

# Simulate designs of container terminals in 15 minutes

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## Abstract

As part of their study Technology, Policy and Management students at the Delft University of Technology learn to develop designs of complex systems in multi-actor environments. They learn about policy making process and technical design support methodologies such as discrete event simulation. Unfortunately, mainly due to the length of time required for a simulation study, they do not use these two technologies in a situation comparable to reality. In this article we describe a one-day game for the design of a container terminal in which the participants use a specially developed support tool. This tool allows participants to design, simulate and evaluate a container terminal in less than 15 minutes.

## Introduction

Discrete event simulation is a powerful methodology for evaluating the designs of systems still to be built. Commonly it is only the designs of logistic systems that use a limited set of resources that can be improved by an evaluation using simulation. This is one of the issues that we teach our students during their study of Technology, Policy and Management at the Delft University of Technology. Secondly students are taught about multi-actor environments and how to arrange the process of discussions in multi-actor environments to promote consensus among the actors so that the group can come to a decision regarding their situation. Using gaming environments the students practice their skills in debating and managing the process, but they do not deal with the integration of development of a detailed design and management of the decision making process.

Several reasons can be identified for this lack:

- Environments are too complex and students lack domain knowledge
- Developing simulation models is a task of weeks rather than hours

- Different actors in a decision making process evaluate the outcome of (simulation) models differently
- Different actors require different kinds of outcome from (simulation) models.

We wanted to develop a one-day game in which students can encounter the benefits of simulation in decision making processes. As a domain we selected a container terminal that transfers containers from ships to storage and then to by trucks to companies situated around the container terminal. In the game we defined ten different actors (ranging from a terminal operator to environmentalist) that together should reach a consensus regarding one or two designs. The groups designs must be evaluated on financial, logistic and environmental performance indicators, which can in part be obtained by performing simulation experiments on the developed designs.

Based on our experience with simulation studies, we know that developing models from scratch is hard and once a simulation model is developed, changes will have to be made to the model for new evaluations. Experts assume that developing valid simulation models of container terminals in the detail that we desire, takes at least a week and that each change will require at least a workday. This amount of time is much more than is available for a one-day game. In this paper we show how we solved the problem of limited time for the game by developing an environment that enables the design, experimentation and evaluation of a container terminal in less than 15 minutes.

We will now describe the theoretical background to our gaming model. This is followed by an explanation of the concepts used to reach 15 minutes for design, simulation and evaluation. The implementation for the container terminal game. In section five we describe how we and 75 students learned from our game when it was played at TPM. We end with some conclusions and ideas for further research.

## Background

Banks (1998) describes a simulation project as consisting of several important steps. Performers of a simulation study need to start with a clear problem statement, to define a conceptual model, to implement a simulation model in a tool environment and to perform the difficult step of gathering the right data. Using a simulation model and data, they can then carry out a verification and validation study to see whether the model behaves as expected and can then finally perform some analysis, after which the whole process starts all over again. In Banks' conceptualization phase, the simulation experts need to absorb all that can be found about the system and transfer this to concepts available in the simulation environment of their choice. This domain knowledge is necessary to decide on the abstraction level of the model and to implement this abstraction level in a valid way.

Within the timeframe of a one-day game, it is not an option that model developers start from scratch and first have to gather enough domain knowledge, to construct a simulation model. An example solution is provided by Hooghiemstra and Teunisse (1998) with their simulator environment for modeling railway networks. Based on a database with information of the network and the train-timetables, they can construct simulation models automatically. The abstraction level they choose is translated into three different modules; a "timetable point", a "railway track" and a "timetable schedule". These modules contain abstracted functionalities and include the calculations of the performance indicators. Using a tool called the DONS-simulator, Hooghiemstra and Teunisse describe how they converge the databases of the Dutch Railways to form correct and valid simulation models, which can be used for evaluation of investments.

The approach described by Hooghiemstra and Teunisse of using modules that are easily and highly reusable has been further evolved in projects for automatic guided vehicles (Verbraeck *et al.*, 1998) and passenger handling at airport (Verbraeck&Valentin, 2002). We call this reusability of models mechanism *building blocks* (BBs), this extends object oriented modeling, and leads to better reusability thanks to composition and interfacing. More about how reusability is achieved using composition and interfacing is described in Valentin&Verbraeck (2002). Further the concept of using building blocks is aimed at models that have high face validity and can be used directly for communication between simulation experts and decision makers. This is achieved by defining building blocks based on what the decision makers encounter in their system. We call these descriptions provided by decision makers *Mental Building Blocks*

(MentalBBs), because they represent the mental pictures decision makers have of their system.

The project of Hooghiemstra and Teunisse shows us the ability of automatic model construction. We use concepts that are based on their work to model container terminals that do not exist yet. We could not just take over Hooghiemstra and Teunisse's concepts because 1) The game represents a multi-actor environment, so the construction of the models, the run of the simulation model and the outcome of the simulation model needs to be clear so it can be discussed on contents. 2) Hooghiemstra and Teunisse develop models based on databases. In a design process, such databases are unavailable and need to be constructed; how this should be done is new. 3) Easy model evaluation requires structuring of the outcome, so somehow the model outcome should be represented in a useful way, preferably automatically after running a simulation experiment.

## Solution: support tool based on domain specific building blocks

### Discuss designs

During design processes domain experts do not think about controls or managers of systems, they start with a physical layout and the defining of the necessary equipment. They assume that controls over equipment and infrastructure will come in later stages. The physical design that is developed is based on the mindset of the domain expert and can be described using MentalBBs. This design process should be done in an easily understandable drawing environment using the different MentalBBs, so all the different actors can join the discussion on the contents.

### Automatic model generation

Definition of MentalBBs is used to define BBs in a simulation environment. If this is done correctly there should be no differences in the functionalities of MentalBBs and BBs. When this is done we can speak about domain specific BBs, as a the conceptual model, i.e. a model described in MentalBBs, has been converged into a simulation model, i.e. a model described in BBs.

### Support evaluation

The BBs provide certain functionalities and calculate all kinds of performance indicators. These statistics should be collected and represented in an overview. Simulation environments like Arena ([www.arenasimulation.com](http://www.arenasimulation.com)) and Promodel ([www.promodel.com](http://www.promodel.com)) provide all kinds of reports with statistics overviews, but these are hard to interpret unless you are exactly aware of what is included at a low implementation level which is not the case when BBs are used. A better representation form more focused to the problem domain is required. This can be done by collecting the statistics of the domain specific BBs and pasting them in a

pre-fixed report specially designed for the domain of container terminals.

Integration in one support tool

Teweldeberhan (2001) has performed an objective evaluation of 50 different simulation environments to find out the current capabilities of simulation environments. None of the tools that he evaluated showed the wide range of characteristics that we need such as: “a flexible way of drawing conceptual model” , “a way to converge conceptual model to simulation model” , “to use domain specific simulation building blocks” and “to show performance indicators structured to domain expert needs”. As an alternative, we have decided to look for different environments for different tasks. Our solution is to link a drawing environment with a simulation engine and a spreadsheet for easy to understand representation.

**Concepts applied for container terminal**

In this section we apply the different useful concepts as part of a design game for container terminals.

The participants of this game are expected to provide and come to consensus on one or two designs for container terminals at a location near to a middle size Dutch village. Different performance indicators need to be evaluated, these are divided in economics, logistics and environmental issues. The process of the container terminal is that containers arrive by ship, are handled by a crane, are moved by internal forklift vehicles to storage, the containers are stored for some time and finally using the forklifts and external trucks delivered to a company near the terminal. This process flow is also followed in reverse from company to terminal.

First we described what the MentalBBs are of the domain experts (i.e. participants in the game). This is followed by a discussion which BBs are used for simulation and the outcome these simulation domain specific BBs provide for representation and how these three tools and tasks are integrated.

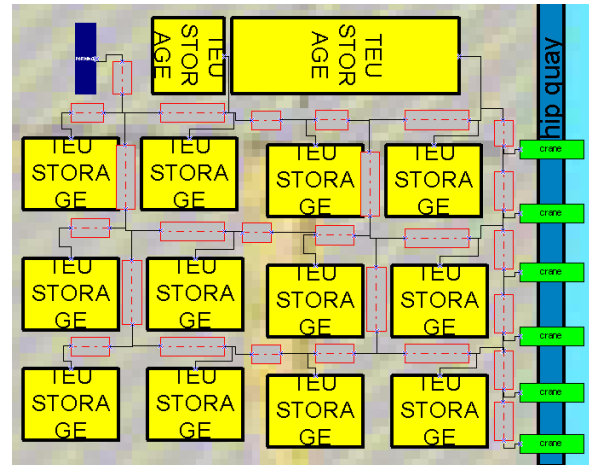
Mental building block

The conceptual designs of the container terminal are developed using two different kinds of MentalBBs. First a drawing of a container terminal is made using VISIO , then database selections are done using MS Access. The drawing is constructed by the following MentalBBs:

- Quay - where ships can lay to be loaded and unloaded by cranes
- Crane - to load and unload containers from ships
- Storage - where containers can be placed by internal vehicles till they are removed to truck or ship

- Parking spot - where trucks can stand while being loaded or unloaded by internal vehicles
- Internal roads - used by internal vehicles to move between storage, crane and parking

The use of these MentalBBs leads to drawings such as shown in figure 1. As the figure is only 2-D, some extra information needs to be included in the MentalBBs by the participants, like the height of the storage and the crane.



**Figure 1: Example drawing of container terminal based on MentalBBs**

The MS Access database is used to support the domain expert in selecting the right equipment for MentalBBs that are not fixed to one place and as a result, can not be drawn in the VISIO-drawing. The MentalBBs that are selected using MS Access database are:

- Vehicles - to move containers between cranes, storage and parking
- Trucks - to move containers between container terminal and company
- (generation of) Containers - create containers at the company and the harbor (see figure 2)
- (generation of) Ships - create equipment that moves containers between container terminal and harbor

Shipcompany name	Average storage time	Total # cont. Terminal to harbour	Total # cont. Harbour to terminal
A en S	5 days	400	400
Batels	4 days	625	625

**Figure 2: Detail of database for selecting MentalBBs**

### Domain specific building blocks

The instantiation of the mentioned MentalBBs can be translated to corresponding domain specific BBs in a simulation environment. Based on the research of Tewoldeberhan (2001) we used the simulation environment Arena because of its ability to develop BBs using the professional edition, its automatic model construction using VBA and its ability to provide textfile-output which can be later imported into Excel spreadsheets.

We implemented the MentalBBs that represent the physical environment described in the previous subsection. Besides these physical BBs we needed some controls that take care of the process flow. These controls are:

- Crane control – assigns a crane to ship
- Quay control – allows a ship to claim scarce resource of quay
- Container control – organizes communication with different controls and signals when a container should be removed from storage
- Storage control – assigns in which of the available storages a container should be stored
- Vehicle control – assigns a vehicle to move a container between parking spot, storage and crane
- Truck control – assigns a truck to transport a container between the container terminal (parking spot) and the companies

The physical and control BBs can automatically be configured based on the information of the physical MentalBBs.

### Outcome

The different domain specific BBs all collect their own statistics. These statistics are saved in small text-files. These textfiles are imported into a predefined Excel spreadsheet. Some of the information in the Excel spreadsheet is:

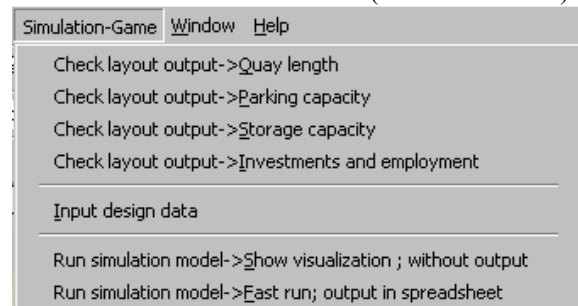
- **Fixed cost** – fixed cost for the equipment per day (salaries, interest, maintenance...)
- **Variable cost** – cost per move of a container
- **Revenue** – revenue per move of a container and of storage for one day
- **Profit** – difference between cost and revenue
- **Utilization** – utilization rate of the equipment at the container terminal
- **Queue length** – number of containers, trucks or ships in queue for a resource at the container terminal
- **Queue time** – time the containers, trucks or ships waited for a resource
- **Throughput time** – total time to move a container from the harbor to the storage of the terminal and further to the company and of course vice versa

- **Employment** – number of jobs created thanks to the container terminal
- **Noise** – noise levels produced by the container terminal in operation
- **Emission** – emission of CO<sub>2</sub> produced by the container terminal in operation

This list of output parameters is required, due to the different roles in the game. For example, environmentalists are mainly interested in the noise and emission levels, while future customers checked the throughput times provided. Further topics like queue length and utilization are included to support the participants in making suggestions for improvement of the terminal.

### Integration

The different tools (VISIO, MS ACCESS, ARENA and MS EXCEL) are linked together using VBA-coding. A basic sheet in VISIO consists of a small user menu (figure 3). This enables the participants to evaluate and quantify their design (check layout....) and to start the simulation model (run simulation....).



**Figure 3: User menu of support tool**

When menu-item “run simulation model” is selected an intermediary database is created which combines information of the MentalBBs of the drawing and the selection database. This is used to construct an Arena model, which can be run with animation or output directly into the Excel spreadsheet.

### **Use of support tool in game**

The game was played three times with three different groups of 25 students divided over 10 different roles. The students had to manage their own activities over the day. This was much harder for them than was expected, which resulted in less time to design terminal layouts using the support tool to actually design the terminal. When they finally started to design different terminal layouts, they decided to do so in groups of 4 to 7 persons, including representatives of different roles with different aims.

During the game we used two kinds of evaluation to investigate the effect of the support tool. First of all the students were obliged to fill in a questionnaire and secondly researchers acted as observers, observing the activities of the students.

Table 1. Assessment of statements in the questionnaire (%). (n= the number of valid responses; 1= agree completely; 2= agree a little; 3= disagree a little; 4 = disagree completely; 0= no opinion)

Statement	n	1	2	3	4	0
1) The support tool provided good support in making a terminal design.	72	64	26	8	2	-
2) The evaluation of terminal performance of various designs was well supported by the support tool.	73	51	34	12	2	1
3) The tool had a positive effect on the quality of the terminal design that was the outcome of negotiations at the end of the day.	73	25	43	21	4	7
4) Working together with persons from other roles on making the layouts and entering logistic data with the tool contributed to generating mutual understanding.	65	62	32	3.1	2	1
5) The use of the support tool speeded up the design process that took place during the day.	73	41	40	16	3	-
6) Making designs (consisting of layout, logistic data and output on terminal performance) with the tool went fast enough in relation to the progress of the game.	73	40	34	21	3	-

### Questionnaire

A few of the statements regarding the use of the support tool that the students evaluated are shown in table 1. The high agreement with statement 1 and 2 regarding the usefulness of the tool (90 and 85 percent) is remarkable. Further the students were of the opinion that the support tool provided them with the ability to have structural discussions with other roles (statement 4) and they agreed with the statement regarding time needed to develop a new design (statements 5 and 6).

As well as statements the questionnaire had some open questions about expected time required to produce designs and the number of designs. They said that a design could be made in 30 to 45 minutes, including discussion with different roles and that they succeeded in making 1 or 2 designs that they liked.

### Observations:

The observations showed that the students were afraid to experiment. They first tried to reach an agreement, before testing importance using simulation, for example it took a lot of time to determine whether they wanted 4 or 5 cranes, while after only one simulation experiment it turned out that one crane was more than enough.

Further they started to look at one performance indicator (mainly profit) and when that one was high enough, they looked for new indicators. They adjusted the design by changing the size of the storage, the number of customers, the frequency of ships, but they still talked as if they were making one design. Observations showed that on average 7 experiments were performed in the 45 minute time frame before the group of students agreed on a design.

### Conclusions and ideas for further research

The evaluation of the container terminal showed that it is possible to use discrete event simulation in decision making processes if only time is limited, like in a gaming environment. Observation of an

average of 7 experiments carried out within only 45 minutes shows that domain specific BBs and of MentalBBs made discussion easy for the student participants.

Further research should show how important the influence is of the architecture of the BBs used. Hooghiemstra and Teunisse have already demonstrated the use of modules. We think that building blocks have an improved effect on the flexibility of models, but more and different experiments are required to prove this.

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