SIMULATION STUDIES OF ROBOTIZED MULTI TERMINAL SYSTEMS

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Abstract

Recently Dutch government decided to allow further extending of the Rotterdam Port area with the so-called “Second Maasvlakte” (MV2). This paper reports on the simulation part of a project concerning the configuration and design of container terminals for MV2. The aim is to determine basic assumptions, preconditions and configuration aspects of the future MV2 terminals. Some general modeling concepts are discussed. The definition and the derivation of the model input from prognoses of future turnover are emphasized in particular. The simulation model is applied to the MV2 case and the results regarding layout, stack dimensions, equipment needed and traffic flows to be expected on the MV2 road network are presented. The results are being used for further design purposes and economic calculations. Though the model in question is at a high level of aggregation, it is prepared to be used for further detailed modeling of subsystems such as terminals and inter terminal transport.

1 Introduction

In the late 60^{th}, the Port area of Rotterdam was extended with the “Maasvlakte”, consisting of land that was reclaimed from the North Sea. In this area several industries have been established, including deep-sea terminals for oil, dry bulk and containers. Recently Dutch government decided to allow further extending of the port area with the so-called “Second Maasvlakte” (MV2).

This work is part of the “FAMAS.MV2” project concerning the expansion of the Port of Rotterdam with the “Second Maasvlakte”. The Rotterdam Municipal Port Management (RMPM) manages the project.

The main objective of the FAMAS.MV2 project is:

“ Design robotized container terminals including inter terminal transport systems for the 2^{nd} Maasvlakte”

The sub-project 'Maasvlakte Integral Container Logistics' (MICL) is defined in order to determine basic assumptions, preconditions and basic configuration aspects of the future MV2 terminals (van Schuylenburg and Miller, 2001). After completion of the MICL project several detailed studies on sub systems like individual terminals and the Inter Terminal Transport (ITT) of containers are anticipated. The MICL project concerns a high level logistic study of the complete set of existing and future terminals in the Rotterdam port area. Part of it is a simulation study to determine:
- lay-outs
- Stack dimensions
- Quay length and resulting berth occupation
- Quay crane capacity
- Capacity of other handling equipment
- Inter terminal transport equipment
- Inter terminal traffic flows on the infra structure; traffic intensity on nodes
- Influence of special arrangements such as the random x-ray scanning of a part of the total container flow.

The essential precondition is that deep-sea ships should never be delayed.
This paper reports the results of the simulation part of MICL.

The reason to use simulation for the initial high-level study of MV2 rather than calculations based on averages, is to investigate the influence of variation in import and export flows and container dwell times. These influences cause peaks in the need for handling and transportation equipment and stacking space. Moreover a new aspect is the introduction of very large container ships of up to 8000 or perhaps even 15000 TEU in the nearby future that may introduce extra high peaks in container flow and stacking space needed.

It is obvious that the quality of model results, directly relates to the quality of the model input. In case of modeling future large-scale systems usually only very rough data based on forecasts is available. In our case there are rough estimates of yearly throughput of containers for a period of about 20 years ahead. A smaller time scale is necessary to investigate peaks in handling, transport and stacking capacity needed.

Consequently a very important step is to decompose the rough yearly-based data to a much smaller time scale, for example hours. A team of experts on the basis of experience and current practice has advised in this matter. A substantial part of this paper is devoted to the derivation and construction of the model input.

The intention of the simulation effort is also to create models that are reusable in further detailed studies of sub systems being individual terminals or the inter terminal transport (ITT) system. Moreover it should be possible for different research groups to develop models of sub systems in parallel using the MICL model as a common basis. As a consequence it was concluded that a distributed modeling approach was necessary for that purpose.

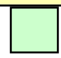
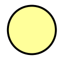
First some important modeling concepts and demands will be explained. After that the logistic concepts that are applied will be discussed. The logistic concepts lead to the type of model input data needed. Finally the MV2 case will be elaborated.

2 Modeling concepts

2.1 Basic Functions

Three basic functions can be distinguished on a multi container terminal:

Table 1. Three basic functions on a container terminal

Function	Examples of equipment	symbol
Transfer	Quay crane, Stacking crane, Railway crane	
Transport	Automated guided vehicle (AGV)	
Stacking	Marine stack, Rail stack, Barge stack	

In the model a multi terminal configuration is composed using building blocks representing one or a combination of the basic functions. A typical example of a combination of transport and transfer functions is an Automated Lifting Vehicle (ALV). The simulation model is generic with respect to any multi terminal configuration to be investigated, (Veeke, Ottjes 2002). In practice a basic function or a combination of basic functions is carried out by equipment. A configuration includes lay out and the road network.

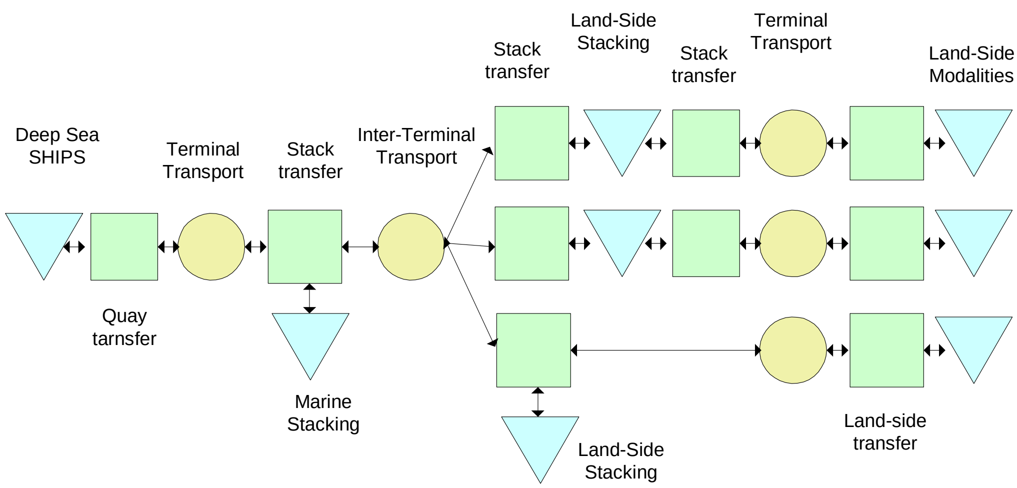


Figure 1: Typical set up of a terminal configuration using standard functions Transfer, Transport and Stacking. The modalities (ships, trains etc.) are modeled as 'Stacks'. Import flows from deep sea are pushed towards the landside modalities and export flows are pulled from landside towards the deep-sea side. In this set up the Marine stack may be bypassed.

Two additional demands were put onto the model design:

- It should be possible to expand high-level modules in the initial MICL model into detailed sub-models that still can run in the global multi terminal environment. This is important to maintain the consistency of the overall container flows. In the detailed sub models planning and control functions are to be implemented and tested. The high-level MICL model then obtains the role of integrated container flow generator.

- Distributed development and running of detailed sub models by different groups should be possible. Model elements (for example terminals or ITT) can be modeled in separate modules (sub models) that may run on different computers.

2.2 Load unit and TEU factor

In model the container flow is modeled at single container level. It is assumed that only sea containers of 20 feet and 40 feet long are involved. The container flow usually is expressed in TEU (Twenty feet equivalents). If x is the fraction of 20-feet containers, the TEU-factor T_x is defined as:

$T_x = 2\text{-}x$

Consequently the number of "real" containers N_c can be calculated from the flow expressed in TEU according:

$N_c = TEU/ T_x$

In each handling and transport activity it is assumed that only one container is involved. The stack space needed is calculated using the TEU factor.

2.3 Model implementation

The model is coded in the simulation package Tomas (Veeke and Ottjes, 2000, www.tomasweb.com). This package allows distributed modeling. In the simulation model the container flow is modeled at single container level. The model is used as "stand alone" model but it is prepared to run "distributed". That means that separate terminal processes may run as "member models" in separate models eventually on different computers. The models then exchange information based on windows messaging via the Internet and are synchronized in time by a timeserver that is also running distributed (Ottjes and Veeke 2001). The "world view" applied is the process interaction approach (Zeigler, 2000).

If a subsystem of the MICL model is to be further detailed, implementing this subsystem in a separate member model and connecting that model to the MICL model via the distributed infrastructure can achieve this. In that way a zooming functionality is created. This approach automatically opens the possibility to parallel model development, even in different simulation packages. In the separate FAMAS MV2 "Backbone" project the Tomas distributed approach is continued with the intension to develop interfaces for synchronization of other (than Tomas) simulation tools.

3 Logistic concepts

In this chapter the general logistic concepts and assumptions and their consequences for modeling and input data required are discussed. In the actual MV2 case the input will be shown.

3.1 Push and Pull

Deep-sea ships bring and collect loads of containers to and from a main port. Usually all activities in the port are aimed to minimize deep-sea ships berth time. Therefore we consider the deep-sea ships as the driving actors in the system. As a consequence the import load of such a vessel is modeled as a container flow to be *pushed* through the system and its export load is supposed to be *pulled* from the system. In Figure 1 this is illustrated.

Deep sea arrivals are responsible for peaks in cargo flows through the terminal and thus peaks in the need of stacking space and transportation and handling equipment, therefore we conclude that model input is needed in the form of arrivals of ships with both import and export loads.

As a consequence of taking the deep sea ships as leading in the total terminal system, the load/unload capacity at deep sea side will generally be the bottle neck in the logistic chain on a terminal. These capacities should be designed to perform according to the demands and all other equipment should be dimensioned in such a way that the quay performance is not decreased. For example if loading/unloading at quayside is done by quay cranes (QC) and the means of transportation from and to the quay is performed by automated guided vehicle (AGV), then the system should be designed in a way that a QC never has to wait for an AGV. As a result of this reasoning we conclude that, in the model the deep sea quay transfer systems should have a finite capacity, all other handling and transport systems should have sufficient capacity not to reduce the quay system performance. Consequently the Quay transfer capacity is a model input; all other capacities are model output.

3.2 Modal split

The landside container flows for import as well as for export are to be derived from the deep-sea flows, as these are the driving actors. Import containers are distributed over the hinterland via other modalities such as rail, road, inland shipping, short see shipping (feeders) or even back to deep sea. The same holds for the origins of export containers. This phenomenon is called “modal split”. If there are several terminals of the same modality in a multi terminal system, the container flow to and from that modality may be even further branched, as is shown in Figure 2. Each container delivered or collected by a deep-sea ship consequently needs its own modal split information.

With respect to the model input needed, we conclude that modal split information of both import and export streams is necessary for the derivation of landside (pushed and pulled) container flows.

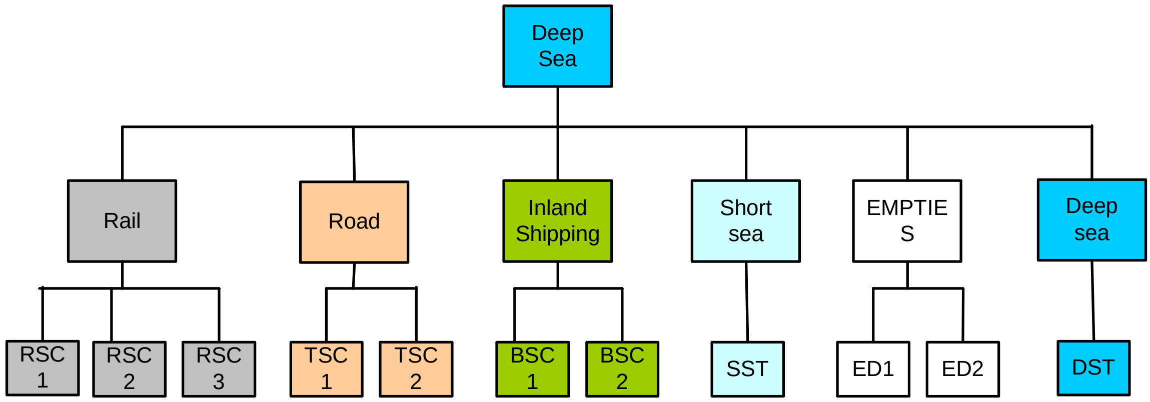


Figure 2. Example of a modal split situation of import and export container flows in a multi terminal set up. Part of the import stream may turn to an export stream, of course via different deep-sea ships.

3.3 Dwell times and stacking

Import as well as export containers may be temporary stored in stacks. Container dwell times at the terminal stacks depend on several factors such as the time the owner decides to fetch his imported containers or supplies his containers for export, time tables and availability of hinterland connections or to deal with load and unload peaks at deep seaside occurring when large ships have to be served in a short time span; moreover dwell times could be controlled if necessary by specific pricing. In the current practice dwell times are in the order of some days. On the landside, for similar reasons, smaller decoupling stacks are common for example in rail service centers and barge service centers. Consequently a container may reside in two successive stacks during its staying time in the container terminal. Another possibility is that only one stack is used, for example if an export container, arriving by rail is directly transferred to the marine stack of its destination ship. Theoretically there is a third possibility namely a container that is not stacked at all and is bypassed from its arrival transport mode to its departing transport mode. It should be possible to model all these options, see also Figure 1.

Because the stack volume needed is proportional to the container dwell times, these are extremely important to know in terminal design. If $\boldsymbol{\tau}$ is the average container dwell time, $\boldsymbol{\lambda}$ the average container flow rate and $\mathbf{n}$ the average number of containers in the system then in a situation of equilibrium, Little's equation (Little 1961) holds:

$$\mathbf{n} = \boldsymbol{\lambda} \, . \, \boldsymbol{\tau}$$

A rough estimate of required average stack volume is obtained if λ is derived using the predictions of yearly turnover and $\boldsymbol{\tau}$ is taken to be similar to the current situation. This however is not good enough for real design purpose, because the stacking volume required might be influenced by varying container flows, either at a small time scale, for example due to of arrivals of big ships, or at a larger time scale, for example seasonal or conjuncture dependent influences. To analyze the consequences of these phenomena simulation is needed. We conclude that dwell time information is a very crucial model input.

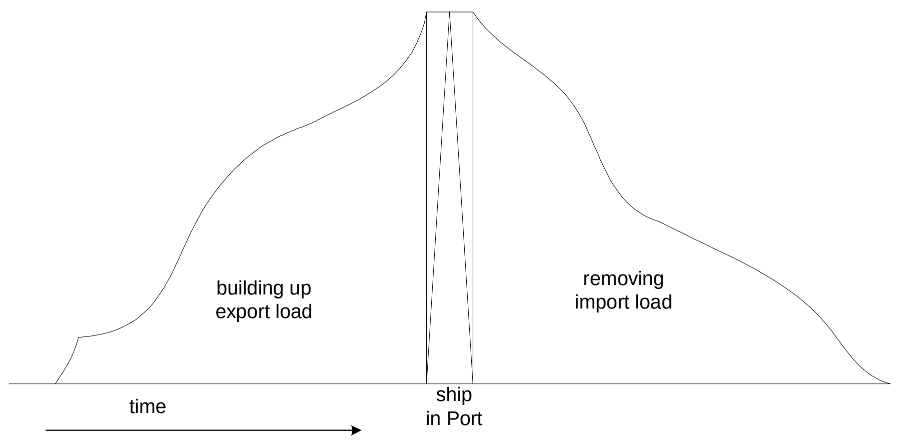


Figure 3. Plot of the development of container stocks for export and import for one deep-sea ship. The curves are a composition of the contributions of different container batches with appropriate modal split and dwell times.

3.4 Conclusions regarding model input

The main model input parameters for the multi terminal model are

- Terminal configurations to be tested
- Deep sea handling capacity
- Deep sea ship arrival patterns
- Deep-sea shiploads for import as well as for export at single container level.
- Modal split information of all containers.
- Container dwell time distributions.
- Division of dwell times over marine and landside stacks.

The overall performance indicator is the berth time of deep-sea vessels.

4 Case: Modeling the “Maasvlakte” terminals.

In this chapter the actual application of the model will be described. The model input is explained and the experimental scheme and results are shown.

Two scenarios are defined representing two stages in the future MV2 development process:

- The situation around 2020
- The fully developed MV2 probably reached in 2025.

For each scenario three configurations are investigated:

- The functional configuration. Here every modality has its own specialized terminal. Advantages are flexibility, efficient use of equipment. A disadvantage will be increased inter terminal transport. In terms of production logistics this configuration is related to ”job shop” production.
- The compact configuration. Terminals serve a set of different modalities and are more or less “self supporting”. In terms of production logistics there is a resemblance to dedicated cell production (Vollmann, 1988). The benefits are reduced order flow time, less work in progress, lower material handling costs and simplified planning and control procedures. The inter terminal transport will be lowered but will still remain to a certain magnitude.
- A combined configuration of functional and compact terminals (also called combined case). This is based on the results of compact and functional variant and expertise of Rotterdam port authorities and other specialists in the field.

4.1 Practical restrictions

There are two existing terminal systems: The so-called Delta Terminal on the ECT peninsula and the Euromax terminal, which is still under construction. Both terminals are situated on the Maasvlakte 1 area. In practice it is not meaningful to change existing terminals on Maasvlakte 1 to compact or functional cases, so these terminals are modeled as they are. For the future terminals of Maasvlakte 2 the different configurations are tested.

In the next section we will describe the model input for this case.

4.2 Input for the MV2 case

Two types of input data can be distinguished:

a. Configuration data
b. Container flow data to be processed by the terminal complex.

4.2.1 Configuration data

The configuration data define the lay out and equipment capacities available as well as the connecting road network.

Lay out data include:
Number of terminals and for each terminal:

- Identification
- Location coordinates
- Number of Quay cranes if the terminal serves deep sea vessels
- Composition of sub systems (modalities) with equipment cycle times
- Inter and intra terminal connections
- Control parameters

The connecting road network and for each road:

- Identification
- Coordinates
- Length

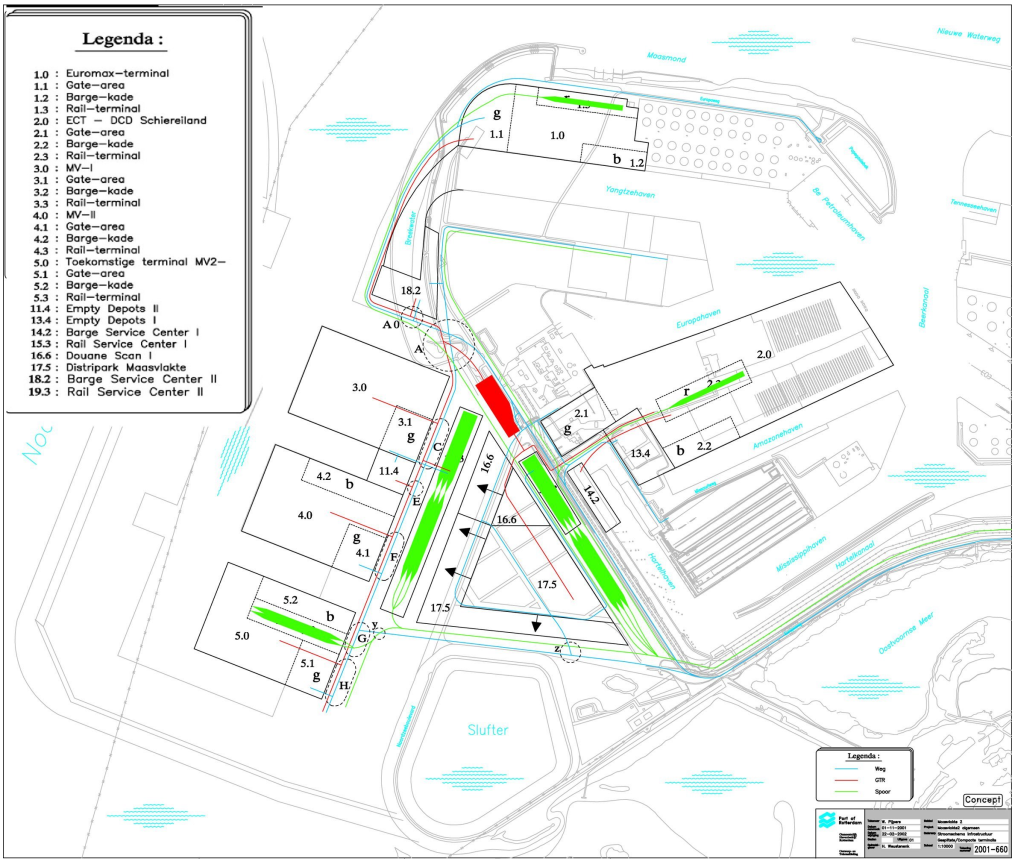


Figure 4. Picture of the combined variant. Source: Rotterdam Municipal Port Management (RMPM). The lower left terminal (number 5.0 MV III) is a typical compact terminal with a deep sea quay, a gate area for road traffic and a barge terminal and a rail terminal.

4.2.2 Container flow data

The basic flow predictions are listed in Table 2. In order to obtain model input on a detailed time basis these flows are resolved into streams of individual containers to and from all the terminals in the modeled system. Though this was done in close cooperation with all experts in the project group it was inevitable to make arbitrary simplifications and assumptions.

Table 2. Predicted number of deep-sea ships and containers for the two scenarios 2020 en 2025

Scenario	Ships		Containers		
	Year	Week	Year	Week	Day
2020	9672	186	8827208	169754	24251
2025	11232	216	10264124	197387	28198

The flows of Table 2 have been projected on deep-sea ships. To that end a number of ship types were defined. They are listed in Table 3. Ship types differ in call size, number of cranes possible and crane move rate possible. As a consequence the berth times differ per ship type. Within one ship type call size is sampled from a distribution, taking into account the parameters of the ship type.

Table 3. Definition of ship types

Ratio	Fraction of total calls this ship type accounts for
L/U-factor	Load/unload factor: fraction of the capacity of this ship type that has the terminal as origin/destination. Here load and unload factor are equal.
Capacity	Load capacity (in TEU) of this ship type
Length	Maximum length (m) of this ship type
#QC	Maximum number of quay cranes possible simultaneously on this ship type
Type	Ship type-indication (A-F)

Ratio	L/U-factor			Capacity (TEU)			Length	#QC	Type
	min	avg	max	min	avg	max	max	max	
0.3618	0.01	0.16	0.43	50	411	1200	150	1	{A}
0.2276	0.02	0.29	0.93	600	1693	3000	200	2	{B}
0.0763	0.06	0.37	0.92	1000	2555	3600	250	3	{C}
0.0719	0.06	0.32	0.80	2700	4599	6600	300	4	{D}
0.2260	0.09	0.22	0.48	4000	6406	8000	350	4	{E}
0.0364	0.30	0.375	0.45	8000	10000	12500	450	6	{F}

4.3 Modal split

Each import container arriving by deep-sea vessel needs a destination terminal. Each export container leaving by deep-sea vessel needs an originating terminal. The destinations and origins of import and export containers respectively are obtained using modal split information. To that end we need an origin destination matrix for both import and export streams. For the combined case these matrixes are shown in Table 5. In this table the actual terminals and the modalities are coded. This code is explained in Table 4.

Example of interpreting Table 5:
In the import table part the first row represents the import deep-sea modalities. Each column shows the distribution over all other modalities of containers that have arrived via the relevant deep-sea terminal. Let us take the "delta" terminal (first index = 2) and its import stream via deep sea (second index = 0). From the table we can read that 36.7 % of the containers have destination 2.1 meaning the truck modality of the same delta terminal and 10.9% is to leave via 14.2 being the barge modality of the terminal called BSC-I.

Table 4 Coding of the terminal and modalities used in Table 5

Fist Index		Second Index	
1	Euromax	0	Sea
2	Delta	1	Truck
3	MV2_I	2	Barge
4	MV2_II	3	Rail
5	MV2_III	4	Empty
10	EMD_II	5	Distri
11	TSC/EMD_II	6	Douane
12	DSC_II		
13	EMD_I		
14	BSC_I		
15	RSC_I		
16	DSC_I		
17	DPM		
18	BSC_II		
19	RSC_II		

Table 5 Modal split for import en export stream for the combined variant in the 2025 scenario.

IMPORT	1.0	2.0	3.0	4.0	5.0
1.0	15.3%	0.2%	0.2%	0.2%	0.3%
1.1	36.7%	0.0%	0.0%	0.0%	0.0%
1.2	28.3%	0.5%	0.3%	0.4%	0.3%
1.3	8.1%	0.0%	0.0%	0.0%	0.0%
2.0	0.2%	15.3%	0.2%	0.2%	0.3%
2.1	0.0%	36.7%	0.0%	0.0%	0.0%
2.2	0.4%	17.3%	0.3%	0.4%	0.3%
2.3	0.0%	6.4%	0.0%	0.0%	0.0%
3.0	0.2%	0.2%	15.3%	0.2%	0.3%
3.1	0.0%	0.0%	36.7%	0.0%	0.0%
3.2	0.0%	0.0%	0.0%	0.0%	0.0%
3.3	0.0%	0.0%	0.0%	0.0%	0.0%
4.0	0.2%	0.2%	0.2%	15.3%	0.3%
4.1	0.0%	0.0%	0.0%	36.7%	0.0%
4.2	0.4%	0.5%	0.3%	28.3%	0.3%
4.3	0.0%	0.0%	0.0%	0.0%	0.0%
5.0	0.2%	0.2%	0.2%	0.2%	14.9%
5.1	0.0%	0.0%	0.0%	0.0%	36.7%
5.2	0.4%	0.5%	0.3%	0.4%	28.3%
5.3	0.0%	0.0%	0.0%	0.0%	8.8%
10.4	0.0%	0.0%	0.0%	0.0%	0.0%
11.1	0.0%	0.0%	0.0%	0.0%	0.0%
11.4	1.7%	0.7%	2.8%	2.8%	2.8%
12.6	0.0%	0.0%	0.0%	0.0%	0.0%
13.4	1.7%	2.8%	0.7%	0.7%	0.7%
14.2	0.4%	10.9%	0.3%	0.4%	0.3%
15.3	0.9%	2.6%	0.2%	0.2%	0.1%
16.6	0.0%	0.0%	0.0%	0.0%	0.0%
17.5	4.7%	4.7%	4.7%	4.7%	4.7%
18.2	0.0%	0.0%	28.3%	0.0%	0.3%
19.3	0.0%	0.0%	8.8%	8.8%	0.1%

EXPORT	1.0	2.0	3.0	4.0	5.0
1.0	14.1%	0.1%	0.2%	0.1%	0.1%
1.1	33.8%	0.0%	0.0%	0.0%	0.0%
1.2	26.6%	0.1%	0.2%	0.1%	0.1%
1.3	8.3%	0.0%	0.0%	0.0%	0.0%
2.0	0.6%	13.5%	0.5%	0.4%	0.3%
2.1	0.0%	32.6%	0.0%	0.0%	0.0%
2.2	0.5%	25.7%	0.4%	0.3%	0.3%
2.3	0.0%	5.7%	0.0%	0.0%	0.0%
3.0	0.3%	0.1%	16.3%	0.2%	0.2%
3.1	0.0%	0.0%	39.2%	0.0%	0.0%
3.2	0.0%	0.0%	0.0%	0.0%	0.0%
3.3	0.0%	0.0%	0.0%	0.0%	0.0%
4.0	0.3%	0.1%	0.3%	12.5%	0.2%
4.1	0.0%	0.0%	0.0%	30.0%	0.0%
4.2	0.4%	0.1%	0.3%	23.6%	0.0%
4.3	0.0%	0.0%	0.0%	0.0%	0.0%
5.0	0.4%	0.2%	0.3%	0.3%	11.5%
5.1	0.0%	0.0%	0.0%	0.0%	28.2%
5.2	0.4%	0.1%	0.3%	0.2%	22.0%
5.3	0.0%	0.0%	0.0%	0.0%	6.9%
10.4	0.0%	0.0%	0.0%	0.0%	0.0%
11.1	0.0%	0.0%	0.0%	0.0%	0.0%
11.4	1.6%	0.6%	3.0%	2.3%	2.1%
12.6	0.0%	0.0%	0.0%	0.0%	0.0%
13.4	1.6%	2.5%	0.7%	0.6%	0.5%
14.2	0.3%	9.7%	0.3%	0.3%	0.2%
15.3	0.8%	2.3%	0.2%	0.1%	0.0%
16.6	0.0%	0.0%	0.0%	0.0%	0.0%
17.5	4.4%	4.2%	5.0%	3.9%	3.6%
18.2	0.8%	0.7%	28.9%	22.2%	20.8%
19.3	4.7%	1.7%	3.8%	2.9%	2.8%

The generator model creates a list of these deep-sea ships that is input for the simulation model.

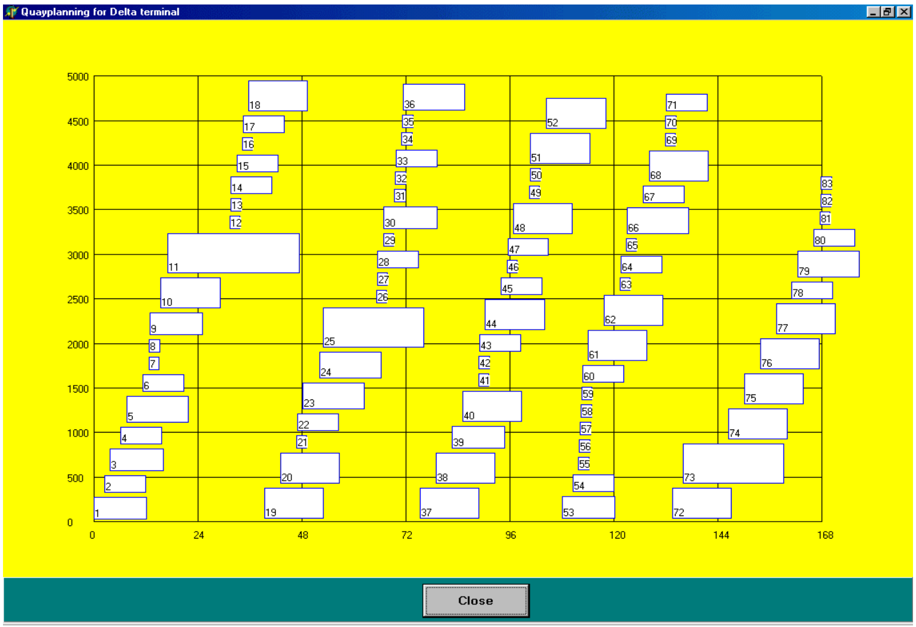


Figure 5. Week planning for the Delta-terminal in the Compact 2025 scenario. In the planning the ships are evenly distributed over the quay-length available.

Table 6. Example of a deep-sea ship definition created by the generator model and used as input for the simulation model.

The ship definition includes:

- Ship name
- Day Number
- Time
- Arrival terminal
- Ship category
- Maximum number of quay cranes allowed
- Container consignments; per consignment:
    - Import or export ('I' of 'E')
    - Originating/ destination terminal and its modality
    - Number of containers (Batch)

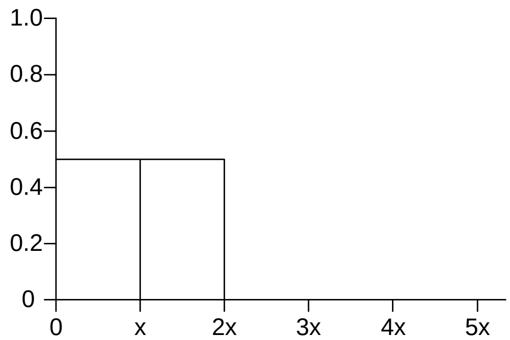
'Ship-B-110_week_1'	5	0.78	'MV2_II'	'B'	2
'I'	'MV2_II.Sea'	11			
'I'	'MV2_II.Truck'	27			
'I'	'MV2_II.Barge'	21			
'I'	'MV2_II.Rail'	6			
'I'	'TSC.Empty'	2			
'I'	'EMD_I.Empty'	1			
'I'	'DPM.Distri'	3			
'E'	'Delta.Sea'	1			
'E'	'Delta.Barge'	1			
'E'	'MV2_II.Sea'	11			
'E'	'MV2_II.Truck'	26			
'E'	'MV2_II.Barge'	21			
'E'	'MV2_II.Rail'	6			
'E'	'TSC.Empty'	2			
'E'	'EMD_I.Empty'	1			
'E'	'DPM.Distri'	3			

For the generation of deep-sea ships and their loads with all necessary data, a separate generator model is developed (Duinkerken 2001). This model generates deep-sea ships as well as an initial berth planning based on average ship lengths and average berth

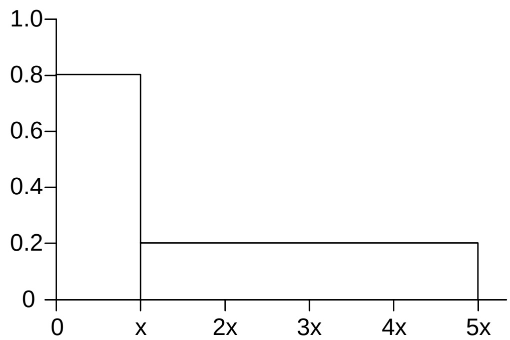
times. An example of a berth planning is shown in Figure 5 and a "ship definition" is shown in
Table 6. The actual arrival time of each ship, its numbers of import and export containers are sampled from distributions.

4.4 Dwell times and dwell time distributions

The dwell time of a container in port is defined as the time between its arrival time and the time at which the container arrives at its final destination modality (ship, truck train, barge etc.). In the model any dwell time distribution may be defined. In the MV2 case a distribution was applied that is formed as a combination of two uniform distributions. This combined distribution can be characterized by its mean value and its maximum value as shown in Figure 6. In the model it is assumed that dwell times depend on the modal split connection the container belongs to. Containers in a ship that have the same modal split connection are called a batch. On each batch the corresponding dwell time distribution is applied. In Table 7 an example of the definition of all possible modal split connections and dwell time distribution parameters is shown.



Maximum = 2 x mean value



Maximum = 5 x mean value

Figure 6. Two examples of container dwell time distributions applied in the MV2 experiments. A distribution is characterized by its mean (x) and its maximum value expressed in x.

Table 7 Definition of the dwell time distribution for each pair of modality connections and the parameters of the dwell time distribution: average and maximum values as defined in Figure 6.

From	To	Mean	Maximum/Mean
Sea	Sea	3.4	2
Sea	Rail	5.2	2
Sea	Barge	3.5	2
Sea	Truck	6.4	2
Sea	Empty	3.0	2
Sea	DistriPark	3.0	2
Rail	Sea	3.7	2
Barge	Sea	3.2	2
Truck	Sea	3.7	2
Empty	Sea	3.0	2
DistriPark	Sea	3.0	2

4.5 Generation of land side modalities and flows

The arrival of a deep sea ship is anticipated by the generating of its export containers according to the modal split data of the export load, before the ship actually arrives, see
Table 6, and the appropriate dwell time. Export containers are generated in batches with a size representative for a transport load of the modality concerned. Import containers are collected at the land side terminal until a batch has formed that represents a transport load of the modality concerned. In Figure 7 an example of generation of import modality load is shown.

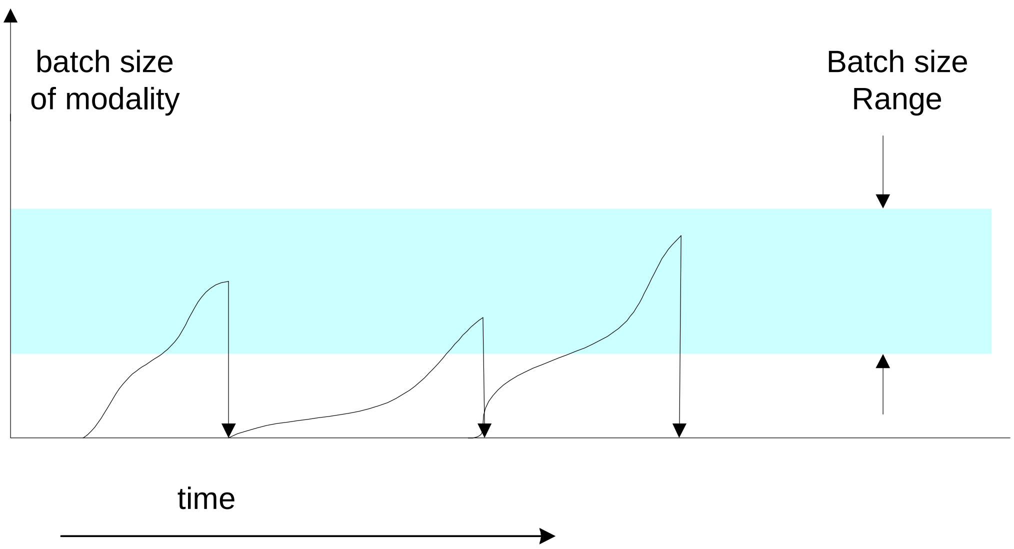


Figure 7. Formation of import batches. As soon as the collected number of containers exceeds the Batch size (sampled from a batch size distribution of the specific modality), the batch is supposed to leave the terminal with a transporter of the appropriate modality.

4.6 Examples of simulation results.

In this section some typical results of simulation experiments are shown. The results of the MICL simulation project are being incorporated in the further design of MV2 and are used for economical calculations within the Famas.MV2 research project. The run length of all simulation experiments was set to 17 weeks, of which the first 4 weeks were used as starting period.

4.6.1 ITT, Quay occupation and Stack Contents

During all runs ITT equipment that is in use, quay length occupied and stack contents was monitored every five minutes. From these data time plots are made, see Figure 8, and the average values and standard deviation and 95% percentile was calculated. The results are summarized in Table 8.

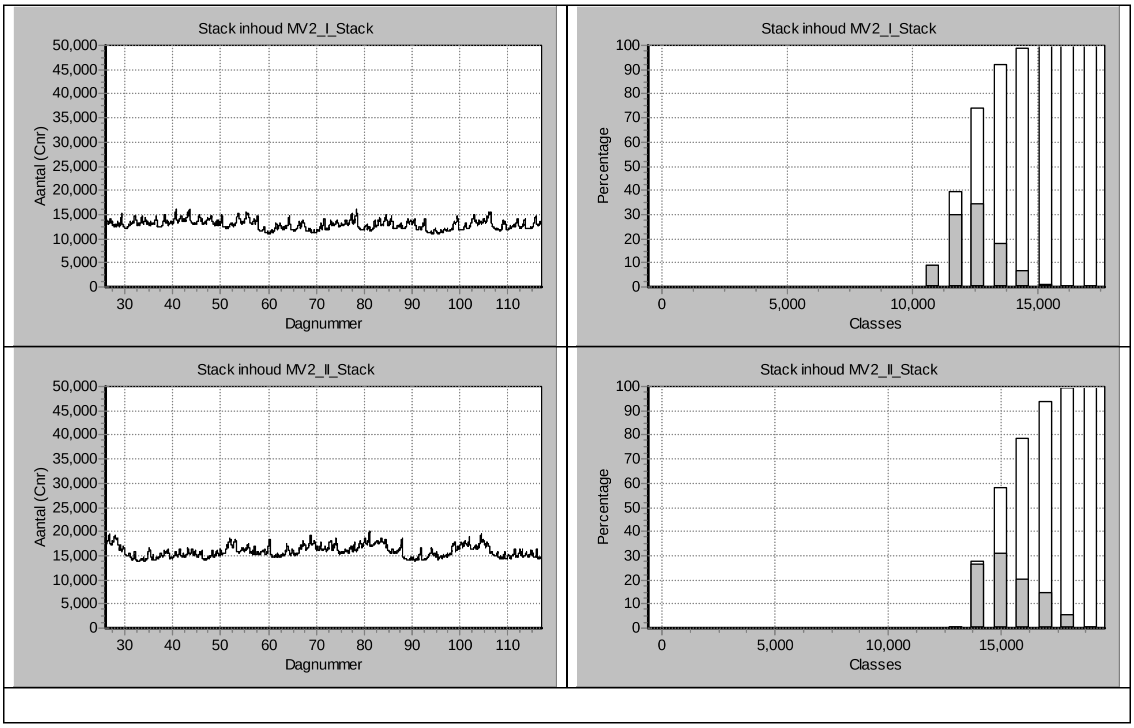


Figure 8. Time plot of MV2 stack contents

Table 8: ITT traffic, Quay Occupation and Stack contents for the 2025 combined case.

ITT Traffic	Average	Stand. Dev.	95%	Maximum
	173	40	249	459

Quay Occupation	Average	Stand. Dev.	95%	Maximum
Euromax	530	289	1052	1550
Delta	1340	469	2166	2750
MV2_I	586	343	1181	1850
MV2_II	644	349	1284	1800
MV2_III	566	324	1159	1700
Total	3666			

Stack Contents	Average	Stand. Dev.	95%	Maximum
Euromax	13631	2042	17297	19231
Delta	33021	2386	38072	41001
MV2_I	12927	972	14810	16146
MV2_II	15917	1222	18254	19923
MV2_III	13694	1646	16462	17892
EMD_II	731	38	798	821
RSC_I	461	41	549	643
RSC_II	1211	81	1371	1480
BSC_I	1609	145	1908	2049
BSC_II	3368	253	3843	4001
EMD_I	636	39	708	751
DPM_I	1846	88	1993	2040
Total	99052			

In Table 9 the ITT need for all three configurations is shown. The number of ITT vehicles used in the combined variant, as was expected, is between the two extreme cases: compact and functional.

Table 9. ITT use for three configuration variants in the case: fully developed MV. In the combined case also the influence of the x-ray scan of 2% of all containers at a central point is given.

Number of ITT vehicles used			
	Compact	Combi Normal/ X-Ray scan	Functional
Average # ITT vehicles	104	173/205	318
95% percentile # ITT vehicles	140	249/281	414

4.6.2 Inter terminal traffic flows on the infra structure

In Figure 9 the traffic flow data on the main nodes of the terminal lay out in the combined variant are shown. The flows appear to have a value between the compact and functional cases.

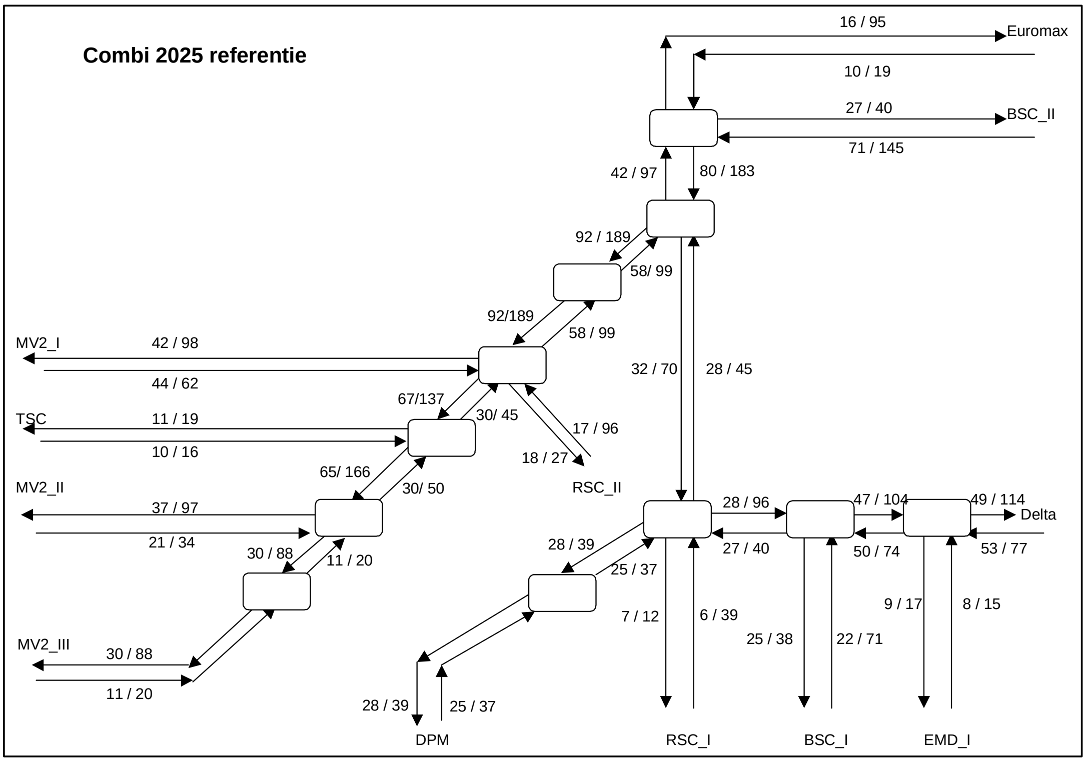


Figure 9. Traffic flows in the combined variant in loaded vehicles/hour. For each direction the average and the 95 percentile of the traffic flow is indicated.

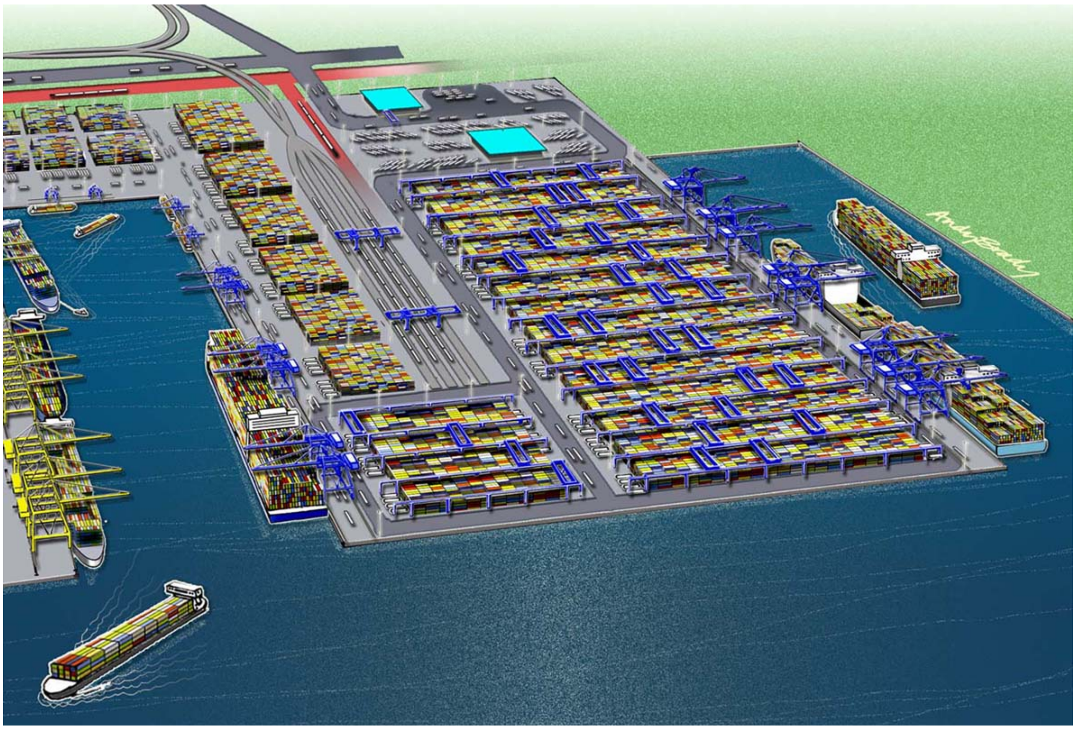


Figure 10. Artist impression of one of the new MV2 terminals (MV2-III) with a deep-sea berth, a rail service center and a barge terminal. Viewpoint is from the North Sea, see also Figure 4. Source: Rotterdam Municipal Port Management (RMPM).

4.6.3 Quay crane capacity and quay length

A deep-sea quayside has a finite unload and load capacity. These capacities are projected on quay cranes that are assigned a certain capacity. Table 10 shows a typical input used in the simulation runs. In the table the anticipated quay length is shown too. It appears that this set of quay cranes is sufficient to cope with the workload and that the available quay length is sufficient.

Table 10. Number of quay cranes per deep-sea terminal used in the simulation runs.

Deep sea terminal	Number of quay cranes	Quay length (m)
Euromax	13	1800
Delta	34	5250
MV2_I	15	2000
MV2_II	15	2000
MV2_III	15	2000

5 Conclusions

The logistic concepts used for the modeling and model input definition are reported and justified. Starting from an estimate of the yearly container throughput, the input set of the MICL model was derived and applied in the MV2 case.

Within the Famas.MV2 research project, the results of the MICL simulation study are now being used to further design of the MV2 container terminals according the combined variant. This design concentrates on:

- Dimensioning deep-sea stack areas as well as land side stack areas.
- Design the traffic road network. Important aspect is the number of lanes needed and whether or not fly-over constructions are necessary.
- Calculations of overall costs and of equipment costs.

The MICL study had led to the recommendation to further develop the combined terminal variant. The lay out is shown in Figure 4.

5.1 Future developments

Several new projects are being prepared for detailed study of:

- The inter terminal transport system
- Rail service centers
- Barge service centers
- Truck service centers

The main issue in these models is the development of intelligent control systems to optimize equipment use and container throughput.

In these studies the MICL model in combination with the backbone structure for distributed model design and simulation may play an important role.

5.2 Acknowledgement

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