in each row need to sum up to 100. These requirements are in more detail described in 5.1 Data requirements for terminal simulation document:

- Ship type per terminal (Fleet mix)
- Train lengths on arrival (Train mix)
- External trucks cargo composition
- Total container volume split per transportation means
- ITU composition – percentage of container sizes (20', 40', 45'), reefers, empties, OOG items etc.
- Peak factors per month/day

Cargo

Table XXIII. Intermodal Transport Unit types

ITU_Type	Size	Stackable	Description
Container	ISO standard 20', 40', 45'	Yes	Intermodal container
Semi-trailer	Varying	No	Trailer without a front axle
Swap body	Varying, related to ISO containers	No	Non-stackable containers with fittings for road/rail transport within Europe

Table XXIV. Container categories and sizes

Container_Category	Length [feet]	Length [metres]	Max Load [kg]	Description
General_20	20	6.1		General category includes all general purpose enclosed container types
General_40	40	12.2		
General_45	45	13.7		
Reefer_40	40	12.2		
Tank_20	20	6.1		

Table XXV. ITU definitions table

Column	Type	Unit	Required	Remarks
unitID	Integer	-	Y	Primary key
ITU_type	String (list)	-	Y	Foreign key
Stackable	Boolean	-	Y	
Owner	String (list)	-	Y	Shipping company name
totalWeight	Real	Kg	Y	Gross weight of the unit
maxPayload	Real	Kg	N	
globalOrigin	String	-	N	Place of origin

Column	Type	Unit	Required	Remarks
globalDestination	String (list)	-	Y	Final destination of the cargo for the simulation model
contentDescription	String	-	N	

Table XXVI. Container definitions table

Column	Type	Unit	Required	Remarks
containerID	Integer	-	Y	Primary Key
unitID	Integer	-	Y	Foreign key
containerCategory	String (list)	-	Y	Type of container and its length
emptyWeight	Real	Kg	N	
containerCode	String	-	N	For specific container identification purposes

Table XXVII. Out of Gauge item definition

Column	Type	Unit	Required	Remarks
itemID	Integer	-	Y	Primary Key
unitID	Integer	-	Y	Foreign key
unitLength	Real	m	Y	
unitWidth	Real	m	Y	
unitHeight	Real	m	Y	

Terminal equipment

Table XXVIII. Ship-to-Shore crane entity parameters

Column	Type	Unit	Required	Remarks
craneID	Integer	-	Y	Primary Key
quayID	Integer	-	Y	Foreign Key
poolID	Integer	-	N	Foreign Key
craneType	list	-	Y	with platform / without platform / working between legs etc.
averageProductivity	real	mph	Y	
allowedLifts	list	-	Y	single / twin / tandem / dual cycle
manufacturer	string	-	Y	
manufacturerTypeName	string	-	N	
span	real	m/TEU	Y	
liftHeight	real	m/TEU	Y	
outreach	real	m/TEU	Y	
clearanceUnderBeam	real	m	N	

Column	Type	Unit	Required	Remarks
backreach	real	m	N	
maxHoistLoad	real	tonne	N	
liftingCapacity	real	tonne	Y	
gantrySpeed	real	m/s	Y	
avgEnergyConsumption	real	kW	Y	

It needs to be noted that for cranes with platforms as defined in Table XXVIII, additional parameters need to be defined. However, these are new types of cranes and only few terminals have them.

Table XXIX. Barge crane entity parameters

Column	Type	Unit	Required	Remarks
craneID	Integer	-	Y	Primary Key
quayID	Integer	-	Y	Foreign Key
poolID	Integer	-	N	Foreign Key
averageProductivity	real	mph	Y	
manufacturer	string	-	Y	
manufacturerTypeName	string	-	N	
maxHoistLoad	real	tonne	N	
liftingCapacity	real	tonne	Y	
craneSpeed	real	m/s	Y	to move the entire crane to a new position
avgEnergyConsumption	real	kW	Y	

Table XXX. Stacking equipment entity table

Column	Type	Unit	Required	Remarks
craneID	Integer	-	Y	Primary Key
poolID	Integer	-	N	Foreign Key
craneType	list	-	Y	SC, RTG, RMG,…
averageProductivity	real	mph	Y	
manufacturer	string	-	Y	
manufacturerTypeName	string	-	N	
operationalHeight	real	TEU	Y	
stackingSpan	real	TEU	Y	
maxHoistLoad	real	tonne	N	
liftingCapacity	real	tonne	Y	
craneSpeed	real	m/s	Y	to move the entire crane to a new position
avgEnergyConsumption	real	kW	Y	

Table XXXI. Terminal transporter entity table

Column	Type	Unit	Required	Remarks
transporterID	Integer	-	Y	Primary Key
poolID	Integer	-	N	Foreign Key
transporterType	list	-	Y	TT, AGV, ShC
averageProductivity	real	mph	Y	
manufacturer	string	-	Y	
manufacturerTypeName	string	-	N	
speedEmpty	real	m/s	Y	
speedFull	real	m/s	Y	
avgEnergyConsumption	real	kW	Y	

Table XXXII. Terminal trailer entity table

Column	Type	Unit	Required	Remarks
trailerID	Integer	-	Y	Primary Key
detachable	Boolean	-	Y	
manufacturer	string	-	Y	
manufacturerTypeName	string	-	N	
capacity	real	TEU	Y	
maxLoad	real	tonnes	N	

Terminal areas

Table XXXIII. Terminal parameters table

Column	Type	Unit	Required	Remarks
terminalID	Integer	-	Y	Primary Key
portID	integer	-	Y	Foreign Key
totalArea	real	m^2	Y	
terminalType	list	-	N	container/bulk/liquid/oil/LNG…
numberOfShifts	integer	-	Y	
employeePoolQC	integer	-	Y	
employeePoolCHE	integer	-	Y	

Table XXXIV. Stack block entity table

Column	Type	Unit	Required	Remarks
stackID	Integer	-	Y	Primary Key
areaID	integer	-	Y	Foreign Key
parrarel	Boolean	-	Y	If not, is perpendicular
groundSpotsTotal	integer	TEU	Y	
groundSpotsReefers	integer	TEU	Y	
reeferSpots	integer	TEU	Y	
totalStorage	integer	TEU	Y	

Column	Type	Unit	Required	Remarks
stackingHeight	integer	TEU	Y	
length	integer	TEU	Y	
width	integer	TEU	Y	
height	integer	TEU	Y	

Table XXXV. Stack spot table

Column	Type	Unit	Required	Remarks
spotID	Integer	-	Y	Primary Key
stackID	integer	-	Y	Foreign Key
type	list	-	Y	general / reefer / empty
size	integer	TEU	Y	
locationCode	string	-	Y	bay/row/tier

Table XXXVI. Stack transfer spot table

Column	Type	Unit	Required	Remarks
spotID	Integer	-	Y	Primary Key
stackID	integer	-	Y	Foreign Key
dedicatedLanes	integer	-	Y	
totalSpots	integer	-	Y	

Table XXXVII. Berth definition table

Column	Type	Unit	Required	Remarks
berthID	Integer	-	Y	Primary Key
quayID	integer	-	Y	Foreign Key
startCoordinates	vector	-		(x,y,z)
endCoordinates	vector	-		start and end z coordinate equal
length	real	m	Y	
draft	real	m	Y	
openingDays	integer	-	Y	number of operational days a year
shiftStartTime	real	h	N	
shiftEndTime	real	h	N	

Table XXXVIII. Quay definitions table

Column	Type	Unit	Required	Remarks
quayID	Integer	-	Y	Primary Key
terminalID	integer	-	Y	Foreign Key
startCoordinates				
endCoordinates				
geometry	vector	-	Y	Coordinated of vital points if quay is not a straight line

Column	Type	Unit	Required	Remarks
totalLenght	real	m	Y	
numberOfBerths	integer	-	Y	

Table XXXIX. Access channel definitions

Column	Type	Unit	Required	Remarks
channelID	Integer	-	Y	Primary Key
portID	integer	-	Y	Foreign Key
terminalID	integer	-	Y	Foreign Key
accessRestrictionsID	integer	-	N	Foreign Key
vesselCapacity	integer	-	Y	
traverseTime	distribution	h	Y	
length	real	m	N	

Table XL. Gate definition table

Column	Type	Unit	Required	Remarks
gateID	Integer	-	Y	Primary Key
terminalID	integer	-	Y	Foreign Key
openingDays	integer	-	Y	number of operational days a year
shiftStartTime	real	h	N	
shiftEndTime	real	h	N	
numberOfLanes	integer	-	Y	
handlingDelay	distribution	h	Y	

Table XLI. Rail terminal definition table

Column	Type	Unit	Required	Remarks
yardID	Integer	-	Y	Primary Key
terminalID	integer	-	Y	Foreign Key
type	list	-	Y	terminal/shunting
tracksNumber	integer	-	Y	
trackLength	real	m	Y	
bufferSpots	integer	-	Y	
openingDays	integer	-	Y	number of operational days a year
shiftStartTime	real	h	N	
shiftEndTime	real	h	N	
area	real	m^2	N	

Output data

Results tables

Table XLII. Simulation overview results

Column	Type	Unit	Remarks
simulationTime	real	h	duration of the simulation
portOperationalTime	real	h	time spent in operation
importedITU	integer	ITU	
importedTEU	real	TEU	
importedCargo	real	tonne	
exportedITU	integer	ITU	
exportedTEU	real	TEU	
exportedCargo	real	tonne	
transhippedITU	integer	ITU	
transhippedTEU	real	TEU	
transhippedCargo	real	tonne	
vesselsDeparted	integer	-	
trainsDeparted	integer	-	
trucksDeparted	integer	-	
totalEnergyConsumed	real	kW	by all yard/quay equipment + transporters

Table XLIII. Equipment utilisation result table

Column	Type	Unit	Remarks
vehicleID	integer	-	Any internal vehicle including internal transporters, yard equipment and quay cranes
vehicleType	list	-	Type of the vehicle
operationalTime	real	hours	total time in operation
idleTime	real	hours	
waitingTime	real	hours	
busyTime	real	hours	
totalITU	integer	ITU	total number of handled units (productive moves)
totalTEU	real	TEU	
totalCargo	real	tonne	
energyConsumption	real	kW	

For Table XLIII the following needs to be preserved:

$$operationalTime = idleTime + waitingTime + busyTime$$

$$utilisation = \frac{busyTime}{operationalTime} [\%]$$

Table XLIV. Gate utilisation result table

Column	Type	Unit	Remarks
gateID	integer	-	
operationalTime	real	hours	
busyTime	real	hours	
vehiclesArrived	integer	-	
vehiclesDeparted	integer	-	
lanesIn	integer	-	
lanesOut	integer	-	

Table XLV. Berth utilisation result table

Column	Type	Unit	Remarks
berthID	integer	-	
operationalTime	real	hours	
occupiedTime	real	hours	
allottedTime	real	hours	occupied time plus reservations
vesselsMoored	integer	-	total number of vessels that have moored at berth
totalITU	integer	ITU	
totalTEU	real	TEU	
totalCargo	real	tonne	

$$allotment = \frac{allottedTime}{operationalTime}\,[\%]$$

$$utilisation = \frac{occupiedTime}{operationalTime}\,[\%]$$

Since the berths can be occupied by more than one vessel, should that actually happen instead of reporting on the berth utilisation, the quayside utilisation needs to be calculated. It is related to length of quay occupied by the vessels.

Logs

Table XLVI. Terminal throughput log

Category	Column	Type	Unit	Remarks
	day	integer	-	Since the start, count from 0
	datetime	datetime	-	for aggregation to months/years etc.
vessels	arrived	integer	-	
	departed	integer	-	
	offloadedTEU	real	TEU	
	offloadedITU	integer	ITU	

Category	Column	Type	Unit	Remarks
	offloadedCargo	real	tonne	
	loadedTEU	real	TEU	
	loadedITU	integer	ITU	
	loadedCargo	real	tonne	
trains	arrived	integer	-	
	departed	integer	-	
	offloadedTEU	real	TEU	
	offloadedITU	integer	ITU	
	offloadedCargo	real	tonne	
	loadedTEU	real	TEU	
	loadedITU	integer	ITU	
	loaded_cargo	real	tonne	
trucks	arrived	integer	-	
	departed	integer	-	
	offloaded_TEU	real	TEU	
	offloaded_ITU	integer	ITU	
	offloaded_cargo	real	tonne	
	loaded_TEU	real	TEU	
	loaded_ITU	integer	ITU	
	loaded_cargo	real	tonne	

Data from Table XLVI can be aggregated in time or MoT. Throughput information can be derived from it over time.

Table XLVII. Storage area utilisation log

Column	Type	Unit	Remarks
stackID	integer	-	
simulationTime	real	h	time interval
occupiedSpots	integer	TEU	

A similar log is as in Table XLVII is done for rail track utilisation

Table XLVIII. Vessel times log

Column	Type	Unit	Remarks
vesselID	integer	-	
vesselType	string	-	
arrivalPBS	datetime	-	Vessel's arrival at the PBS
departurePBS	datetime	-	
arrivalBerth	datetime	-	
processingStart	datetime	-	
processingFinish	datetime	-	
departureBerth	datetime	-	

Column	Type	Unit	Remarks
departurePort	datetime	-	Time of reaching the PBS for the second time
unloadedITU	integer	ITU	
unloadedTEU	real	TEU	
unloadedCargo	real	tonne	
loadedITU	integer	ITU	
loadedTEU	real	TEU	
loadedCargo	real	tonne	
maxServicingCranes	integer	-	Maximum number of cranes servicing the vessel at once

Vessel waiting time is the difference between departure and arrival at the PBS. Consequently, unloading duration is the difference between processing finish and processing start, etc.

Table XLIX. Train times log

Column	Type	Unit	Remarks
trainID	integer	-	
arrivalShuntingYard	datetime	-	Train's arrival time at a shunting yard
departureShuntingYard	datetime	-	
arrivalRailYard	datetime	-	
processingStart	datetime	-	
processingFinish	datetime	-	
departureRailYard	datetime	-	
departurePort	datetime	-	Time of reaching the shunting yard for the second time
unloadedITU	integer	ITU	
unloadedTEU	real	TEU	
unloadedCargo	real	tonne	
loadedITU	integer	ITU	
loadedTEU	real	TEU	
loadedCargo	real	tonne	

Table L. Truck times log

Column	Type	Unit	Remarks
truckID	integer	-	
arrivalPort	datetime	-	Truck's arrival time at the port
arrivalGateEntry	datetime	-	on arrival
departureGateEntry	datetime	-	on arrival
waitingAreaEntered	datetime	-	before loading
waitingAreaExited	datetime	-	
firstCargoLoaded	datetime	-	
lastCargoLoaded	datetime	-	

Column	Type	Unit	Remarks
arrivalGateExit	datetime	-	
arrivalGateExit	datetime	-	
departurePort	datetime	-	Time of reaching the shunting yard for the second time
unloadedITU	integer	ITU	
unloadedTEU	real	TEU	
unloadedCargo	real	tonne	
loadedITU	integer	ITU	
loadedTEU	real	TEU	
loadedCargo	real	tonne	

Table LI. Rail track occupation log

Column	Type	Unit	Remarks
ID	enum	-	automatic enumeration
trackID	integer	-	
trackType	list	-	classification: main track, secondary, connecting, siding, rail yard, shunting yard, parking for locomotives
areaID	integer	-	if belongs to particular rail/shunting yard
claimedTime	datetime	-	time when a train reserved the track
releasedTime	datetime	-	time when the track becomes available for other reservations
arrivalTime	datetime	-	time when a train arrived at the track
departureTime	datetime	-	time when a train left the track

Animation data

Actual animation data structure will be determined at a later stage when the requirements are better recognised and understood.