MODELING PORT SECURITY

Francesco Longo, Letizia Nicoletti (Italy)

1. INTRODUCTION

Starting from 1990 a continuous globalization has taken place concerning markets and relatives cargos as well as flow of people. It's well known that the 90% of world cargo moves by containers and the economic interests involved in such activities are the basis of global economy. At the same time the recent events testify that one of the fundamental terrorism goals is the complete destruction of these economic interests.

The seaports face today the same security problems of airports after September the 11^{th}.

Considering only United States of America, we can easily understand the intrinsic difficulties of the port security problem. More than 317 ports of entry (air, sea and lands) and thousands of miles of borders receive millions of people as well as every type of goods (by means of containers) that yearly enter and exit from USA. Issues concerning with seaport security regard several aspects such as perimeter security, internal security and operative controls, maritime security, port community systems, decision support systems, prevention and emergency management and so on.

Answers to these issues obviously look in different directions such as access control and fencing surveillance, internal area monitoring, cargo equipment control as well as passenger and baggage control, water surveillance in front of piers and traffic control, risk analysis, emergency alarm systems. However when considering threats that can be placed within containers, two opposite needs should be considered: if from one side the only way to discover a threat is the container inspection from the other side the only way to improve container terminal performances is to handle the container in the least time (as soon as possible the container must leave the port).

Normative and standards are extremely clear about the guidelines for securing seaport activities; at present the most important normative and initiatives are the following:

- U.S. Custom service's Container Security Initiative (CSI);
- Customs-Trade Partnership Against Terrorism (C-TPAT);
- International Ship and Port facility Security code (ISPS code);
- U.S. Maritime Transportation Security Act of 2002;

Very often the major effort is in the prevention phase, people and goods must be inspected before leaving from the port of origin as for instance required by the Container Security Initiative (CSI) for containerized cargo. This policy allows, as explicitly said by the White House in 2002 "extensive pre-screening of low-risk traffic, thereby allowing limited assets to focus attention on high-risk traffic [and] use … advanced technology to track the movement of cargo and the entry and exit of individuals".

It's important to stress that standards and normative help keep events like September 11 from happening establishing the right guidelines but they don't offer explanations about the choice of all the possible tools, methodologies and technological advances to secure seaport and relative activities and above all they don't directly deal with the impact of the security procedures on system performances.

Among the security issues previously mentioned, the container inspection phase plays a critical role because of threats that by means of containers can enter or exit a seaport. Focalizing on this aspect, the only way to jointly consider security and efficiency is the integration of all available container information in order to evaluate a container risk factor. The container risk evaluation allows to reduce the inspection times guarantying no additional delay for low risk container as well as detailed inspections for containers that may pose a risk for terrorism.

The intrinsic difficulties related to tune such type of approach can be faced using simulation in order to estimate inspection phase effects and reliability as well as the impact on performance system of an emergency situation.

2. SECURITY INDEX FOR CONTAINERS SELECTION

In order to evaluate a risk or security index for each container entering the port it is necessary to consider several information sources. Suppose to subdivide the information sources in three main categories:

- container history information;
- container configuration information;
- alert information.

The container history essentially groups four information sub-categories:

- *vectors*, logistic companies that have transported the container until the present port;
- *nodes*, destination points before entering the present port;
- *vendor*;
- *regions*, previous country passed before entering the present port.

The container configuration reports information about the following characteristics:

- *container type*, such as 20 feet, 40 feet, reefer containers and so on;
- *good type*, goods characteristics transported inside the container;
- *manifest of non-conformity* noticed on container
- *security NC*

Finally the alert is defined by the following information:

- *security level* inside the port;
- *intelligence police* e relative reports about security issues;
- *port location*;
- *ship entering the port*.

All these information – opportunely used and combined by means of Data Fusion – bring to container risk index definition. Such risk index must be used in order to plan the container inspection.

Obviously, as previously mentioned, this type of approach cannot be tuned directly on the real system. An optimal solution is to test and tune the approach by means of a virtual environment. This virtual environment is made up by two fundamental parts:

- *Virtual Cargo Generator*
- *Seaport Simulation Model*

In the following part of the paragraph is reported a detailed description of *Virtual Cargo Generator*, please refer to next sections for *Seaport Simulation Model*.

The *Virtual Cargo Generator* provides virtual security scenarios to analyze by means of port simulation model and it is based on the information sources previously described. The logical steps followed by the *Virtual Cargo Generator* are:

- *Virtual Path* generation containing all the information relative to container history;
- *Virtual Cargo Configuration* reporting information about container characteristics;
- *Virtual Alert Scenario* regarding report and alert in a specific period of time;
- *Virtual Threat*, such as radioactive substances, narcotics, weapons (and so on) sitting in a container.

The Virtual Path, the Virtual Cargo Configuration and the Virtual Alert Scenario allow to define the container risk level, distinguishing between high risk, medium/high risk and low risk. The Virtual Threat could be discovered by means of inspection phase.

3. SEAPORT SIMULATION MODEL

If from one side a *Virtual Cargo Generator* has been created, providing in this sense several and different security scenarios, it is now necessary – from the other side – a *Seaport Simulation Model* that will be used to monitoring the container inspection phase reliability as well as the impact of different security level on the port performances.

In other words the entire virtual environment (union of *Virtual Cargo Generator* and *Seaport Simulation Model*) is used to carry out integrated distributed control with input consisting of various information flow opportunely combined by means of Data Fusion.

The simulation model has been implemented on the basis of a real container terminal. This containers terminal is characterized by 1200 meters of piers for docking operations. In particular the technical equipment in the docking area is made up by 12 cranes for unloading operations with tonnage in the range 30T to 65 T, height from 20 m to 40 m, outreach from 30 m to 50 m. Connections between Docking Area and Yard Area are assured by trucks. Containers storage in the Yard Area is performed using Transtainers with capability up to 50000 kg. Containers movements in the yard area are also performed using forklifts and top-loaders.

Containers enter and exit the terminal by trucks passing through the main gates, by trains using the rail as well as by means of local ships to reach other ports.

As required by the standards and normative (as for instance the *Container Security Initiative*, CSI) the ship cargo manifest is known 24 hours before ship leaving from the port of origin. For each ship entering the port a list of containers that must be subjected to inspection is consequently available.

The containers inspection phase is made up several and different operations aiming to analyze the container using gamma ray inspection, detector devices and checking container structure as well. These actions take a certain amount of time for each container.

Obviously during the inspection some anomalies can be detected. In relation to anomaly origin a particular security action is performed (requiring an additional interval of time). The resources used during the container inspection phase are:

- manpower used to perform all inspections operations;
- trucks used to move containers into the inspection area and to move containers during the inspection;
- space for containers, used to store containers before inspection.

In addition another important parameter is the percentage of container to be inspected (in order to study resources utilization).

Among the performance indexes, one of the most important for its critical role is the number of containers in output from the inspection phase.

The main idea is to evaluate the impact of some critical factors on the performance of the containers inspection operations. The critical factor are manpower to execute inspection operations, trucks to move containers to be inspected, space for containers storage before the inspection operations and percentage of containers to be inspected. variation on the number of containers in output from the simulation model. To this end a simulation model of the containers terminal has been implemented using a discrete event simulation software. The model implements all the port main activities as, for instance, ships arriving, containers unloading, containers movements toward storage area, containers movements toward inspection area, containers inspection phase, containers movement outside the port (see figure 1).

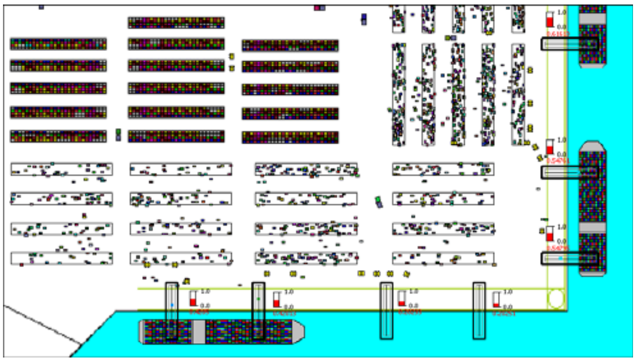

Figure 1: Simulation model of the container terminal

One of the most critical issue during the modelling phase is the number of entities moving in the simulation model. It' evident that the problem is caused by the high number of containers that could bring to have a simulation model computationally to heavy (with problems during the graphic animation as well as the speed of the simulation).

This type of problem can be solved substituting the entity flow with an information flow. Consider, for instance, the containers directed to the yard area, actually this containers must not be inspected. Consequently it's only necessary to model the movement toward the yard area and to store in a data base all the information relative to the container without generate an entity corresponding to the container.

A similar method can be used during the ship unloading or loading phase. A single entity making a loop between berth and ship successfully model this activity.

Obviously the situation is quite different for what concern the containers inspection phase. In this case, due to the approach used to study the problem, it's necessary to create the entity container as well as the relative information.

It's extremely clear that a terminal container is a non-terminating system, the duration of a simulation run is not fixed. The first objective in this type of simulator is to understand the optimal length of a simulation run. To this purpose the *Mean Square Pure Error* Analysis (MSpE) has been used. Considering that the attention is focalized on the security problem and in particular on container inspection phase, the container mean waiting time before inspection and the container mean service time during the inspection were chosen as performance measures in order to establish, by means of MSpE, the optimal simulation run length. We finally evaluated an optimal simulation run length equal to 160 days.

DESIGN OF SIMULATION EXPERIMENTS

To reach the objective previously mentioned we used the Design of Experiment to plan the simulation runs. Since our aim was the analysis of parameters variations on the performance indexes container per day in output from the inspection, we have used the *factorial experimental design*. In this type of design the simulation runs are made for all possible level combinations of the factors taken into account, (see table 1).

Table 1

Factors and levels

Factor	ID	Level 1	Level 2
Percentage to inspection	F1	2% (-1)	10% (+1)
Trucks number	F2	1 (-1)	3 (+1)
Buffer space	F3	10 (-1)	50 (+1)
Manpower	F4	2 (-1)	6 (+1)

Considering only two levels for each factor we have a 2^4 design, in other words we need 16 different simulation runs. Previously analysis made on this simulation model have shown that, in order to obtain reliable statistical results it is necessary to replicate 2 times each simulation runs with a simulation length of 160 days (16 x 2 = 32 replications).

It is important to underline that we deal with fixed factors, the objective of the work is to infer information about the values reported in table 1, and we are not interested on the entire population of the factors levels.

SIMULATION RESULTS ANALYSIS

The results obtained by the simulation runs have been analyzed by means of Analysis of Variance. The first step was the definition of a simple general linear input output model for the inspection phase. Let Y be the number of inspected containers per day, let x_i is equal to the F_i factors (with x_i varying between -1 and +1) and let β_{ij} the coefficients of the model. The equation 1 shows the linear model.

$$Y = \beta_0 + \sum_{j=1}^{j=k} \beta_j x_j + \sum_{i<j} \sum \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

As it's well known from the theory, the analysis of variance allows to evaluate those factors that have a real impact on the performance index considered, quantifying this impact or in other words, evaluating the coefficients in the equation 1 and deleting insignificant factors from the model.

The graphs in the figure 2 show the analysis of variance results in terms of the impact of the main factors effects on the performance index. Varying the percentage of containers that must be subjected to inspection from 2% to 10% the number of containers effectively inspected per day increases until 200 (the assumption of linearity cannot be totally accepted as we will better explain in the next paragraph).

The effects of manpower and truck availability are almost the same. Varying the number of trucks from 1 to 3 and the number of manpower from 2 to 6 it's possible to see an increment from 100 to 180 containers inspected per day.

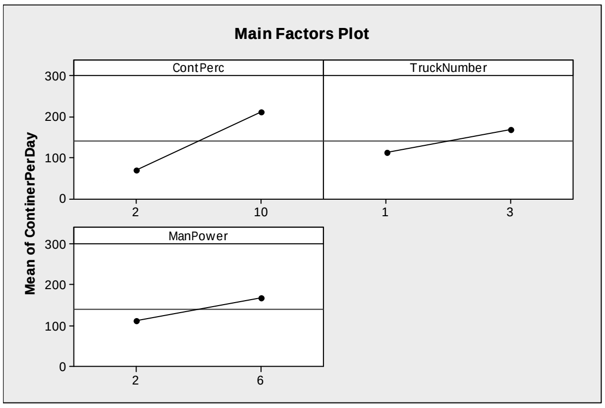

Figure 2 - Main effects

The figure 3 reports the 2-way interactions. For low percentage of containers that must be subjected to inspection the addition of new trucks or more manpower doesn't increase the number of inspected containers per day. The behavior is completely different for high percentage value, as we can see from the red line in the second and in the third square in the upper part of figure 3.

These results are also confirmed by the other 2-way interactions graphs. The fork between black line and red line becomes bigger as the percentage of containers that must be subjected to inspection becomes higher.

The trend is quite different for the other 2-way interactions (the increase in the black line red line fork is smaller than the previous case).

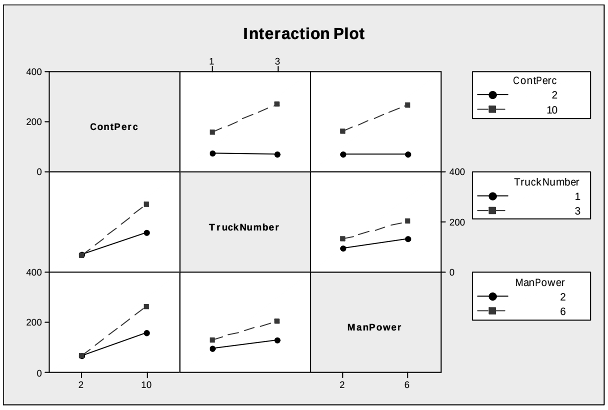

Figure 3 – Two-way interactions

The equation 2 reports the general linear model and the relative coefficients in output from the analysis of variance.

$$Y = 140.72 + 71.97 * x_1 + 27.53 * x_2 + 27.22 * x_3 - 28.78 * x_1 x_2 - 26.72 * x_1 x_3 - 9.03 * x_2 x_3 \qquad (2)$$

TESTING A QUADRATIC MODEL

The validity of the analysis of variance must be checked by means of residuals analysis. The starting hypotheses of ANOVA are the following:

- observations normally distributed;
- observations independently distributed;
- same variance for any combination of levels of factors.

The residuals analysis, made using some graphic tools (as for instance normal probability plot, histogram of residuals, and plot of residuals versus observations order) shows that the initial hypothesis cannot be completely accepted.

In this context it's important to say that a potential problem in the analysis of variance with factors characterized by two levels is the assumption of linearity. Considered the results of residuals analysis we decided to test for some curvature in the input-output model. The simplest method that gives protection against curvature consists of adding center points in the 2^k design. If the difference between the average value of the performance index at the factorial points and the average value of the performance index at the replicated center point is not small, we can assume the presence of curvature in the model.

Consequently the addition of the center points in the 2^k design add to the model the pure quadratic effects, as reported in equation 3.

$$Y = \beta_0 + \sum_{j=1}^{j=k} \beta_j x_j + \sum_{i<j}\sum \beta_{ij} x_i x_j + \sum_{j=1}^{J=k} \beta_{jj} x_j^{\;2} \qquad (3)$$

Therefore the ANOVA has been repeated considering center points and results show that the hypothesis of curvature in the model can be accepted.

The ANOVA results can be further analyzed by means of *Pareto Chart of Standardized Effects* and by *Normal Probability Plot for Standardized Effects*, see respectively figure 4 and figure 5. From both graphs it's possible to highlight the importance of the main effects and the 2-way interactions effects.

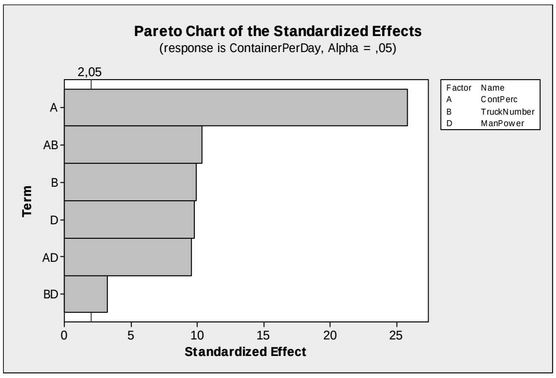

Figure 4 – Pareto Chart

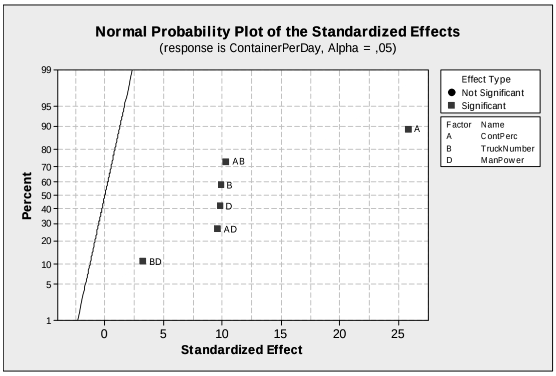

Figure 5 – Normal Probability Plot

At last the repeated residuals analysis shows that the all the starting hypothesis of the Analysis of Variance can be accepted.

The deviation of observations from the normality is not severe (see figure 6, normal probability plot) as well as we can accept the hypothesis of same variance for any combination of the levels of the factors (figure 6, Residuals versus the fitted value) and the hypothesis of residuals independently distributed (figure 6, histogram of residuals).

IMPACT INSPECTION OPERATIONS ON CONTAINER TERMINAL PERFORMANCES

Finally an additional analysis has been carried out. In relation to value assumed by the container risk index (in output by the container risk evaluation phase) the container itself will be subjected to a particular type of inspection.

The inspection phase implemented in the *Seaport Simulation Model* is made up by five stations, respectively:

- Radiation Screening;
- Chemical Screening;
- Biological Screening;
- Gamma Ray Inspection;
- Full Inspection.

It's extremely clear the possibility to jointly use the *Virtual Cargo Generator* and the *Simulation Model* to test and improve the control reliability.

In fact if from one side it is not known the potential threat inside a container, from the other side all the container information are used in order to classify the container dangerousness and choose the right order inspections. Several simulation runs have been made to monitor the inspection phase reliability in terms of discovered threats.

Besides taking into consideration some performance indexes (such as moved TEU per Portainer or moved TEU per berth length) it's possible to analyze the impact on the system performances of different security level (see figure 7).

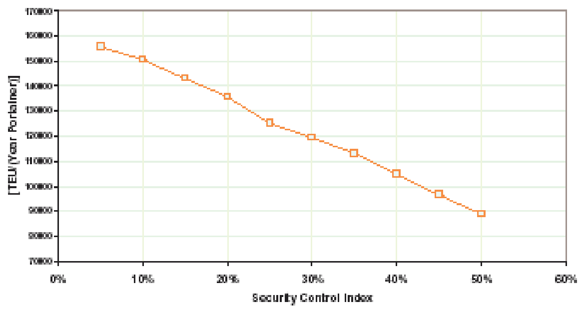

Figure 7 – System performance versus security level

The simulation model allows to compare different solutions for the inspection phase. A particular scenario has been analyzed introducing some new portable equipment for the inspection phases and grouping (thanks to new equipment) the radiation screening, the chemical screening and biological screening in one phase. The consequence is a container waiting time and container service time reduction. The effects can also be seen on system global performances.

Figure 8 shows the difference per year per portainer between the two different inspection solutions underlying the positive effects of new portable equipment as well as grouping phases.

Figure 8: Two possible inspection solutions

CONCLUSIONS

Several and different analysis regarding the containers inspection phase have been made, aiming to quantify the impact of different design parameters on the number of inspected containers per day.

In particular it has been analyzed the effect of four important parameters: percentage of containers that must be subjected to inspection, number of available trucks, buffer space for containers storage before inspection and manpower.

From the initial analysis it is resulted that the buffer space has no impact on the performance index considered, on the contrary the remaining factors, including the 2-way interactions must to be considered as significant factors. In addition the coefficients from a general linear input-output model of the inspection phase have been found.

The successive residuals analysis has shown some problems with the initial ANOVA assumptions so it was decided to check for some curvature in the model adding 5 replicated center point to the 2^k design.

The results obtained by the new analysis of variance have confirmed that the hypothesis of a linear model must be rejected in favor of quadratic model. At last the repeated residuals analysis confirms the goodness of the results obtained by means of ANOVA.

Furthermore the impact of different security levels on the container terminal efficiency has been evaluated. The results show that (i) higher security levels negatively impact port efficiency and (ii) new portable equipment or different inspection solutions may positively affect port efficiency.

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