CONTAINER TERMINAL SCENARIOS ANALYSIS AND AWARENESS TROUGH MODELING & SIMULATION

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ABSTRACT

The paper proposes a simulation model used to analyze and testing several operative and security scenarios in a container terminal.

In particular all the main state variables describing system behavior has been completely parameterized so the user, by means of a general graphic interface, is able to generate different operative conditions regarding all the port main activities. The user actions are opportunely reflected in the performance indexes output section giving the possibility to analyze system behavior thanks to graphic and statistical tools.

INTRODUCTION

Every year several millions of containers move, trough the world wide network of container terminals and seaports, almost every kinds of goods and items. For this reason container terminals are the most important "ring" of the global supply chain.

There are various kind of activities that characterize the operative conditions of all the multimodal terminals, for example unloading goods from ship to yards and vice versa, docking of ships, inspections of containers, maintenance services and so on. The activities have different level of complexity but all are important to improve the performance and the security of the structures. For what concern security the attention is increased after September the 11th 2001, in fact all the security procedures have been reviewed to improve the defense to threat and terrorism attack.

Actually the terminal management was already a complicated matter in which the theories and the analytical models proposed by researchers very often lock horns with practical real problems. The security problems, perhaps one of the most important at the moment, add, let's say, more "degree of freedom" in terms of new system parameters and more difficulties in system improving (considering the obvious negative effects provided by security procedures on system performances).

In this context, for instance, several research works (Longo and Bruzzone, 2005) have proved the increase of the security level in terminal containers leads to the total block of the main activities with a huge impact on supply chain performances.

The authors propose an approach based on the complete parameterization of a container terminal simulator giving to the user (system's experts) an advanced interactive tool for scenarios testing, what if analysis and problems solving.

Starting from a container terminal simulator (implemented during the previous year for studying port operations and security procedures in a real container terminal) the main state variables have been parameterized choosing ad-hoc values ranges and statistical distributions have been implemented in a easy-to-use graphic interface. The user actions (at simulation begin or run-time) can be observed in terms of consequences on system behavior and performances using the default output section or specific graphic tools or analyzing by means of statistic tools as shown in the application example proposed in this paper.

CONTAINER TERMINAL DESCRIPTION

The main port activities that we have considered to build the model are summarized in Figure 1, the layout proposed shows also the main infrastructures of a generic multimodal terminal. In this research work the terminal container was modelled using a simulation package based on java language. The uploading and unloading of the ships at the dock are performed by portainers-crane. These kinds of crane are powered by electrical engines and move on rail.

Forklifts are used for moving the containers trough/from/to the yard (storage area). The operations of docking and sailing of the ships are supported by Tugboats.
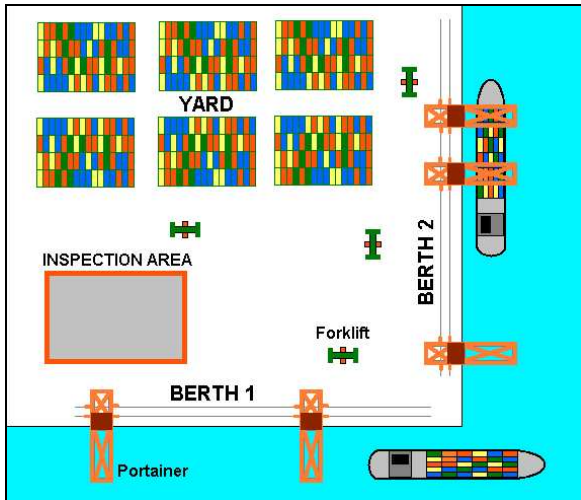
Figure 1: Schematization of the container terminal

CONTAINER TERMINAL INPUT PARAMETERS

In the following section all the container terminal operations are described in terms of main variables and operative parameters. We can subdivide all port activities in five main sections, each one reporting specific parameters:

- ships arrival;
- ships characteristics;
- technical equipment;
- external trucks characteristics;
- inspection phase.

In the *Ship Arrival* section the slider relative to the ships mean inter-arrival time can be varied as shown in figure 2. The inter-arrival time, IT, that is the time between two consecutive ships arrives, is considered as Poisson process; consequently it is inferred from a negative exponential distribution as reported in equation 1.

$$IT = Distr\_NegExp(1/MeanIT); \qquad (1)$$

IT: inter-arrival time;
MeanIT: mean inter-arrival time;

In addition the number of ships per arrival can be set used a text box not shown in figure 2. The *Ship Characteristics* section is made up by two sliders (see figure 2) enabling the possibility for the user to vary the minimum and maximum number of containers to unload from the ship. The exact number of container to unload, NC, is inferred from a uniform distribution following equation 2:

$$NC = Distr\_Uniform(minNC, maxNC) \qquad (2)$$

NC: number of containers to unload;
minNC: minimum number of containers to unload;
maxNC: maximum number of containers to unload;

The technical equipment section is made up by 6 sliders (see figure 2). It's possible to set the number of tugboats, the mean tugboat speed (the actual tugboat speed, TS, is inferred form a triangular distribution, see equation 3), the minimum and maximum container unloading time (the actual container unloading time, CUT, is inferred from an uniform distribution, see equation 4), the number of forklifts and the mean forklift speed (the forklift speed, FS, is inferred from a triangular distribution, see equation 5).

$$TS = Distr\_Triangular(minTS, meanTS, maxTS) \qquad (3)$$

$$CUT = Distr\_Uniform(minCUT, maxCUT) \qquad (4)$$

$$FS = Distr\_Triangular(minFS, meanFS, maxFS) \qquad (5)$$

minTS: minimum tugboat speed;
meanTS: mean tugboat speed;
maxTS: max tugboat speed;
minCUT: minimum container unloading time;
maxCUT: maximum container unloading time;
minFS: minimum forklift speed;
meanFS: mean forklift speed;
maxFS: maximum forklift speed;

The *External Truck Characteristic* section is referred to trucks that, arriving from the external side, enter the port, pick-up the containers and move the containers outside the port (or vice versa). There are two sliders (see figure 2) respectively used to set the number of trucks and the mean truck speed according to a triangular distribution (see equation 6).

$$TrS = Distr\_Triangular(minTrS, meanTrS, maxTrS) \qquad (6)$$

TrS: Truck speed;
minTrS: minimum truck speed;
meanTrS: mean truck speed;
maxTrS: maximum truck speed;

Particular attention has been paid for the *inspection phase* section. As previously mentioned the simulator aims to consider both the technical port operations and security procedures related to containers inspection phase. The parameters implemented in this setion regard:

- percentage of containers to be inspected;
- manpower specifically working on the inspection phase;
- type of procedures for containers inspection;
- space for containers storage before the inspection;
- number of trucks specifically used for inspection operations;

Figure 2: Seaport Simulator graphic user interface

- lower bound, upper bound and number of intervals for containers service time data collection;
- lower bound, upper bound and number of intervals for containers waiting time data collection.
- lower bound, upper bound and number of intervals for inspected containers per hour data collection;

All the parameters above described are implemented in the graphic user interface shown in figure 2.

System's experts can use the sliders, the text boxes, the check boxes to modify the container terminal operative conditions both for specific port activities and security procedures related to containers inspection.

The parameters changes can be made at the beginning of the simulation and run time during the simulation. In the last case the simulator is equipped with a *reset button* to delete all the statistics and results previously collected.

CONTAINER TERMINAL OUTPUT SECTION

The impact on system behavior and performances caused by changing the input parameters can be observed in the output section. All the statistics relative to the performances indexes defined in the simulation model are plotted on graphics, diagrams, histograms as well as can be exported on excel or text files. In the simulation model the statistic output are subdivided in two main sections: *Inspection Operations* and *Port Operations* as shown in figure 3.

In particular the collected values regard the following performance indexes (refer to figure 3):

- number of inspected containers per hour indicated as *Inspection Output* (in addition the model evaluates the mean value and the standard deviation);
- inspection service time; it is evaluated on hourly basis. In other words each collected

value is the mean service time of the containers inspected during the last hour, indicated as *Service time* (in addition the model evaluates the mean value and the standard deviation);
- inspection waiting time; it is evaluated on hourly basis. Each collected value is the mean waiting time of the containers to be inspected during the last hour, indicated as *Waiting time* (in addition the model evaluates the mean value and the standard deviation);
- containers daily flow entering the port indicated as *Containers flow-in* (in addition the model evaluates the mean value and the standard deviation);
- containers daily flow exiting the port indicated as *Containers flow-out* (in addition the model evaluates the mean value and the standard deviation);
- total number of containers entered in the port indicated as *Total Containers in*;
- total number of containers exited by the port indicated as *Total Containers out*;
- actual number of stored containers in the port indicated as *Stored Containers*;
- cranes utilization; (one indicator for each cranes located in correspondence of the cranes animation, not-shown in figure 3);

All the performance indexes are shown in the animation during the simulation.

TOOL POTENTIALS AND APPLICATION EXAMPLES

All the main activities of a generic container terminal were involved in the simulation model in order to recreate the high complexity of a container terminal functionality.

The animation (see figure 4) shows containers movements, from ship arrivals to containers unloading, from storage in the Yard area to the inspection.
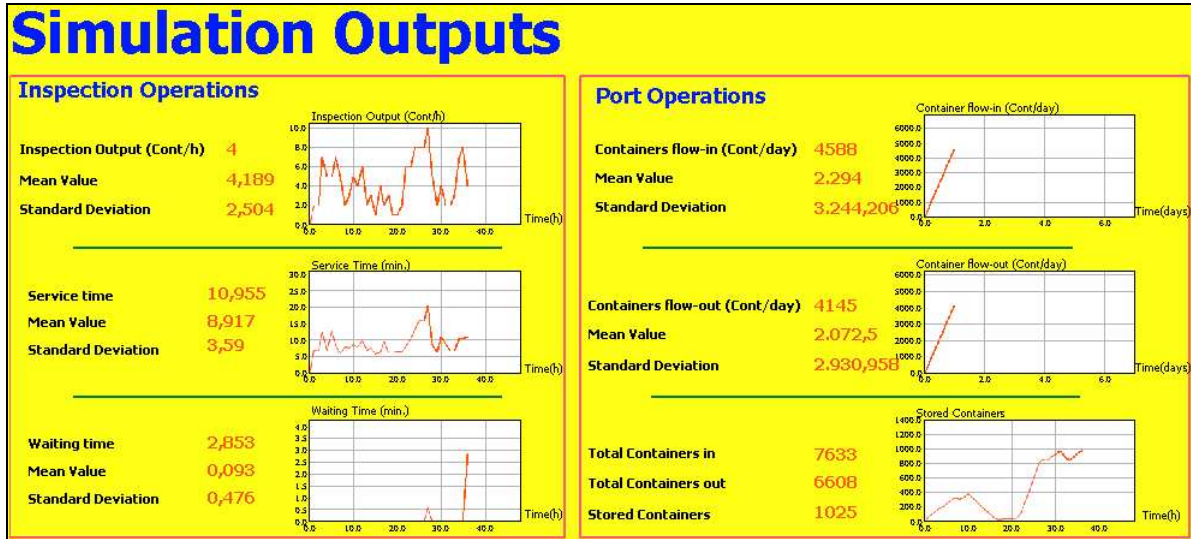
Figure 3: Simulator output

The simulator can be used not only to test different configurations (in terms of infrastructures and layout) and scenarios but also to make several what if analyses.

For instance suppose to consider the container terminal design and management. Very often system's experts need to evaluate the impact of different parameters on performance indexes in order to correctly use available resources.
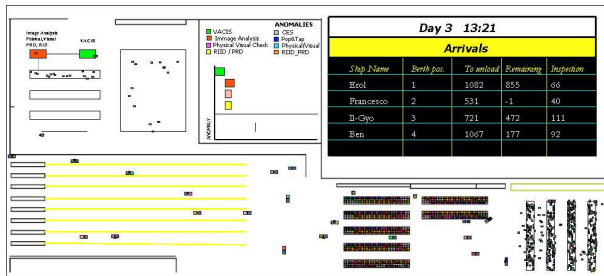

Figure 4: Simulator animation

The application example proposed in this paper regards an analysis on the total number of containers stored inside the terminal.

The objective is to identify the most important parameters (here in after factors) having an impact on the total number of stored containers (here in after performance index).

To reach this purpose the simulator has been used in combination with Design of Experiments (DOE) for planning simulation runs and Analysis of Variance (ANOVA) for studying factors relevance and evaluating a statistic input-output model.

PLANNING THE SIMULATION RUNS

As before mentioned the simulation runs have been planned using the Design Of Experiment. The factors taken into consideration for experiments are described as follows.

Ships mean inter-arrival time; the ships inter-arrival process has been implemented in the model by means of a Poisson's process.

Cranes mean unloading time; this factor has been implemented in the model by means of a uniform distribution.

Forklifts number per crane; this factor expresses the number of forklift available for each crane.

Trucks Number; this factor has been used for modeling the flow of containers entering and exiting the port.

Each factor is characterized by two levels reported in table 1. The factorial experimental design has been used for studying the factors effects on the performance index, executing all possible combinations of the factor levels. In particular a 2^4 factorial experimental design with 16 simulation runs has been executed replicating each run twice and, in addition, a single run replicated three times in correspondence of the center points.

Table 1: Factors levels

Factor	ID	Level 1	Level 2
Inter-arrival Time	IT	720 minutes	1080 minutes
Unloading time	UT	1.5 minutes	4.5 minutes
Forklifts Number	FN	10	14
Trucks number	TN	25	50

From a previous Mean Square Pure Error analysis, made on the same simulation model, it was evaluated a

simulation run length equals to 150 days. After the execution of each simulation run the mean value of the performance index (the total number of stored containers on 150 days) has been evaluated.

ANOVA FOR ANALYZING SIMULATION RESULTS

The simulation results have been analyzed by means of ANOVA approach to explain data variability as function of factors levels taken into consideration. The results of analysis of variance are shown in table 2. The first column is the source of variation, the second column is the degree of freedom the third column is the adjusted mean squares, the fourth column is the Fisher statistic and the last column is the probability used to confirm ANOVA hypothesis.

As well known from the theory of Analysis of Variance if the probability P reported in table 2 is greater than the confidence level used during the analysis ($\alpha=0.05$) then the factor influence on the performance index can be neglected.

The ANOVA results show that the factor FN (forklifts number) has no impact on the number of stored containers.

Table 2: ANOVA results considering 4 factors

Source	DF	Adj MS	F	P
IT	1	4764013	173,95	0
UT	1	6073484	221,76	0
FN	1	52569	1,92	0,184
TN	1	5929707	216,51	0
IT*UT	1	4022157	146,86	0
IT*FN	1	8224	0,3	0,591
IT*TN	1	3733961	136,34	0
UT*FN	1	20554	0,75	0,398
UT*TN	1	5910782	215,82	0
FN*TN	1	30320	1,11	0,307
IT*UT*FN	1	9214	0,34	0,57
IT*UT*TN	1	3727133	136,09	0
IT*FN*TN	1	14663	0,54	0,474
UT*FN*TN	1	33476	1,22	0,284
Error	17	27388		
Total	31			

Such information can be used for correctly designing the number of forklifts working for each crane; taking into consideration the terminal operating conditions, 10 forklifts for each crane can be considered as a suitable number.

The Analysis of variance has been repeated considering only three factors (neglecting the number of forklifts). The results obtained confirm the previous analysis. All the main effects, the second order effect and the third order effect have an impact on the total number of stored containers.

The ANOVA approach allows evaluating a linear statistic model to express the performance index (the number of stored containers, SC) as function of the factors. Equation 6 reports the model and the relative coefficients in output from analysis of variance.

$$SC = 570.84 - 385.84 * IT - 435.65 * UT - 430.47 * TN + 354.53 * IT * UT + 341.56 * IT * TN + 429.78 * UT * TN - 341.28 * IT * UT * TN \quad (6)$$

Equation 6 can be used considering the factors levels expressed as (-1) for *Level 1* and (+1) for *Level 2*.

The linear statistic model is a powerful tool to correctly set the number of resources in relation to yard area utilization (available space for containers storage).

Figure 5 shows the main effect plot obtained using equation 6. Varying the ship mean inter arrival time from 720 minutes (12 hours) to 1080 minutes (16 hours) the total number of containers stored in the yard area is subjected to a strong reduction. An analogous behavior can be observed varying the cranes mean unloading time and the trucks number.
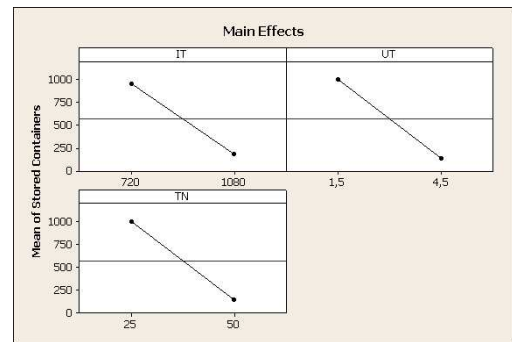

Figure 5: Main effect plot

CONCLUSIONS

Nowadays it's extremely clear the need to face container terminal problems keeping under consideration two different aspects: security procedures from one side and standard operative procedures (that define technical and economic efficiency) from the other.

In addition it becomes quite difficult to correctly integrate the aspects before mentioned.

The approach presented in this research work use simulation as cognitive and analysis tool giving to system's experts (thanks to an easy graphic user interface) the ownership of the analysis and the achievement of the established objectives.

The container terminal scenario has been modeled using a Java-based simulation software. The simulation model recreates the high complexity of the container terminal in terms of ships arrivals, unloading operations, port equipment, security procedures and so on.

The tools potentials have been tested with an application example regarding the Yard area design and management evaluating and testing an input-output model.

At the moment further researches are still on going trying to improve the analysis tools available for the users and the functionality of the graphic user interface.

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Enrico Bocca achieved the Management Engineering during 2003 with the thesis on "Innovative Technology Management in Retail Sector". During 2003 June-July he participated to IEPAL experience coordinating an International Team of Engineering and MBA Students on introduction of innovative IT in supermarkets. He worked as consultant on different initiatives: BRB Studio, Business Plans related to R&D Projects; Logistics and Project Management for CFLI; currently he works as researcher in Simulation Team of DIP with special attention to Logistics in Retail Business.

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