A GENERIC SIMULATION MODEL FOR SYSTEMS OF CONTAINER TERMINALS

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KEYWORDS

Model design, Discrete simulation, Object-oriented, Processoriented, Transportation

ABSTRACT

This paper presents the design of a simulation model that is being used in a research project to investigate terminal structures for container handling on the planned extension of the Rotterdan port area "Maasvlakte 2". The research project will use simulation for decision support from the very start of the research until the detailed operational and control studies in future. The model described in this paper is the first simulation model developed for global studies, but it will also be used in future detailed studies. The requirements for modeling, the first results and the future use of the model are highlighted.

INTRODUCTION

The increasing volume of container shipping makes it necessary for the Rotterdam port to expand its handling facilities. For this purpose a new piece of land will be created near the current area of the Maasvlakte. A large research project is started to investigate the best ways of using this new area and to formulate detailed proposals. During this project simulation will play a major role in decision support. In this paper the development and results of the first global simulation model is described. Experiences in earlier large projects have led to a more demanding goal on this model. The model not only must give a global insight into dimensions, but should also serve as an environment for detailed studies to preserve consistency between different studies. This demand asks for a general approach of container handling and a combination of aggregated and detailed modeling.

THE PROJECT "MAASVLAKTE 2"

A number of projects have been defined in a research program FAMAS.MV2 [1]. This simulation research is part of of the project "Maasvlakte Integral Container Logistics" (MICL). The task of the project is to define the starting-points for the program as a whole. It concerns the definition of conditions

and layouts for the the extended Maasvlakte area te be used for container shipment. The area is shown as a white spot in fig. 1.

Above that the requirements on the system as a whole must be quantified. To do so the transportation requirements must be derived, layout alternatives must be defined, investigated and





evaluated to support decision making based on technical, operational, economical and social considerations. Simulation plays a major role in the definition and evaluation of layouts.

On the area several container terminals will be situated, each of them being an autonomous organizational unit. Each unit will handle all or only some specific transportation modalities. Containers will be transported between the terminals by means of an ITT-function (Inter Terminal Transport).

THE GOALS OF THE GLOBAL SIMULATION MODEL

The goals of the MICL simulation model are:

1. To provide quantitative insight into the dimensions of terminal and transportation needs on Maasvlakte 2 for each configuration possible.

2. To provide a basis for further detailed studies with a chosen alternative. The aim is to preserve the starting-points, conditions, characteristics and dimensions during the future research projects.

The first goal asks for a high level of aggregation. Vast flows (millions) of containers must be handled during a long period of simulation time. The second goal however asks for a sufficient degree of detail to be able to distinguish all functional units and to support separate studies of these units. Assuming that detailed studies will focus on autonomous terminal units, on technical or organizational subsystems and separate resources, the structure of the model must reflect these components. Detailed studies will use specific dimensions and characteristics of the components, which are not part of the global logistic model. However, the dimensions and characteristics of the container flows will be prescribed by the global model to maintain the demands on the work load. For this reason the container flow is modeled as a flow of individual containers instead of a continuous flow. The individual containers can then be transferred to detailed models at any moment.

THE ELEMENTS OF THE MODEL

In the past many models for container handling have been developed. Highly aggregated models use mostly continuous container flows [2], where detailed models always use specific characteristics of resources and/or control [3]. To define a general approach where single containers can be handled we must abstract from the physical view to a functional view of handling containers [4].

Each type of container handling can be modeled –both technical and organizational, both aggregated and in detail- by some kind of a structure of three elementary functions:

- 1. *A transportation function*: defined as physically moving a container with no change of modality.
- 2. *A transfer function*: physically moving a container including a change of modality
- 3. A stacking function: physically keeping a container.

Changing the modality is used here in a wide sense. Inside a terminal a container can change of modality by transfer to another type of equipment. So the transfer of a container from quay crane to a transportation vehicle is considered a change of modality.

Every equipment, resource, subsystem or terminal can be composed as a structure with one or more of these functions. The relation between the three elementary functions is shown in fig. 2.

Fig. 2. Shows clearly that for each container entering and leaving the system at least one transfer function must be executed. A transfer function can be coupled to both transport and stack. For example a quay crane (transfer) can be coupled to an AGV-system (Automatic Guided Vehicles), which is a transport function; another set of cranes (transfer) can be coupled to a stack area (stack function).

The structuring also allows different levels of aggregation. If at one level a straddle carrier is considered a transport function, it can also be considered a combination of transfertransport-transfer functions at a lower level of aggregation. Each function should be considered a combination of operation and control. The same holds for any combination of elementary functions.



Fig. 2. Relations between elementary functions

As a principle, the model being used in this study does not contain any control at all. Every combination of functions is assumed to have "sufficient" capacity to handle the container flows. This means, that performing the function itself takes time, but there will be no waiting times. How this assumption still leads to a realistic representation of dimensional needs is explained later.

TERMINAL STRUCTURES

Once the elementary functions are defined, any structure of container handling units can be represented. Below some variants of units are shown.



Fig. 3. A full equipped terminal

First of all a terminal is shown, that is capable of serving all modalities. At seaside a transfer function loads and unloads deepsea ships, while on land side trains, trucks, barges and ITT can be handled.

There can be specialized terminals also. Suppose a Rail Service Center is equipped to handle only containers arriving and

leaving by train. Such a terminal would be structured as shown below.

So we can construct any structure for container handling.



Fig. 4. A Rail Service Center

As mentioned before the ITT function plays an important role for exchanging containers between these organizational structures.

Calling each structure a "terminal" we get a general model structure for the peninsula "Maasvlakte 2".



Fig.5. Structure of a terminal complex

Each of the centers can have its own operational structure composed of elementary functions.

Having defined the structures, two questions need to be solved:

- 1. How to implement the effects of "control"?
- 2. How to describe the elementary functions in a behavioral way?

GLOBAL SIMULATION OF CONTROL

There are two aspecs involved in simulating the control functions of container handling:

- 1. Although control algorithms themselves will not be implemented, the effects of control must be modeled.
- 2. For future detailed simulations it must be straightforward to extend the model with control algorithms for specific functions.

For the first aspect it is important to realize that control normally effects the effectiveness and efficiency of operations in case of limited capacities. The global model however does not contain limited capacities and does not contain sophisticated algorithms to assign jobs to equipment. Every control will generally result in some pattern of time the containers will stay inside the terminal area, after arrival. The question now is how to generate these patterns? Well, it is generally known that the arrival patterns of all land side modalities (train, truck, barge) are concentrated around the arrival of a deep sea ship. Keeping that in mind, we now only need a distribution for the so-called "dwell time" of containers. For import containers this dwell time is defined as the period between the moment a container is picked up from a ship and the moment the container is put on a land side modality (or another ship). For export containers it is just the other way around. Dwell times are already measured in real operations, so it is no problem to use them. And by using them as input data, sensitivity analysis becomes also possible for different scenarios.

Dwell times normally differ for each combination of arrival and departure modality, so for each combination a dwell time distribution must be entered.

Above that deep sea ships show a big variation in size and load. For each type of ships different berth times are required. To reach an acceptable berth time in the model, we introduce the only capacity restriction. For each type of ship a number of quay cranes are defined, that are normally assigned to these ships. Small ships are handled by two quay cranes, large ships even up to six quay cranes. Quay cranes do have a cycle time, so with the restricted number per ship we reach a realistic rate of loading or unloading containers.

At the moment a quay crane picks up a container from the ship, the dwell time of the container starts. At the end of its dwell time, it signals this to the correct transfer function and it will be delivered to the right land side modality. Containers that must be loaded into the ship are forced to arrive at the terminal at such a moment that it's dwell time finishes at the moment of arrival of the deep sea ship. To explain this mechanism, see fig. 6.



Fig. 6. Ship bound container arrival and departure rates

Approaching the arrival date of ship the number of arriving containers, that must be loaded, increases. After departure the same happens the other way around.

To provide an easy way to implement advanced control and detailed operations in later stages we specify the (combinations of) elementary functions according to the 'control paradigm' of De Leeuw [5]. Each system he considers as a combination of two partial functions: control and operation. Control assigns jobs to equipment and stays in touch with the environment. Operation executes the jobs and communicates progress to control. In a general way we therefor model the elementary functions in a way like fig. 7.



Fig. 7. Structure of an elementary function

In the simulation model the term 'system' is used to reflect the control part of a function. So a transportation system is a control system, controlling job assignment to a distinguishable set of transportation vehicles. A terminal system is a control system, controlling job assignment (or release) to subsystems within the terminal etc.

By doing so, the interfaces between operation and control are (and stay) clear and layered control can easily be implemented.

THE DESCRIPTION OF ELEMENTARY FUNCTIONS

In a first approach the functions were described in an informal way. The reason for this is mainly to get a better understanding of all functions involved and (even more important) to preserve the communication about the model implementation with project management and operational

experts.

For example the description of a transportation system and its vehicles is given below.

The descriptions read simple, because all formalities of computer languages are left out. For this reason it was easy for the modelers to explain the modeling assumptions and discuss decisions made (p.e. only the FIFO-principle is used in assigning jobs). For final implementation a Process Description Language is developed, that bridges the gap between this kind of intuitive modeling and the formal computer implementation. [6] Besides that it becomes clear that for implementation of these descriptions, a simulation platform is needed that supports the process interaction approach [7].

Combined with the goal, that further detailing should be easy and detailed modules will be developed in future separately (most likely in a distributed way), the decision was made to use the open and free source package TOMAS [8]. The main reason was, that at the moment of simulation development it could not be foreseen, if all needed facilities are offered by closed commercial platforms. Especially the demand of supporting different levels of aggregation and separate development of model parts seems to be quite innovative. With TOMAS the project has full control on the simulation engine and can develop in the general programming platform of Delphi.

Also, translation of process descriptions as presented, is straightforward in TOMAS and is almost one-to-one.

Process of Transportation_System	
1. Repeat	
1.1. While (Number of ContainersToTransport > 0 And Vehicles Available)	
1.1.1. Select first vehicle And remove it from Available_Vehicles	
1.1.2. Select first container And remove it from ContainersToTransport	
1.1.3. Assign container to vehicle	
1.1.4. If this system is ITT Then	
1.1.4.1. Determine route between source and destination	
1.1.4.2. Calculate Transport time on route	
1.1.5. Else	
1.1.5.1. Transport time of vehicle is distance/average speed	
1.1.6. Calculate Arrival Time of Vehicle	
1.1.7. Start Vehicle	
1.2. Wait	

Process of Transportation_Function

- 1. Wait until Arrival_Time
- 2. Enter Available_Vehicles
- 3. Register Arrival
- 4. Add Container of this Vehicle to the ContainersToTransfer of Transfer_System at Arrival_Point
- 5. Reactivate Transfer_System at Arrival_Point
- 6. Reactivate Transportation_System
- 7. Stop

In the project three alternatives for configuring the new Maasvlakte area were defined:

- a. A "compact" alternative with mostly terminals that serve all modalities.
- b. A "split" alternative with mostly terminals dedicated to a single modality.
- c. A "combined" alternative which is a mixture of a and b.

A screen view of the compact alternative is shown below.



Fig. 8. The compact alternative

Besides general terminals like Delta, MV2_I etc. a number of specialized terminals is defined as BSC (Barge Service Centre) and EMD (Empty Depot). All terminals are connected by a road network to be used for ITT-traffic.

For all alternatives two scenario's for workload expectations had to be simulated, one scenario based on average growth of container traffic and one scenario based on maximum use of the area.

All alternatives were configured via input files, while for each scenario arrival patterns of ships and their loads were generated, specified in terms of container flows between modalities.

Because the number of containers to be handled runs into millions, run duration was carefully selected based on the desired results. The results involve:

- the needed stack space for each terminal
- The needed driving space for Inter Terminal Traffic (ITT).
- The number of vehicles for ITT needed.
- The quay space needed.

Above that the model registers capacity used by each elementary function and subsystem to be used as a startingpoint for further detailed studies on control. Before the measuring of these characteristics can start, the simulation must reach a kind of "steady state". This moment is mainly determined by the dwell time distributions being used. With increasing variance a longer period is needed. For experimenting it is profitable to keep this period as short as possible. Therefor two "extremes" were investigated.



Fig. 9. Dwell time distributions

Both distributions have the same mean value, but the left one has a short tail, while the right one has a long tail. In practice the mean dwell time for containers arriving or leaving by truck is approximately 6 days. To reach a steady state the container arrival patterns must at least be stable, so we need 2 x maximum dwell time value to arrive there. In the case with a maximum of 5 x the mean value the model must run 60 days before measurement can start, in the short tailed case we only need 24 days. The long tailed distribution is an estimation of current reality, but does the tail length influence the results? Below the results for some of the big stack contents and ITT are summarized.

	Short tail			Long tail		
	Mean	σ	95%	Mean	a	95%
ITT vehicles in use	91	19	131	90	20	131
Stack 1 (# cnrs)	13940	1391	16562	13504	1210	15811
Stack 2	34258	2383	38932	33186	1971	37399
Stack 3	15115	1734	18456	14961	1523	17716
Stack 4	17632	1783	21127	16723	1105	18678
Stack 5	1697	157	1985	1508	97	1684

Differences in stack contents are in the order of 3%, where the short tailed distribution requires more space than the long tailed version. Because the differences are that small, the project group decided to use the short tailed distribution for all experiments.

The graph below shows the behavior of stack contents for one of the new terminals at the Maasvlakte.



Fig. 10. Stack contents behavior

For validation purposes the relation between mean stack contents and mean dwell times was investigated. Theoretically this relation must be linear, because Little's law states that the mean number of elements in a system equals the product if the arrival rate of elements and the throughput time. The dwell times (throughput time) are given, the arrival rate is a constant, so changing the dwell times should result in a change of stack contents. A number of experiments has been executed where

the original dwell times were multiplied with some factor.

Fig. 11 shows the relation is indeed linear. With zero dwell times there still remains some time to transfer and transport containers. Handling containers is not completely immediate because quay crane capacity is limited.



Fig. 11. Relation stack contents and dwell time



Fig. 12. ITT Traffic intensities

RESULTS

A series of experiments has been done. The results are at this moment being interpreted to be used in the final report for area configuration.

The total stack space needed is for all alternatives approximately the same. The space needs for the scenario's are related according to the container workloads. As could be expected ITT traffic increases enormously in the "split" alternative, because in this alternative only a few terminals handle all modalities. Most arriving containers must be transported to another terminal of departure. The number of vehicles needed in the "split" alternative is approximately 3 times higher than in the "compact" alternative, both on the average as for the 95% level.

To determine the dimensions of travel lanes and crossings for ITT traffic on the Maasvlakte area the models shows also the passing frequencies at all crossings of the layout. They are presented as in the figure below.

For each crossing and destination the average number of transports and the 95% level per hour were measured for each direction separately. Graphical data are also available. These data are being used as input for the design of the layout. The output can be so detailed by using individual containers instead of container flows. During each experiment approximately 2.5 million containers are handled. Each experiment takes about 4 hours on a normal PC to finish.

FUTURE USE OF THE MODEL

The model is developed during the first stage of research on the future area Maasvlakte 2. It gives a global insight into the required dimensions of space, contents, traffic and equipment. From now on more detailed studies will start on parts of the area. This model will serve as an environment for these studies.

One can easily extract one function, subsystem or terminal from the general model and model it in more detail. The goal is to use the general model as an input generator of containers for these studies. To realize this a concept of distributed simulation is needed. At this moment this concept has already been developed -- in another project of FAMAS MV2- by means of a simulation 'backbone'. The backbone supports synchronization of separate models by means of simple standardized windows messaging. It offers common simulation functions as logging, 3D animation and run control, all in a distributed way. Above all however, the most innovative aspect concerns the support of any simulation platform. Models developed in Arena, eM-Plant and TOMAS already can be synchronized and communicating; depending on the needs of the project groups other languages can easily be connected.

The backbone is already being used for a combination of this general model and a separate ITT-model. By doing so the conditions and parameters of the general model are automatically being transferred to the detailed ITT-model. So sub optimization can be avoided and the consequences of decisions at detailed levels are immediately reflected at the global level.

Key items to achieve these results were:

- the abstract functional way of representation of container handling
- the use of individual containers at the highest aggregation level.

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