# MULTILEVEL APPROACH MODELLING FOR PORT CONTAINER TERMINAL SIMULATION

**Marcos Sanz[a], Daniel Juste[b], Carlos Lozano[c], Marina Vallés[d], José Luis Navarro[e]**

[(a)-(e)]Instituto de Automática e Informática Industrial
Universidad Politécnica de Valencia
Spain

[a]marsanri@ai2.upv.es, [b]dajuslo@ai2.upv.es, [c]carloga3@ai2.upv.es, [d]mvalles@isa.upv.es, [e]joseluis@isa.upv.es

**ABSTRACT**
In this paper, it is analyzed how to aggregate the operations carried out in a container terminal for the construction of simulation models. Also, the productivity or efficiency indexes commonly used in terminal management are related to every abstraction level, so the user will select the appropriated simulation model based on the indexes he want to obtain.

Furthermore, the models must give coherent results, so some parameters of a more abstracted (or aggregated) model can be obtained from a more detailed one using simulation. In the opposite direction, if it is known an aggregated parameter, some dependent parameters of a more detailed model can be obtained by means of a search procedure that will find the best solution for this set of parameters.
As a result of this analysis, a hierarchical multilevel model is proposed for the simulation of port container terminals.

Keywords: Container Terminal, bottlenecks, Balanced Scorecard, simulation.

## 1. INTRODUCTION
In recent times, the use of simulation has become in an important tool in the different logistic processes, especially those that have high cost and risks, for example simulation of a container terminal, in which exists expensive logistic equipment and very heavy (cranes, trucks, RTG's, etc.).

In our case, the simulation models are developed to assess the dynamic processes of container terminals. This allows generating and analyzing different statistics (Steenken et al. 2004), such as average productivity, mean of waiting time, etc, can also be used as a tool support to make decisions since in the field of container terminals, a small change in a terminal (e.g. add a crane in the docking line) can be a high cost in terms of money and maybe once the new element has been added to the terminal, it does not have positive changes in productivity (or other indicators to measure). Therefore, the introduction of simulation tool can help to find out if is necessary (or not) a change in the terminal.

Because of the many advantages offered by these simulation tools, the use of these has been increased in different intermodal systems and specifically in maritime environment (Rouvinen 2005; Korkealaakso et al. 2007).

Simulation models built can be used to improve many facets of a container terminal operation. In general, a simulation tool helps in our goals to increase throughput, improve equipment utilization, reduce waiting time and queue sizes, reduce bottlenecks, balance workload allocating resources efficiently and study alternate investment ideas.

To simulate it is needed simplify reality due to the high complexity of the real system, for which reason it only takes into account a number of parameters and indicators that are considered important and necessary for further analysis. However, in our model, we generate different simulation levels varying the detail level, from a more simple and generic model (level 1) to a more detailed and closer to reality (level 5) taking into account the limitations on the use of simulation.

The paper is structured as follows. In Section 2 is described the proposed hierarchical model, with 5 levels of aggregation for the container terminal. In Section 3 are detailed the different used indicators. In Section 4 is explained the model implementation and the coherence between different levels. Finally, Section 5 gives concluding remarks.

## 2. HIERARCHICAL MODEL
The first step for constructing the model of a system is defining the limits of the system and the objectives of the study. This step will lead us to define which are the inputs and the outputs for the model, that is, variables that are needed being defined in order to characterize the model for a specific problem. However, depending on the objective of the study, different levels of detail for the system can be defined and so, different variables are needed to be introduced.

At this work, 5 levels of model definition are proposed for the case of container terminals. The main components of the model are the yard and the intermodal links (maritime, road and rail) which are modeled with different degree of detail from the most abstract to the more detailed.

At the first level, the container terminal is modeled as a single warehouse. At level 2 operational details are added in the maritime gate. The existence of different storage areas in the yard is considered at level 3. At level 4, each area of the yard is divided in blocks. Finally, at level 5 the maximum detail of the container terminal is considered.

So, levels from 1 to 4 can only be used for simulation purposes while level 5 can be used for emulation. Definitions and comparisons between these two terms can be consulted at (Joschko et al., 2009).

Next, each of these five levels is described in detail.

### 2.1. Level 1: Single warehouse

At this first level all internal components of a container terminal are abstracted: the yard is modeled by a virtual store that only keeps statistics on the total number of containers and dwell time.

All transport elements (ships, trucks and trains) arrive at the terminal with an interarrival time following a statistical distribution. It also assigns a service point as element (docking, terrestrial door or railway) and remains in service for a time modeled by another distribution function. During this service containers are transferred from the terminal, modeling approximately the number of stored containers or the spent time.

The behavior of this model is determined by the distribution functions assigned to the interarrival times of transport, service times, idle times, etc.

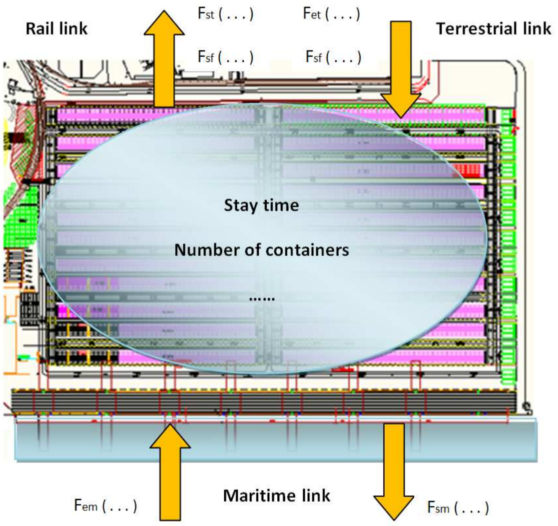


Figure 1: Level 1 scheme

In the maritime link, the ships are created by a statistical distribution that simulates the time between arrivals of the ships. The ship queue at the port entrance is modeled by a FIFO and the berth line is modeled by a discrete number of docking positions. Once the ship is moored, it will stay in the berth during a statistical service time.

In the rail link, the railroads are modeled by a finite number of ways. Once a train is assigned, it will stay a service time characterized by a distribution function. The value of this function can be affected by variables of the model: number of busy railroads, number of containers in the terminal, etc.

In the terrestrial link, there will be a FIFO queue that will model the waiting time of trucks at the entrance to the terminal. Once the truck is in the terminal, it will wait during the dwell time in the yard while the containers are unloaded and loaded.

### 2.2. Level 2: Maritime gate

In the second level operational details are added only in the maritime link, as has been said before.

The details of the maritime gate considered at this level are berth allocation to ships, port operations and entry docking maneuvers, allocation of cranes in the ship service (depending on this the service time) and exit maneuver port.

The critical point of this model is the determination of the distribution functions of the number of movements per hour of machines and algorithms used for the distribution of space in the berth line and the allocation of the number of cranes. So it is necessary to set more parameters than at the previous level and make available more specific information to obtain the distribution functions.

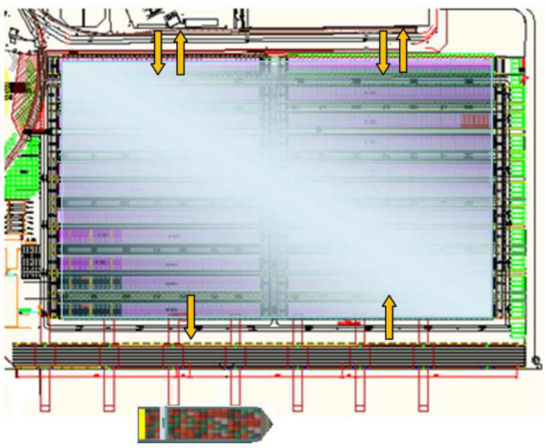

Figure 2: Level 2 scheme

The yard is modeled in the same way as level 1.

#### 2.2.1. Ships arrival

The user could select among three options to model the load of the terminal:

- **Generic model:** it is defined “n” types of ships based on characteristics of length, width and depth. It will be used a distribution function to model the interarrival time and a discrete distribution function to define the type of the ship that arrives. The movements needed for a ship will be obtained through distribution functions with parameters dependent on the maximum capacity of the boat. These values are stored in local variables for import and export.

- **Service model**: In this case, the arrivals of ships are modeled in accordance with a schedule to replicate the services of a specific terminal. It is added variability in arrivals (advances, delays and cancellations) using appropriate distribution functions. The service characteristics and ships will be obtained through consulting the database of the Terminal Operating System (TOS).
- **Historical model**: The traffic of the terminal will be obtained from real traffic data of the terminal. It will be added variability by distribution functions to the interarrival time, movements for each ship and alteration of the order of arrivals. It will be added a scaling factor that allows varying the traffic level in a simple way (k = 1 models the same traffic, k < 1 models a reduction of traffic and k > 1 models a proportional increase). Data will be obtained from the TOS database.

#### 2.2.1.1. Berth allocation

For modeling the berth the real profile of the berth line of the terminal is considered and data from bollards, depth and crane work areas (if they have different characteristics) is incorporated.

For the allocation, the order of ships in the arrival queue, waiting time, required service time, movements to make, length and beam, draft and operative load of the terminal in that moment (assigned berths and available cranes) (Saurí 2009) is considered.

Some scheduling algorithms may require the use of forecast of arrivals in a determined number of hours (24, 48 hours, etc.). In that case, it would have to add a delay line between the traffic generation and the arrival to port.

The berth allocation process can be combined with the crane allocation process (ship service) that it is described in the next point, to optimize together the berthing operative and service.

Other aspects to consider in the decision process are its any-time behavior and its reactivity. Regarding the later, it should be considered the ability to re-dock planning to incidents, delays or relevant changes in the scenario.

#### 2.2.1.2. Ship service

Once assigned the berth, the port entry time and the docking time are modeled with a distribution function of time or as an average speed and distance (using data from the port layout).

The ship service process must set the number of cranes allocated to the operations of loading and unloading. This allocation process can be built into the berth allocation algorithm or in an independent algorithm. It should be taken into account the operational features of each crane in relation to the characteristics of the ship (beam, number of bays, etc). Depending on the number of cranes that are working in the ship, it will be assigned a number of containers that should manage each one.

The operation of a crane is characterized by the number of movements per hour, and an appropriate distribution function obtained from experimental data is used. The data will include the time to be in service and the travels of the crane along the berth.

The allocation of cranes may not be static during the service time of a ship and could vary depending on the service requirements of docked ships.

Once the service is ended, it is added the undocking time and departure time from the port.

During the ship service the import containers are transferred to the yard and it is extracted the containers marked by the variable export.

### 2.3. Level 3: Yard partitioning

At this level the existence of different storage areas in the yard is considered. Every area has different resources and operational strategies, so time spent handling the container depends on the area where it is allocated. Internal transport elements between areas and gates are also included in the model, but the handling equipment inside the areas (RTGs, RMG, reach stacker, etc.) is not modeled.

Each area of the terminal is modeled as a homogeneous container storage that stores a particular type of container.

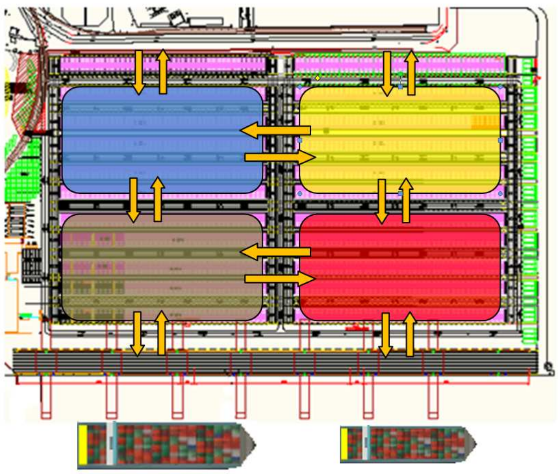

Figure 3: Level 3 scheme

In the yard it is common to use areas for import, export, empty and trans-shipment containers, but, if needed, a further subdivision can be done.

At this level, it is added data about the movements depending on the container types on each ship. For transfer containers and empty containers it is distinguished the number of loaded and unloaded containers.

### 2.3.1. Ship service

As at this level internal container transport is included, the service time of a crane is modeled including the interaction between the crane and the elements of internal transport, so synchronization between crane and the transport is needed.

### 2.3.2. Terrestrial link

Trucks that enter in the terminal should indicate the operation that they will do: leaving containers (1 or 2) and pick up (1 or 2), empty or full. After the gate, if they bring containers, they will go to a specified zone and later will go to the import zone to pick up import containers. The stay time in terminal will be set by movements within terminal and the service time in each one of the zones.

### 2.3.3. Model of operations in the yard areas

For each zone of the yard will be defined a stay time, that will provide the time spent managing an order for a transport element (container loading or container unloading). This time will depend on the transport operative (maritime or terrestrial), the assigned machine number to the management area, the spatial dimensions of the zone and its fill level. These functions can be obtained by simulation of more detailed level models.

There will be a manager module of the yard that it will plan all the orders of the transport elements. This plan may be global to the terminal or be oriented to the crane services that are in operation (management by human operator (Pérez 1997)).

## 2.4. Level 4: Block level

At this level, the details of the yard operation are increased, taking in consideration the storage yard layout, how the blocks are arranged, streets, etc. Containers will not have distinct identity within a service, so that certain operations, such as removals or housekeeping functions will be modeled by efficiency functions or by increasing service times.

For each block that enters the terminal attributes for determining the area or stack storage have to be supplied, a container location system, models to simulate the operation of the machinery responsible for managing the stack (RTG's for example), number of machines available and service areas assigned to each of them are also needed.

Figure 4: Level 4 scheme

For access to street blocks traffic directions for the streets are specified.

Each block can store containers of 20 or 40 feet. Mixed stacks will not be considered.

A block will be assigned to a preferential operational type (or exclusive): import, export, empty, transshipment. Transfers can be treated as export.

Each stack can be assigned a service, ship or destination to make easier the segregation of containers.

### 2.4.1. Maritime link

This level adds information regarding bays: number of bays, container movement capacity by bays. It will be differentiated 20 feet containers and 40 feet containers. So, for the allocation of cranes it will be taken into account the numbers of expected movements per bays.

### 2.4.2. Model of operations in the yard areas

For each area of the yard it will define a service time that will give the time spent managing an order for the transport element (loading or unloading of container). This time will depend on the operational transport (maritime or terrestrial), the number of machines assigned to the zone management, the spatial dimensions of the area and their filling level. These functions can be obtained from experimental dates or from the results obtained by more detailed simulation models.

## 2.5. Level 5: Terminal emulation

In the last level you get the highest degree of detail. All elements and essential operations are included in the model. Each container has all the characteristics relevant for its allocation in the terminal and its management. The simulator can be connected with the terminal operation system and interact with it in real-time or in accelerated time. This can be used for checking the operation of the TOS or see what happens when some configuration parameters are changed. But these results are valid for short time predictions because the results are very dependant of the state when the simulation starts.

# 3. PERFORMANCE INDICATORS

There are some well known performance indicators that are widely used in container terminal management. The proposal is to obtain these indicators from the simulation model.

Some of the indicators will be used as simulation parameters depending of the selected level. Others will be obtained from the simulation results. In this case, the indicator will be assigned to the simpler level where it can be computed (that one with the lowest number). If an indicator can be obtained in level i, then it also will be obtained in level i+k. Also, some indicators obtained in level i will be used as simulation parameters in level i-j.

At each level it must be done a comprehensive analysis to identify all the indicators that are assigned to each one. At each level we have assumed that it would need the indicators shown in the Table 1, but may be other parameters that are not indicators but necessary for the simulation.

Table 1: Indicators and parameters

| Indicator/Parameter | Type | Level |
|---|---|---|
| Ship length | Input | 1, 2 |
| Dock length | | |
| Docking positions | | |
| Ship service time | | |
| Number of gantry cranes | | |
| Average waiting time of anchored ships | Output | |
| Average time from the ship arrival to port until docking ending (excluding anchoring). | | |
| Number of access gates an available gates | Input | 3 |
| Number of trucks entering the terminal per gate number | | |
| Number of trucks entering the terminal per gate number in rush hour | | |
| Queue time of trucks | | |
| Truck service time in terminal | | |
| Traffic volume of loaded containers and unloaded container in maritime operations | Output | |
| Availability of trucks | | |
| Utilization of trucks | | |
| Number of containers per truck | | |
| Maximum capacity of the yard | Input | 4 |
| % Utilization of the yard | Output | |
| Space utilization in the terminals | | |
| RTG's utilization | | |

In the first column it is defined some of the indicators or parameters assumed in simulation. The second one shows if the indicator is input data (input) or whether it is a result of the simulation (output). The third one is the level where the indicator is taken into account the first time.

## 4. IMPLEMENTATION

The simulation tool will be usually used by technical staff of port container terminals and, commonly, they are not experts in simulation languages or tools. So, it is necessary to develop an environment for defining the terminal layout, components, its behavior, relations and parameters. Also, it is necessary to provide different tools for testing, validating and querying the terminal models using up-to-date technologies of man machine interfaces.

So, it will be helpful to use an object oriented simulation language for defining component libraries with the models of terminal interfaces, handling equipment, scheduling operations, etc. Also, it will be useful to use graphical 3D representation of simulation objects (figure 5) for showing how the terminal objects interacts and helping in model validation stages.

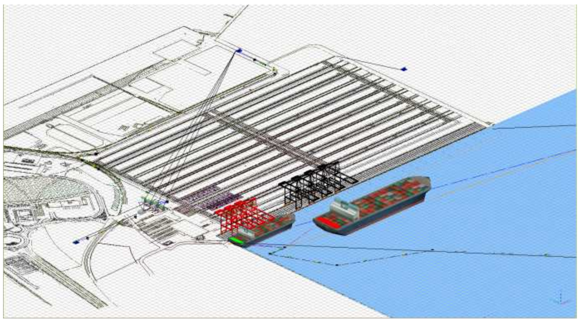

Figure 5: Simulator preview

In our case, the program used to implement the simulation is Flexsim® Simulation Software, a fully 3D simulation software environment. This software is a multipurpose simulation tool that has been used in manufacturing industry, health-care, or communications. The choice of this simulator is based on the following characteristics:

- Open structure to programming.
- Intuitive interface.
- Direct insertion of 3D elements.
- Works under OpenGL®, free graphics library.
- Programming in C/C++ and a proprietary scripting language (flexscript).
- Use of sequenced tasks for the coordination of object operations.
- Scheduling of movements based on kinematics parameters.

In addition, this simulation tool has a library for container terminals (FlexsimCT), that incorporates some the most common equipment and operations found in container terminals. But it has not been used in this development because it is a end-user library and it is not possible to include all the extra functionality presented in this paper.

Every hierarchical level is implemented as a different simulation model, that it is automatically generated using a terminal editing tool, because the simulation code is more efficient. Also, different instances of the model can be run in parallel, speeding the results.

Another critical issue in constructing simulation models for container terminals is the acquisition of object parameters from equipment specification, from real exploitation data or from both. As the model is more detailed it will be necessary to use an increased number of parameters. On the contrary, as more abstract is a model, less parameters, but there is more imprecision or uncertainty in the results. So, it is necessary to select the simulation level that best fits the performance indexes that we are interested in. This is usually the more abstract level (simpler one) that obtains those indexes as results.

But the data must be also coherent between the simulation levels: statistical density functions can be used to represent a complex behavior of different parts of the terminal operation. Then, the simulation results of all the levels must be similar (if not equal) for all these functions. Two cases can be met:

- Abstracting: the statistical functions used in level i can be obtained from simulation of model of level i+1. In this case, it is only needed to simulate the model of level i+1, record the statistical results and incorporate these to the level i as parameters.
- Detail increase: in this case, the known information is the functions of level i. Then, values of some parameter of level i+1 must be found in order to statistical results of both levels will be similar. This is a harder problem that can be solved using optimization. For measuring the similarity between statistical functions it can be used differences in mean values and variances or, even, histograms.

All the functions described here are schematized in figure 6. The user edits the terminal layout, equipment and defines the abstraction levels in the editor. Then, simulation models can be automatically generated. Parameters hint and validation tool can be used for aiding in the introduction and validation of simulation parameters. Finally, runtime scheduler and monitor are used to launch different simulation instances in parallel and collect the results.

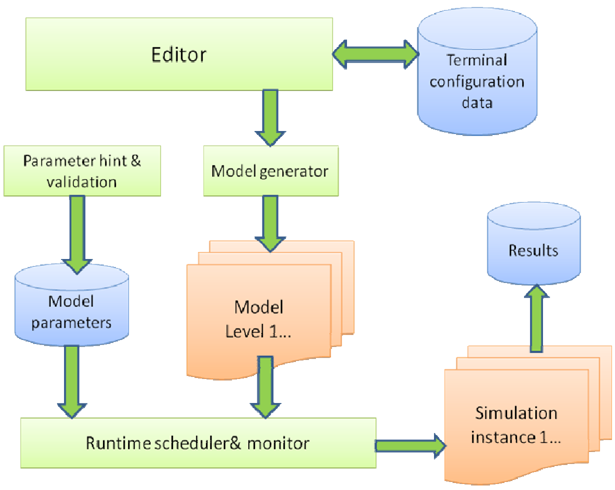


Figure 6: Simulation tool components

## 5. CONCLUSIONS

In this paper a proposal for the construction of hierarchical simulation models for container terminals has been presented.

The complexity of every model agrees with the results that will be obtained from simulation and, actually, they are a subset of the performance indexes used in container terminals for monitoring strategic, tactical or operations levels. This produces a simpler simulation model with less parameters and the simulation run can be more efficient and faster.

Also, a global structure of the simulation tool has been presented and, at this moment it is being developed.

## ACKNOWLEDGMENTS

This work was supported by the project 19/08 –Ayudas a Proyectos I+D en Transporte e Infraestructura del Ministerio de Fomento from Spanish Government.

## REFERENCES

Joschko, P., Brandt, C., Page, B., 2009. Combining Logistic Container Terminal Simulation and Device Emulation Using an Open-Source Java Framework. *In Proceedings of the International Conference on Harbor, Maritime & Multimodal Logistics. Modeling and Simulation*.

Korkealaakso, P. M., Rouvinen, A. J., Moisio, S. M. and Peusaari, J. K., (2007). Development of a real-time simulation environment. *Multibody System Dynamics*, 17:177-194.

Pérez Fiaño, J., 1997. Optimización del Proceso de Asignación del Trabajo Portuario en las Terminales de Contenedores. *Tesis Doctoral. Departamento de Transporte y Territorio. Universidad Politécnica de Cataluña.*

Rouvinen, A. (2005). Container gantry crane simulator for operating training. In Publishing, P. E., editor, *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics*, volume 219, pages 325-336.

Saurí Marchán, S., 2009. Operaciones y colas de los barcos en los puertos. *Departament d'Infraestructura del Transport i del Territori. Universitat Politècnica de Catalunya.*

Steenken, D., Voss, S., Stahlbock, R., 2004. Container terminal operations and operations research – a classification and literature review. In: *OR Spectrum 26*, pp. 3-49. Berlin, Heidelberg, New York: Springer.