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Design and integration of the containers inspection activities in the container terminal operations

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ABSTRACT

A key problem of a container terminal is the design and integration of the security procedures, such as the containers inspection, in the normal container terminal operations. The main goal of this paper is to advance a research approach for designing effective operational policies and practices to manage better the flow of containers toward the inspection area as well as understanding the impact on the container terminal efficiency of the integration of the inspection activities in the normal operations. To this end the author uses a modelling and simulation-based approach supported by advanced design of experiments, techniques and response surface methodology.

1. Introduction

Every year several millions of containers move, through the worldwide network of container terminals and seaports, almost every kind of goods and items. Nowadays, container terminals and seaports have to be regarded as the most important "rings" of the global supply chain. As well known, before September 11th attack to the Twin towers, the economic development was going toward a borderless world with production systems and companies integrated in worldwide just-in-time supply chain. The focus was, above all, on supply chain efficiency, robustness, flexibility and velocity neglecting or slightly considering vulnerability and security issues.

In effect, container terminals and seaports have several vulnerability points: consider for instance the access gates, the perimeters, the extension of the yard area, entrance allowed also to unauthorized persons. In addition, a container in itself can be the "most suitable weapon" for a terrorist attack. Note that, if the only way to discover a threat inside a container is the container inspection, the only way to improve container terminal performance is to handle the container in the shortest time (as soon as possible the container must leave the port). To this end, the main goal should be an efficient solution for containers inspection capable of guarantying, at the same time, acceptable container terminal performances.

An efficient solution for container terminals security starts from an international cooperation devoted to support the implementation of normative and standards. Actually, as natural consequence of 9/11, normative and standards in the field seaports security prevalently born in United States, nevertheless today the problem of seaports security involves all the countries and all the companies operating in the global supply chain. Note that, standards and normative help keeping events like September 11 from happening establishing the right security guidelines, but they do not offer solutions about the choice of all the possible tools, methodologies and technological advances to secure seaports operations. Moreover, they do not directly deal with the impact of the security procedures on systems efficiency (Longo and Bruzzone, 2005). Among security procedures, containers inspection plays a critical role because of threats that, sited within containers, can enter or exit a seaport.

As before mentioned, the main goal should be the reduction of the containers inspection times guarantying no additional delays for low risk containers as well as detailed inspections for containers that may pose a risk for terrorism. To this end, the design and integration of inspection activities in the port main operations require to select correctly equipment and tools (for carrying out the inspection activities), to schedule accurately manpower availability, to select correctly containers to be inspected. The intrinsic difficulties related to tune such type of approach can be faced by using Modelling & Simulation (M&S) in order to estimate the effects of critical parameters on the operational efficiency of the inspection phase as well as to investigate the impact on the container terminal efficiency of the integration of inspection activities. The approach is based on two different ideas. First, a complete parameterization of a container terminal simulator provides the users (system's experts) with an advanced interactive tool for scenarios testing, what-if analysis

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and problems solving. Then the combination of M&S with advanced statistical tools (i.e. Design of Experiment and Response Surface Analysis) is used for designing effective operational policies and investigating the integration effects. Note that the combined use of M&S and statistical tools is mainly due to the highly stochastic nature of the container terminal operations.

2. State of the art overview

Finding ways to intercept illicit materials, shipped via the maritime transportation system, is an exceedingly difficult task. Practical complications of the containers inspection involve the design of the inspection activities as well as the impact on shipping and import terminal facilities and the tradeoffs between costs and potential risks, among others. Until recently, even with increased budget, emphasis and rapid development of technology, only a very small percentage of incoming containers are inspected.

Starting from 2001, the first step towards the accomplishment of security measures inside ports and container terminals was the updating and development of normative and standards. The most important proposed or revised after 9/11 include the following:

- Container Security Initiative (CSI);
- International Convention for the Safety of Life at Sea (SOLAS);
- Maritime Transportation Security Act of 2002 (MTSA);
- Convention for the Suppression of Unlawful Acts (SUA).

Specific details on normative and standards can be found in the Marine Log (2003, 2004a, 2004b), Safety at Sea International (2003) and Security Management (2003). As mentioned into the introduction, standards and normative do not directly deal with methodologies, tools, equipment and technological advances to secure container terminals and do not evaluate the impact of the containers inspection activities on the overall efficiency of a container terminal.

Note that, in the field of container terminals design and management, research works proposed in the past years have always considered as primary aspect the efficiency of port operations rather than the security concerns. Typical container terminal operations include cargo flows (cargo vessels arrivals and departures), berth management (cranes allocation and loading/unloading operations scheduling), yard management (including yard equipment allocation and activities scheduling). A number of stochastic factors and variables interact and dynamically evolve during the execution of the above-mentioned terminal operations. The complexity of a container terminal scenario requires to apply ad hoc models (in fact, analytical approaches rarely succeed in properly identifying optimal solutions). In designing and managing such kind of facilities, it is becoming evident, during the last years, the importance of using an approach capable of considering the system being studied as a whole. To this end, the M&S approach is usually the most suitable methodology for studying the container terminal behaviour, conducting what-if analysis and defining technical configurations and management policies to be applied. In effect, the following state of the art overview highlights that:

- M&S approach plays an important role as problem solving methodology for investigating the behaviour of supply chain nodes (Longo and Mirabelli, 2008; De Sensi et al.2008) and it is very effective for design and management of container terminal operations;
- Design and management of container terminal operations continue to provide challenging problems to researchers working in this field.

Simulation is often used for studying the behaviour and the performance of container terminals. Yun and Choi (1999) propose a simulation model for analyzing the performance of a real Korean container terminal. Shabayek and Yeung (2002) investigate to what extent a simulation model could predict the actual container terminal operations with a high order of accuracy. Kia et al. (2002) use simulation for comparing two different container terminal scenarios in relation to handling equipment and their impact on the capacity of the terminal. Furthermore, simulation is also used for carrying out optimizations on specific problems. Legato and Mazza (2001) propose a simulation model of the arrival, berthing and departure processes of vessels at a container terminal; after the validation, they illustrate the use of the simulation model for carrying out a what-if optimization of the berth planning problem. Gambardella et al. (2001) present a solution to the problem of resources allocation and scheduling of loading and unloading operations in a container terminal. The optimized resources allocation is tested by using a simulation model, achieving reduction of both costs and crane conflicts. In addition, other research works show that simulation is used for system design and as a decision support tool. Lau and Zhao (2008) improve the equipment scheduling and consequently the productivity of an automated container terminal proposing a multi-layer genetic algorithm successively tested by using simulation. Lee et al. (2007) discuss the scheduling problem of transtainers and minimize the total loading time by using a simulated annealing algorithm. Moorthy and Teo (2006) focalize on the berth allocation problem to a set of vessels; in particular, the authors propose a framework to address the berth allocation design problem. In investigating ways to improve container terminals efficiency, Bielli et al. (2006) propose a simulator as decision support tool for increasing vessels traffic. Alattar et al. (2006) use simulation as support tool for investment decision (reduction of the queue of incoming vessels). Still on simulation as decision support tool, Ottjes et al. (2006) propose a simulation model for the design and evaluation of multi-terminal systems for container handling. In this last research work, even if the authors focalize above all on containers flow and port equipment efficiency, they also take into consideration the consequence of applying security scanning of containers.

Note that until 2001, research works have not considered container terminals security and the containers inspection problems. The 9/11 has strongly underlined the need of designing and integrating security activities into the container terminal normal operations. In effect, design and integration of security operations is a young research area (most of the research works have been developed after 9/11). Consider the containers inspection process: one of the main issues is the trade-off between the percentage of containers to be inspected and the consequent delay of departure ships, trucks and trains. Lewis et al. (2002) propose an approach for evaluating the balance between the percentage of containers to be inspected and the delays of departure vessels. They use a best-first heuristic search procedure for problem modelling and for understanding the relation between percentage of containers to be inspected and departure delays. However the paper is a preliminary study; the formulation proposed is quite simple and it does not accurately recreate a real container terminal scenario. Babul (2004) proposes a detailed analysis of security measures for ports vulnerabilities and investigates their economic effects. Wenk (2004) describes the security related activities in a container terminal and proposes a list of security precautions. Further research studies focalize on technologies for containers inspection operations. The Stanford Study Group (2005) examines how existing technologies and resources can be applied most effectively to prevent illicit nuclear materials transportation (terrorist activities). Brown (2003) proposes a survey on a number of technologies available today for containers inspection, focusing on gamma-ray, X-ray and neutron inspection system. Orphan et al. (2005) describe the Integrated Container Inspection System (ICIS), an optimized system with high detection capabilities for nuclear and radiological materials, based on the integration of existing inspection technologies. The state of the art overview in this specific field highlights that:

- There is a lack of research studies on design and integration of the containers inspection activities into the normal terminal operations;
- There is a great need to improve the efficiency in the current inspection processes;
- Modelling & simulation is one of the most suitable approaches for container terminal operations design and management.

In order to understand the contribution of this paper to the state of the art, the following aspect must be considered. The operational efficiency of the containers inspection process is generally measured in terms of containers throughput, vessel/vehicle turn-a-round time and/or unproductive times. In light of the literature investigation on container terminals and security, containers inspection activities can turn out to be the choke point of efficiency in this very complex logistic system. Among the difficulties, it appears that design and management of inspection processes have been quite experience-based and have not received a great deal of attention. Operational practices for containers inspection vary from container terminal to container terminal according to technical and organizational aspects that can be driven by inspection location (on-site, off-site), target-based inspection (container origin, destination, shipper, contents, etc.), steps and modalities of the inspection process (single or batched cycle, with containers movement or resources movement), detection technologies (X-ray/gamma-ray scan machine, global positioning transponders, manual examination, combination of multiple technologies).

The main contribution of this paper is to design effective operational policies for supporting the containers inspection process, by using a Modeling & Simulation based approach combined with advanced design of experiments techniques (i.e. central composite design) and analysis of variance (i.e. Response Surface Analysis). By measuring the operational efficiency of the inspection process in terms of containers throughput (number of inspected containers per day), the main goal of the paper is to develop analytical models that express the operational efficiency as function of critical parameters of the inspection process. Such analytical relationships work as effective operational policies and practices to manage better the flow of containers towards the inspection area. Furthermore, an additional research effort is carried out for understanding the impact (on container terminal performance) of the integration of the inspection activities in the container terminal operations.

3. Container terminal operations and inspection process description

Name and location of the container terminal taken into consideration in this research work as well as some of the data provided by companies operating inside the container terminal (for simulation model development and results analysis) are not reported in the paper due to confidential nature of such information. The total length of the berth is 1300 m (the first side is 700 m in length the second 600 m) and ships docking/sailing operations are supported by tugboats. The technical equipment in the docking area includes cranes for containers unloading/loading operations with tonnage in the range 30–65 T, height from 20 to 40 m, outreach from 30 to 50 m. Cranes are powered by electrical engines and move on rail. Tractors and chassis are used for containers transportation from the docking area to the yard area and vice-versa. Containers storage in the yard area is performed by using transtainers with capacity up to 50 T. Containers handling in the yard area is supported by forklifts and toploaders. Containers leave (or reach) the terminal by trucks (passing through the main gates), by trains (using the express rail service) as well as by means of local ships (to reach other ports).

As required by the *Container Security Initiative*, CSI, the ship cargo manifest is known 24 h before ship leaving from the port of origin. For each ship entering the port, a list of containers that pose a risk for security and must be subjected to inspection is available. Depending on the actual port conditions (in terms of number of containers, space availability, resources availability), a specific part of the yard (called segregation area) is used for temporarily storing containers to be inspected (usually close to the inspection area). One of the port management main objectives is to complete the inspection of segregated containers at most in 48 h from their arrival. Actually, this segregation policy is required because of the limited availability of officers and equipment for carrying out containers inspection. As soon as the inspection resources become available, containers are moved from the segregation area to the inspection area. Containers inspection is performed following two different modalities. In the first case containers are stored and piled up, a truck picks up a container and moves through the inspection phase. The truck is released at the end of the inspection and it becomes available for taking another container. In the second case, the containers are lined-up and officers and equipment move along the line inspecting each container.

The containers inspection requires to perform different operations. First of all, a scanning equipment is passed over the container (i.e. VACIS) or the container is moved under the equipment (depending on the inspection type) to create a container digital image. Once the image has been acquired the officers analyze the image, perform a visual and physical check of the container, carry out the radiation screening, the chemical screening and biological screening. The image analysis aims at discovering container anomalies or threats looking at the digital image obtained by means of gamma ray. Officers walking around the container (physical and visual check) accurately analyze the container's external part, carrying out, at the same time, the radiation, chemical and biological screening. Obviously during the inspection some anomalies can be detected. The anomaly can be detected from image analysis, from physical and visual check, from radiations, chemical and biological screening. In each case the container is opened and interiorly inspected. If such inspection gives a positive alarm the container is moved into a specific terminal area for accurate inspections.

The resources used during the container inspection process are:

- Officers (manpower) performing inspections activities;
- Trucks used to move containers into the inspection area and handle containers during the inspection;

- Space for containers, used to store containers before the inspection.

In addition, another important parameter is the percentage of containers to be inspected. Among performance measures, one of the most important (for its critical role) is the number of containers in output from the inspection process (it measures the operational efficiency of the inspection process).

4. Container terminal simulation model

The container terminal scenario was modelled by using the java-based simulation package Anylogic, by XjTech. The following sections provide the reader with an accurate description of the objects modelling aspects of the container terminal. In particular the following entities are defined within the simulation model:

- *vessel* entity, it transports *containers* entities and seizes (during the simulation) resources such as berths and tugboats;
- *tugboat* entity, it is used as resource by vessels to enter and exit the port.
- *container* entity, it flows through the simulation model seizing resources of different types, such as cranes, trucks, forklifts, portainers and tractors;
- *berth* entity, it is defined as static resource seized by vessels entities;
- *crane* entity, it is used as resource for containers loading/unloading operations;
- *tractor and chassis* entity, it used as resource for containers movement between the yard area and the docking area;
- *forklift* entity, it is used as resource for containers movements within the yard area;
- *toploader* entity, it is used as resource for containers movements within the yard area;
- *transtainer* entity, it is used as resource for containers handling within the yard area;
- *truck* entity, it is used as resource for containers transportation;
- *truckInsp* entity, it is used as resources for containers movements within the inspection area.

The container terminal simulation model is in three parts: (i) the flow chart (including data, variables and parameters) that recreates the main port operations; (ii) transportation networks (built on the container terminal layout) handle entities and resources movements within the container terminal defining, at the same time, the animation main frame; (iii) graphic user interface and output section respectively for container terminal scenarios definition and performance measures monitoring.

4.1. The simulation model flow chart

Fig. 1 shows the simulation model flow chart that recreates the main container terminal operations. Vessels entities are generated by using a Source object; once generated the vessel enters the harbor area, checks berth availability and eventually a specific berth position is assigned to the vessel entity. Docking operations require the vessel entity to seize a tugboat resource: tugboat is used to maneuver the vessel entity in the harbor area and perform docking operations. After docking operations the vessel entity enters the load/unload class object. The load/unload object recreates containers loading and unloading operations by using cranes resources. Moreover the load/unload object has two different exits: the first one used by vessels entities for leaving the port after the unloading/loading operations, the second one used by containers entities to reach the yard area. After loading/unloading operations, the vessel entity waits for an available tugboat resource, seizes it and leaves the port.

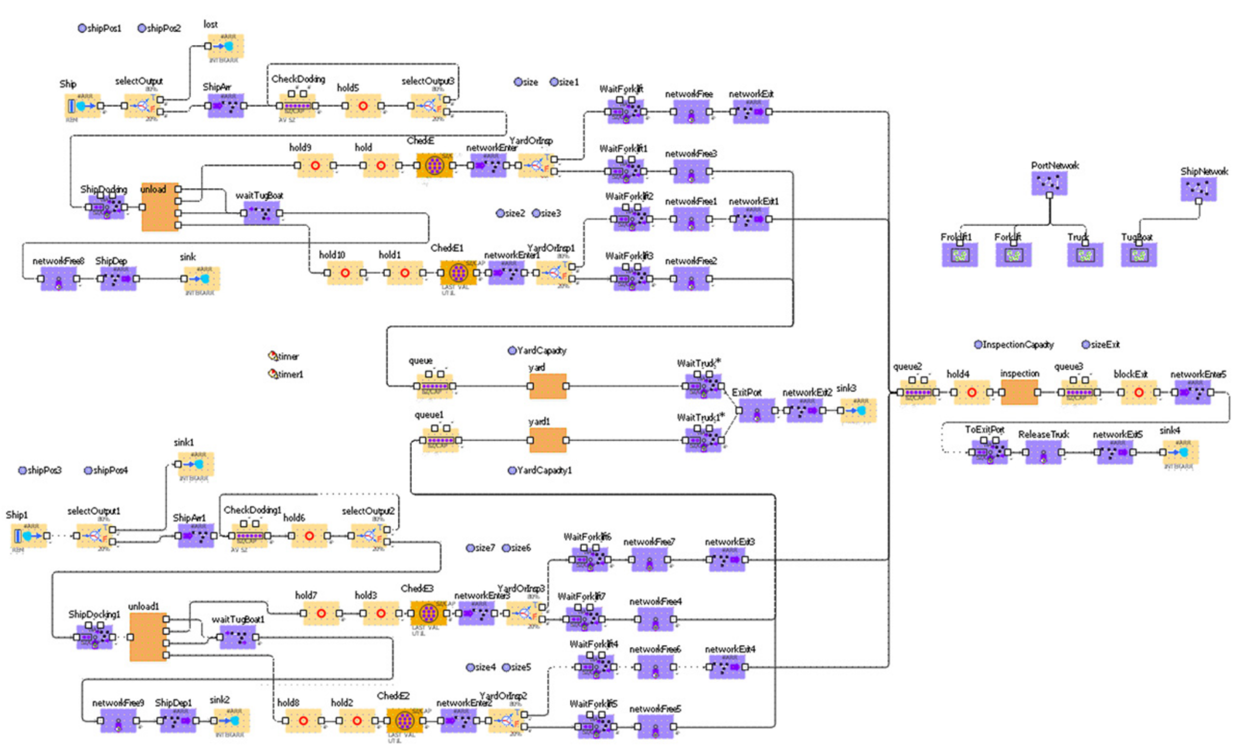

Fig. 1. Simulation model flow chart

Consider now the case of containers unloaded from a vessel and available to be moved to some destinations in the yard area. Containers entities wait in buffer areas (close to cranes) and check for tractors availability; once a tractor becomes available, the container entity seizes it and the tractor transports the container entity to some destinations in the yard area (note that tractors transport containers entities to be inspected in the segregation area). Once in the yard area, the container entity waits until it is loaded on a truck, train or vessel to reach another destination. If the container entity has to be inspected, it remains in the segregation area until inspection resources become available, then a truck transports it in the inspection area (where the container entity is inspected) and finally in the yard area. Note that, at busy time (i.e. several ships are at berths and huge number of containers are simultaneously unloaded), the simulation model handles containers to be inspected by using the segregation area for temporarily storing containers, until inspection resources becomes available (such solution faithfully recreates the solution adopted in the real container terminal).

The simulation model selects the containers to be inspected based on two different modalities: (i) a certain percentage of incoming containers (ii) the evaluation of a risk index. Note that in order to evaluate a risk index for each container entering the port, the simulation model considers several information sources subdivided in three main categories:

- Container history information;
- Container configuration information;
- Alert information;

The container history essentially includes four information sub-categories:

- *vectors*, logistic companies that have transported the container until the actual port;
- *nodes*, destination points before entering the actual port;
- *vendor*, company owner of the goods inside the container;
- *regions*, previous countries visited before entering the actual port.

The container configuration includes the following sub-categories:

- *container type*, i.e. 20 feet, 40 feet, reefer containers and so on;
- *good type*, goods and items transported inside the container;
- *manifest of non-conformity* (NC) noticed on container
- *security NC* noticed on container

Finally the alert information (alert level) depends on the following sub-categories:

- *security level* inside the port;
- *intelligence police* and relative reports about security issues;
- *port location* (port geographic area);
- *ships entering the port*.

These information – opportunely used and combined by means of Data Fusion – bring to the container risk index definition. It is not the objective of the paper to get into details of the container risk evaluation. In effect, a research work is still on going trying to develop a *Virtual Cargo Generator* (a generator of containers and associated risk indexes) to be used in combination with the simulation model for evaluating and testing the inspection process reliability (Bocca et al., 2005). The objective of the paper is the design of operational policies to manage better the flow of containers toward the inspection area. As usually happens in real container terminals the number of containers to be inspected is based on a certain percentage.

Finally as additional aspect, the simulation model flow chart also considers breakdowns during port equipment lifecycle. The author already investigated in another research work the implementation (within a container terminal simulation model) of logic and rules for recreating equipment failures and maintenance activities (please refer to Bruzzone et al., 2007 for further information). Breakdowns and maintenance activities regard berth cranes and yard resources (forklift, toploaders and transtainers). For each crane, transtainers, forklift and toploader, the following parameters have been taken into consideration: the failure rate (Fr-1) during the Infant Mortality Period (IMP), the failure rate (Fr-2) during the Useful Life (UL), the failure rate (Fr-3) in the last part of the equipment lifecycle, Wear Out Period (WOP) and the Life Extension Date (LED). The approach used by author for modelling the equipment failure rate is a graphical representation known as *bathtub curve*. The approach based on the bathtub curve is reported in many books on reliability theory (Birolini, 2003; Rausand and Hoyland, 2004).

The failure rate during the IMP and during the WOP is calculated using a two-parameter Weibull distribution. The failure rate during the UL makes use of a negative exponential distribution. Equations (1) and (2) are used within the simulation model for evaluating the reliability and the failure probability density function of each container handling equipment.

$$R(t) = e^{-\int_0^t Fr(t)dt} \tag{1}$$

$$f(t) = Fr(t) \times e^{-\int_0^t Fr(t)dt} \tag{2}$$

where $R(t)$ reliability function; $Fr(t)$ failure rate, defined as number of failures per unit of time; $f(t)$ failure probability density function.

4.2. The simulation model networks and animation

Transportation networks (built on the container terminal layout) handle entities and resources movements within the container terminal defining, at the same time, the animation main frame of the simulation model. In effect networks definition requires to insert class objects both in the simulation model flow chart and in the simulation model animation. Within the simulation model flow chart, a network is made up by several objects that allow entering the network, seizing resources of the network, moving in the network, free resources and exiting the network. Within the simulation model animation a network is made up by rectangles and lines (respectively resources location and trajectories between locations). A rectangle represents a network entry or exit point, the idle position for some resource, a destination point in the port. A line is the path followed by an entity moving among rectangles.

Three different networks recreate correctly all the transportation activities within the container terminal: the Vessels Network (used by vessels for entering and exiting the port), the Port Network (used by containers handling equipment) and the Inspection Network (used for containers inspection operations).

The animation of the simulation model is then completed by adding icons for vessels, cranes, tractors, forklifts, toploaders, transtainers and so on. The left part of Fig. 2 shows the vessels network, the right part of Fig. 2 shows the final animation of the simulation model.

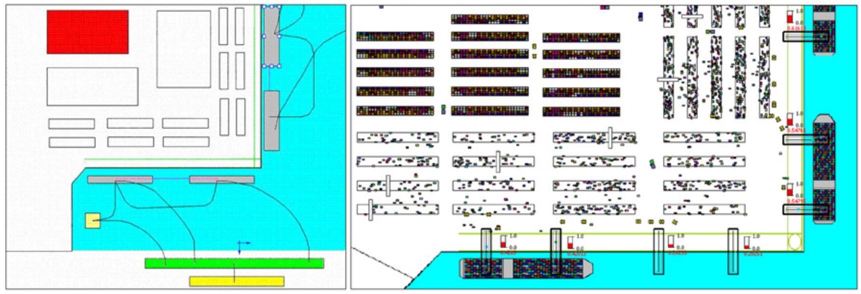

Fig. 2. Vessels arrival and departure network (left part) and Final Simulation model animation (right part)

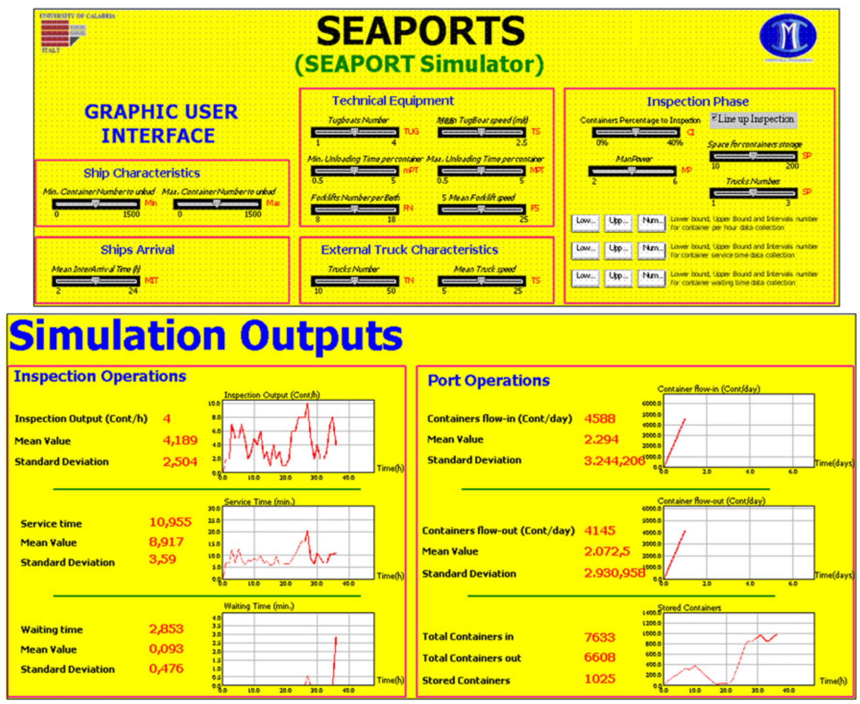

Fig. 3. Graphic user interface (upper part) and simulation output section (lower part)

4.3. *The simulation model graphic user interface and output section*

In order to develop an advanced interactive tool for scenarios testing, what-if analysis and problems solving, the simulation model has been completely parameterized. An easy-to-use graphic interface hosts all the container terminal main parameters; each parameter has specific range values and statistical distribution forms. The simulation model parameterization allows to investigate the parameters variation effects on container terminal behaviour and performance. The upper part of Fig. 3 shows the graphic user interface. Note that the user modifies parameters values by using sliders, text boxes, and check boxes. The user can test different container terminal scenarios (both in terms of port activities and security procedures related to containers inspection process). The *Ship Characteristics* and the *Ship Arrival* sections contain three sliders enabling the possibility for the user to vary the minimum and maximum number of containers as well as the vessels inter-arrival time. The technical equipment section is made up by 6 sliders. It is possible to set the number of tugboats, the mean tugboat speed, the minimum and maximum container unloading time, the number of forklifts and the mean 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. Two sliders are respectively used to set the number of trucks and the mean trucks speed. The last section is the *Inspection Process* section. The sliders are respectively used to change the containers percentage that must be inspected, the number of inspection officers, the space for container storage before the inspection, the number of trucks used for inspection. The check box *Line-up Inspection* is used to choose the type of inspection (lined-up or piled up, refer to section 3 for further details). In addition the *Inspection Process* section presents 9 edit boxes used to set lower bound, upper bound and number of intervals of three histograms respectively representing the containers per hour in output from the inspection process, the container inspection service time and the waiting time before the inspection. These histograms are shown in a separate chart during the simulation runs.

The lower part of Fig. 3 shows the output section for performance measures monitoring (note that simulation results can also be exported to text files and successively analyzed by using statistic tools, as shown in the last part of the paper). The output section is in two parts: the left part monitors the performance measures of the inspection process, the right part monitors the performance measures of the normal port operations.

4.4. Verification, simulation run length and validation of the container terminal simulation model

The results of a simulation study should be sufficiently credible; to this end, one of the most important steps of a simulation study is the verification and validation. The verification aims at determining if the simulation model is an accurate representation of the developer's conceptual model. In this paper the verification has been carried out by using the debugging technique. Dunn (1987) describes the debugging technique as an iterative process for finding and correcting the model errors, improving at each iteration, the simulation model representation. Once an error is identified, the model is opportunely corrected and tested once again both for ensuring error elimination and for detecting additional errors as well. In the case proposed, the debugging technique has been carried out during the simulation study life cycle: numerical errors on input data were detected and corrected as well as the rules and the logics governing the container terminal operations were investigated and implemented in accordance with port operations experts suggestions.

Once completed the simulation model implementation, the step before the validation was the evaluation of the simulation run length. A simulation model is able to recreate a real system only when the random error – the mean square error (due to the statistical distributions implemented in the model) – does not cover up the experimentation results. Note that the mean square error depends on the simulation run length. A container terminal is a non-terminating system (the simulation run length is not a priori fixed), the system is in perpetual operation (Banks, 1998). To this end, the random error can be expressed as function of the simulation time by using the *Mean Squares Pure Error* (MSpE) analysis. Considering the statistical distributions implemented in the simulation model, the experimental error of the operational efficiency of the containers inspection process (simulation results) is characterized by a normal distribution, $N(0, \sigma^2)$. The best estimator of σ^2 is the mean squares error. The simulation run has to be long enough to have small values of the MSpE, or, in other words, the experimental error must not "cover" the simulation results. Let *CPD* be the number of inspected containers per day, the MSpE is

$$MSpE(t) = \sum_{h=1}^{n} \frac{(CPD_h(t) - \overline{CPD}(t))}{n-1} \tag{3}$$

$CPD_h(t)$, value of the number of inspected containers per day at instant of time t during the replication h. $h=1,\ldots,n$ number of simulation replications

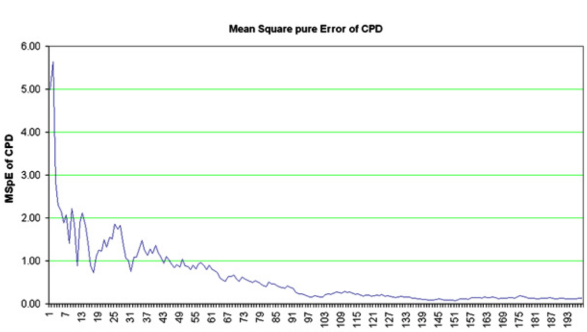

Fig. 4. Mean Square pure Error analysis and simulation run length

The simulation run length chosen is 200 d. Such time, evaluated on 4 simulation replications, assures a negligible *CPD* mean squares error, MSpE = 0.29, (see Fig. 4). Note that the standard deviation is 0.54, it means a 0.11% random error.

Finally the validation aims at determining the level to which a simulation model is an accurate representation of the real system considered. The validation phase has been conducted using the *Face Validation* technique, choosing for each simulation run the length evaluated by means of MSpE analysis (200 d). A set of different graphs (i.e. number of inspected containers per day versus simulated time, containers waiting time versus simulated time, etc.), plotting both the real curve and simulated curves, were presented to port operations experts asking them to distinguish between the real curve and the simulated curves on the basis of their estimates. The experts were unable to distinguish the simulated curves from the real curve, consequently stating the validity of the simulation results in its domain of application.

5. Design effective container inspection operational policies

The main goal of the paper is to design operational policies and practices to manage better the flow of containers toward the inspection area. To this end, the simulation model is used in combination with Design of experiments techniques (factorial experimental design and central composite design) and with the Analysis of Variance (general linear model analysis and Response Surface Analysis). In particular, the analysis proposed in the next sections consider the effects of four critical parameters (percentage of containers to be inspected, number of available trucks for inspection, number of available officers and available space for containers storage before the inspection) on the operational efficiency of the containers inspection process (the number of inspected containers per day). In addition, the last analysis proposed in the paper will aim at evaluating the impact (on the container terminal efficiency) of the integration of container inspection activities. The analysis carried out by using the simulation model are as follows:

1. General Linear Model analysis: inspected containers per day versus percentage of containers to be inspected, number of available trucks and officers, space for containers storage before the inspection;
2. General Linear Model analysis: inspected containers per day versus number of available trucks and number of available officers;
3. Response Surface Analysis: Inspected containers per day versus number of available trucks and number of available officers;
4. Integration of inspection activities in the normal port operations: evaluation of the impact on the container terminal performance.

Before getting into details of the analysis, consider that the effective design of the inspection activities requires to develop analytical tools capable of expressing the operational efficiency of the containers inspection process as function of the most critical parameters. Let Y be the operational efficiency of the inspection process, let x_i be the parameters with x_i varying between predefined levels and let β_{ij} be the coefficients of the model, the general relationship that expresses Y as function of x_i is as follows:

$$Y = \beta_0 + \sum_{j=1}^{j=4} \beta_j x_j + \sum_{j=1}^{j=4} \sum_{i<j} \beta_{ij} x_i x_j + \sum_{j=1}^{J=4} \beta_{2j} x_j^2 + \ldots + \varepsilon \tag{4}$$

The polynomial order of equation (4) depends on the accuracy of the model; the accuracy is the capability of the analytical model to express the variability of Y as function of the first-order effects, interaction effects, second-order effects and so on (usually the greater is the polynomial order the lower is the random error ε).

5.1. General linear model: Inspected containers per day versus percentage of containers to be inspected, number of available trucks and officers, space for containers storage

Let CPD be the number of inspected containers per day and let x_1, x_2, x_3 and x_4 be respectively the percentage of incoming containers to be inspected, the number of available trucks, the space for containers storage before inspection and the number of officers for carrying out the containers inspection process. The analysis shows the dependence between CPD and x_i. In order to find out the input–output analytical relationship between CPD and x_i, the general linear model proposed in equation (5) has been tested.

$$CPD = \beta_0 + \sum_{j=1}^{j=4} \beta_j x_j + \sum_{j=1}^{J=4} \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon \tag{5}$$

The evaluation of coefficients of equation (5) requires to carry out a number of simulation runs by using a specific Design of Experiments. To this end the *factorial experimental design* has been used. In this type of design, simulation runs are made for all possible levels combinations of the parameters x_i (see Table 1).

The *factorial experimental design* considers two levels for each parameter (2^4 design) and requires 16 simulation runs. According to the MSpE analysis (see section 4.4), each simulation run is replicated 4 times with a simulation runs length of 200 d ($16 \times 4 = 64$ simulation replications). Further information on Factorial Experimental Design and General Linear Model analysis can be found in Montgomery and Runger (2006). After simulation runs execution, the results have been analyzed by using the Analysis of Variance (ANOVA). It is common knowledge that the ANOVA analyzes the importance of the effects (in this case linear and interaction effects) by factorizing the total variability of detected data in different components and by comparing the various elements by means of Fisher statistics. Linear or interaction effects have an impact on the operational efficiency of the inspection process if the probability P (of accepting the hypothesis that the effects can be neglected) is lower than the confidence level (in the case proposed the confidence level is $\alpha = 0.05$). The ANOVA results show that only the factor x_3 (space for containers storage before the inspection) and its first-order interactions have no impact on the number of inspected containers per day. Consequently, the ANOVA has been repeated deleting the factor x_3. Table 2 reports the ANOVA final results.

The ANOVA evaluates the coefficients of equation (5). By using these coefficients, the equation (6) expresses the operational efficiency of the inspection process as function of percentage of containers to be inspected (x_1), number of available trucks (x_2) and officers (x_4) and their first-order interaction effects.

$$CPD = 179.08 - 49.58x_1 - 37.83x_2 - 65.08x_4 + 30.33x_1x_2 + 49.58x_1x_4 + 22.83x_2x_4 \tag{6}$$

The equation (6) has to be regarded as operational policy to manage better the flow of containers toward the inspection area. The graph in the Fig. 5 plots the first-order effects (main effects) of equation (6). By varying the percentage of containers to be inspected from 2 to 10%, the number of containers inspected per day increases up to 230. The effects of officers and trucks availability are almost the same. By varying the number of officers from 1 to 4, the number of inspected containers per day increases up to 250.

Fig. 6 shows the 2-way interactions plots. For low percentage of containers to be inspected, additional trucks or officers do not increase the operational efficiency of the

Table 1
Factorial Experimental Design: parameters and levels (general linear model involving all the parameters).

Parameters	ID	Level 1 (−1)	Level 2 (+1)
Percentage to inspection	x_1	2%	10%
Trucks number	x_2	1	4
Buffer space	x_3	100	500
Officers (manpower)	x_4	1	4

Table 2
ANOVA results (general linear model: CPD versus percentage of containers to be inspected, number of available trucks and officers).

Source	DF	SS	MS	F	P
x_1 (Percentage)	1	98307	98307	88.19	0.000
x_2 (Trucks)	1	57229	57229	51.34	0.000
x_4 (Officers)	1	169390	169390	151.96	0.000
$x_1 \times x_2$	1	36784	36784	33.00	0.000
$x_1 \times x_4$	1	98307	98307	88.19	0.000
$x_2 \times x_4$	1	20839	20839	18.69	0.000
Error	33	36785	1115		
Total	**39**	517**643**			

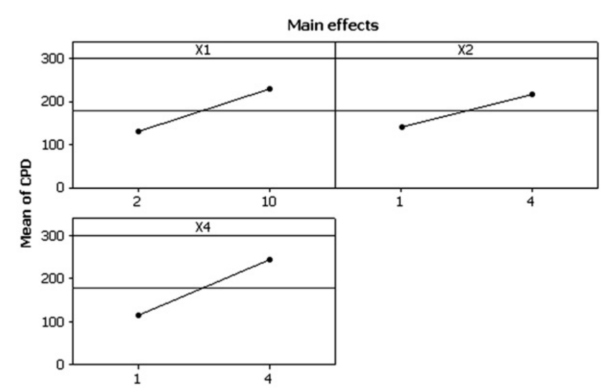

Fig. 5. Main effects for the general linear model (*CPD* versus percentage of containers to be inspected, number of trucks and number of officers)

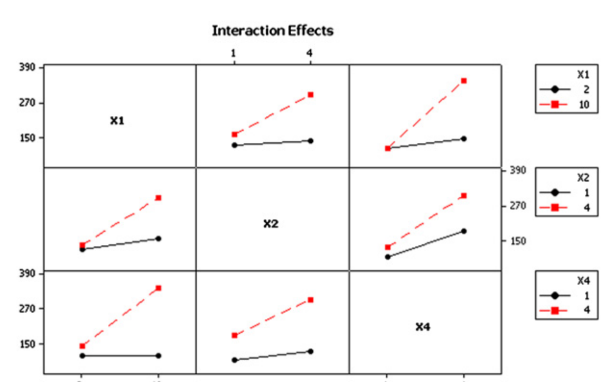

Fig. 6. Interaction effects for the general linear model (*CPD* versus percentage of containers to be inspected, number of trucks and number of officers)

inspection process. Conversely, for high percentage of containers to be inspected, additional trucks or officers have a remarkable impact on the operational efficiency of the inspection process (see the red line in the second and in the third square in the upper part of Fig. 6). The other 2-way interactions plots also confirm these results. The fork between the black line and the red line becomes bigger as the percentage of containers to be inspected becomes higher.

Note that the equation (6) hypothesizes a linear relationship between the number of inspected containers per day and the main parameters of the inspection process. The ANOVA results reported in Table 2 do not check for model curvature. Furthermore, in a real container terminal if the alert level remains constant, the percentage of containers to be inspected remains approximately constant. The analyses in the next sections consider the case of constant percentage of containers to be inspected and check a linear and a quadratic analytical relationship between the operational efficiency of the inspection process and the number of available trucks and officers.

5.2. General linear model analysis: Inspected containers per day versus number of available trucks and number of available officers

The analysis considers as input parameters the number of available trucks and officers for carrying out inspection activities. The *factorial experimental design* with center points (for checking model curvature) considers all the possible combinations of the parameters levels. As in the previous case the parameters (trucks and officers) have two different levels: the minimum number of trucks is 1, the maximum number of trucks is 4 (the same range is considered for officers). Additional 5 simulation replications in correspondence of parameters center points will be used for checking model curvature (note that for both parameters the center point is 2.5, i.e. it means 2 full time officers plus 1 half time officer).

Table 3 consists of ANOVA results both in terms of polynomial effects (upper part) and in terms of parameters effects (lower part). Note that the general linear model must include both the linear and 2-way interaction effects (the *P*-values are both zero). In addition the model curvature cannot be neglected, the *P*-value of center points is zero (it means that a quadratic model should fit better the simulation results than a linear model).

Equation (7) expresses the number of inspected containers per day as function of number of trucks, number of officers and interaction effect between trucks and officers.

$$CPD = 71.69 - 13.69 \times x_2 + 17.17 \times x_4 + 23.76 \times x_2 \times x_4 \quad (7)$$

Both the variations of number of trucks and officers have a positive effect on *CPD*, even tough the variation of the number of officers (manpower) has a stronger impact on the operational efficiency of the inspection process. Note that the greater is the number of officers the greater is the effect on *CPD* of additional trucks.

As before mentioned the ANOVA results state that the model curvature cannot be neglected. The next section evaluates a general quadratic model by using the response surface analysis.

5.3. Response surface analysis: Inspected containers per day versus number of available trucks and number of available officers

A quadratic model requires an apposite design of experiments capable of evaluating the second-order terms. To this end the *Central Composite Design* (CCD) is used for planning simulation runs and the *Response Surface Analysis* (RSA) for analyzing simulation results. Further information on the CCD and RSA can be found in Montgomery and Runger (2006).

Table 4 reports the Response Surface analysis results (polynomial effects in the upper part and parameters effects in the lower part). In effect a quadratic surface fits the simulation results better than a linear model (note that both the quadratic terms $x^2{}_2$ and $x^2{}_4$ have a zero *P*-value). Approximately 87.7% of the *CPD* variability is explained by the response surface.

The equation (8) expresses the *CPD* surface as function of x_2 (number of available trucks) and x_4 (number of available officers).

$$CPD = -129.37 + 154.88x_2 + 92.33x_4 - 37.10x_2^2 - 16.23x_4^2 + 23.77x_2x_4 \quad (8)$$

Fig. 7 shows the response surface plot. Note that also the response surface shown in Fig. 7 has a lack of fit. In effect the "lack of fit" term reported in the upper part of Table 4 has a zero *P*-value. However the response surface is a good approximation of the real system (better than the General Linear Model) because is capable of explaining most of the CPD variability (87.7%).

Equation (8) allows to set correctly the resources allocation in terms of number of trucks and officers by knowing (in advance) the flow of containers toward the inspection area. Note that the resources allocation is a critical issue also in case of multiple inspection processes. In effect, a typical marine port consists of multiple marine terminals, each running its container handling and inspection operations. Following cargo arrivals, a set of designated containers have to be inspected. It happens that

Table 3
ANOVA results.

Source	DF	SS	MS	F	P	S	R-Sq
General Linear Model: Inspected containers per day versus available trucks and officers (ANOVA expressed in terms of polynomial effects)							
Linear	2	357879	178939	2421699.29	0.000	0.271	100.0%
2-way Interactions	1	57167	57167	773675.96	0.000		
Curvature	1	22562	22562	305339.59	0.000		
Error	20	1	0				
Total	**24**						
Terms	**Effect**	**Coef**	**SE Coef**	**T**	**P**	**S**	**R-Sq**
General Linear Model: Inspected containers per day versus available trucks and officers (ANOVA expressed in terms of parameters effects)							
Constant		228.89	0.06078	3765.75	0.000	0.271	100.0%
x_2 (trucks)	137.12	68.56	0.06078	1127.97	0.000		
x_4 (Officers)	229.73	114.86	0.06078	1889.73	0.000		
$x_2 \times x_4$	106.93	53.46	0.06078	879.59	0.000		
Center point		75.10	0.13591	552.58	0.000		

DF–degree of freedom; **SS-**sum of squares; **MS–**mean squares; **SE Coef–**estimated standard error; **F–**Fisher statistics; **T–***t*-student statistics; **P–**probability of obtaining a test statistic that is at least as extreme as the actual calculated value, if the effect being considered can be neglected; **S–**square root of the mean square error; **R-Sq–**coefficient of determination.

Table 4
RSA results.

Source	DF	SS	MS	F	P	S	R-Sq
Response Surface Regression: *Inspected containers per day versus available trucks and officers* (*RSA expressed in terms of polynomial effects*)							
Linear	2	523881	261940	142.73	0.000	42.84	87.7%
Quadratic	2	265077	132538	72.22	0.000		
Interaction	1	57167	57167	31.15	0.000		
Lack-of-fit	3	108270	36090	393235.92	0.000		
Pure error	56	5	0				
Total	**64**	954**399**					

Terms	Coef	SE Coef	T	P	S	R-Sq
Response Surface Regression: *Inspected containers per day versus available trucks and officers* (*RSA expressed in terms of parameters effects*)						
Constant	304.10	8.568	35.494	0.000	42.84	87.7%
x_2 (trucks)	43.50	6.773	6.422	0.000		
x_4 (Officers)	105.85	6.773	15.628	0.000		
x_2^2	−83.38	7.264	−11.479	0.000		
x_4^2	−36.53	7.264	−5.029	0.000		
$x_2 \times x_4$	53.46	9.579	5.581	0.000		

SE Coef–estimated standard error; **T**–*t*-Student statistics; **P**–probability of obtaining a test statistic that is at least as extreme as the actual calculated value, if the effect being considered can be neglected; **S**–square root of the mean square error; **R-Sq**–coefficient of determination.

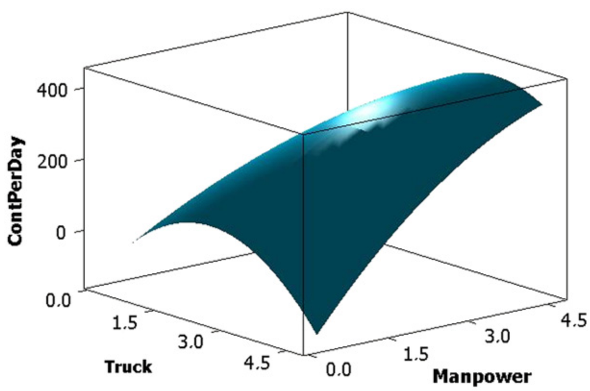

Fig. 7. Response Surface: containers inspected per day versus number of available trucks and officers

officers and inspection equipment at a given port handle all the terminals, polling each one at some order. The equation (6) helps in scheduling simultaneous inspection operations in different terminals of the same marine port.

As already mentioned, operational practices for containers inspection vary from container terminal to container terminal according to different technical and organizational aspects. There is no optimal time for containers inspection; in the case proposed in the paper, one of the most important port management objectives is to complete containers inspection within 48 h from their arrival. Equation (8) allows to allocate correctly the number of resources (trucks and officers) both when the container terminal is operating at its peak and in case of normal traffic conditions. In effect from Fig. 7 (or from equation (8)), by knowing in advance the flow of containers to be inspected (that depends on traffic conditions), it is possible to determine the number of trucks and officers for carrying out inspection activities. This is the most important information for scheduling correctly resources availability in case of both officers and equipment handling multiple terminals and single terminal.

5.4. Integration of the containers inspection activities in the normal port operations: impact on the container terminal efficiency

The input–output analytical models presented in the previous sections allow to design operational policies and practice to better manage the flow of containers toward the inspection area. Another critical issue is the integration of the inspection activities in the container terminal operations (such integration has a remarkable impact on the container terminal efficiency). In effect, the port management aims at handling the containers in the shortest time (as soon as possible the container should leave the port). Conversely, the border protection officers' aims at inspecting as many containers as possible for improving the inspection phase reliability in terms of discovered threats.

The analysis proposed considers the effect of the containers inspection process on the whole container terminal efficiency. To this end, the performance indexes taken into consideration are defined as the number of *moved TEUs per structural unit* (TEUs are equivalent 20″ containers). These indexes measure the total efficiency of the container terminal in terms of resources utilization. The most important resources (called also structural units) are the berth length (*BerthLenght*), the dimensions of the yard area (*YardArea*) and the number of cranes (*CranesNumber*). The equations (9–11) define the performance indexes above mentioned.

$$Index1 = \frac{movedTEUs}{BerthLenght} \tag{9}$$

$$Index2 = \frac{movedTEUs}{YardArea} \tag{10}$$

$$Index3 = \frac{movedTEUs}{CranesNumber} \tag{11}$$

The objective of the analysis is the evaluation of the impact on the container terminal efficiency of different security levels: note that higher security levels require specific security measures being undertaken as well as a greater number of containers to be inspected. The paper does not report the relationship between the security levels, the security measures and the percentage of containers to be inspected because such type of information are classified as confidential data. In this paper different security levels are classified in terms of colors (from green to red) and each color has different categories.

Table 5 reports the mean values of the performance indexes, indicating the overall efficiency of the container terminal, in correspondence of different security levels.

The decrease of the container terminal efficiency in correspondence of higher security levels highlights the system tendency to reach the block of all the main activities. The values

Table 5
Impact of the container inspection process on the container terminal performance.

Security Level	Index1 (TEUs/mt)	Index2 (TEUs/hectares)	Index3 (TEUs/cranes)
Green-1	910	11548	155901
Green-2	881	11170	150791
Green-3	837	10612	143263
Green-4	794	10075	136008
Orange-1	733	9294	125469
Orange-2	698	8855	119538
Orange-3	662	8398	113378
Red-1	614	7790	105166
Red-2	565	7165	96725
Red-3	520	6590	88969

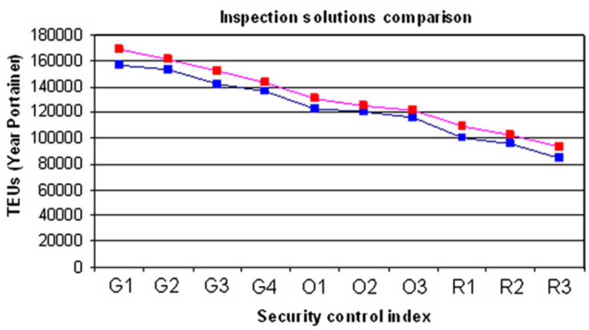

Fig. 8. Comparison between two different inspection solutions

taken by the cranes efficiency (index 3), 155901 TEUs/crane relative to the security level *green-1* and 88969 TEUs/crane relative to a security level Red-3, show a strong efficiency reduction. Note that the analysis of the container terminal efficiency allows to make technical considerations in order to establish the right tools to achieve the objectives related to security: more technology advances or better reorganization of internal logistics.

As application example a particular scenario has been analyzed introducing into the simulation model 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 new equipments cause a containers waiting time and containers service time reduction. The effects can also be seen in terms of container terminal efficiency. Fig. 8 shows the difference in terms of TEUs per crane (over 1 year) between the two different inspection solutions underlying the positive effects of the new portable equipment.

6. Conclusions

The paper proposes a research approach for designing operational policies and practices to manage better the flow of containers to be inspected within a container terminal. The author proposes a simulation model capable of recreating the high complexity of a real container terminal in terms of ships arrivals, unloading/loading operations, port equipment, containers inspection activities and so on. After verification and validation, the simulation model has been used in combination with advanced Design of Experiments techniques and Analysis of Variance for the operational efficiency of the containers inspection process as function of some critical parameters. On the basis of simulation results, three different analytical models have been proposed. The first input–output analytical model expresses the number of inspected containers per day as linear function of percentage of containers to be inspected, number of available trucks and officers. The second input–output analytical model considers the relationship between the number of inspected containers per day and the number of available trucks and officers. In this case the factorial experimental design with additional center points shows that, even if a linear model allows to gain knowledge about the inspection process behaviour, the model curvature cannot be neglected. The evaluation of a quadratic model required a *central composite design* whose results have been analyzed by using the *Response Surface Analysis*. In effect a quadratic surface fits the simulation results better than a linear model.

The input–output analytical models must be used for designing effective operational policies and practices to better manage the flow of containers toward the inspection area as well as for inspection resources allocation and scheduling. Furthermore, the simulation model has been used for understanding the impact of the containers inspection process on the container terminal efficiency. The analysis considers three different indexes (capable of expressing the whole efficiency of the container terminal) under the effect of different security levels and shows the system tendency to reach the block of all the main operations in correspondence of high security levels. Finally an additional analysis shows that the integration of the container inspection process into the container terminal operations is a matter of optimal trade-off between more technology advances (additional equipment) or better reorganization of internal resources (i.e. available trucks and officers).

Further researches are still on going trying to find out, by means of data fusion, quantitative models to evaluate the container risk index in order to analyze the inspection process reliability.

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