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A study of economic efficiency in port security inspection†

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SUMMARY

The purpose of this paper is to study an economic efficiency for the prediction of additional truck turnaround time and for determining the number of the port security inspection equipment required at a terminal inspection station. The economic efficiency with six base models was developed to assist terminal operators' decision-making. In addition, this study developed an optimal procedure that terminal operators could use to optimally run in terms of various statistics processes including exponential, deterministic, and others, seeking a solution that was beneficial for both terminal operators and truckers.

As a result of this research of the additional cargo turnaround time for port security delay, the following conclusion can be drawn and made. The average additional delay time in the inspection station is very dependent on the inspection rate of the lower stage. The higher weighted inspection time based on raising security level allows less number of trucks to be inspected, which will derive high delay in the inspection station. Increase of rate of Green Lane usage will allow a decrease in the arrival rate, which may derive improvement of inspection equipment efficiency and average delay time at the inspection station. In multiple stage model, total number of trucks and delay time very closely follow those of low inspection stage rate and number of inspection units. Free Lane is to be followed by Customs-Trade Partnership Against Terrorism and standardization of customs, packing, loading and unloading, documents, procedure, and exchange working in each country. Copyright © 2012 John Wiley & Sons, Ltd.

KEY WORDS: Green Lane; Turnaround time; Port security; Terminal inspection; Six base models; Multiple stage model

1. INTRODUCTION

Following the tragic events of 11 September 2001, the International Ship and Port Facility Security Code (the ISPS Code [1]) and the International Convention for the Safety of Life at Sea (SOLAS) Amendments were adopted on 12 December 2002 to enhance maritime sector security.

The new provisions are required to form an international framework through which ships and port facilities are capable of cooperating to detect and deter acts threatening security in the maritime transport sector. These new requirements have changed the structure of the global supply chain security system (SCSS) extending to that of shipping port Logistics and Supply Chain Management (LSCM) and the world economy [2,3]. These circumstances, with the fast evolution of Information Communications and Technology (ICT) and LSCM, have expedited changes in a new international maritime order (NIMO) with the focus on the shipping port's dynamic activities [4].

The global LSCM security system has led to an increasingly significant role for international seaborne trade [5]. In particular, container transport and maritime trade are important parts of international transport as about 90% of the world's cargo value moves by container. Each year, about 10 million containers enter

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seaport container terminals in Korea. As a result of the terror at ground zero in Manhattan, special attention has been given to the vulnerability of container transport to terrorist activities. This fact has made it impossible for Korea to ignore potential terrorists' dangers and threats and the potential use of dangerous goods such as nuclear and radiological weapons at seaport container terminals [19].

At this juncture, there have been some researches in the importance and analysis of either the security of SCM or the competitiveness of container ports [6]. But there are few studies on the related model development and its application to the improvement of the competitiveness in terms of economic efficiency of SCM security in port. The changes in security and seaborne trade and the requirement for the application of a model to these issues as well as economic efficiency as applied to port security inspection therefore necessitate this study.

This research aims at studying an economic efficiency to predict additional truck turnaround time and to determine the number of the port security inspection equipment required at a terminal inspection station. With reference to the economic efficiency, six base models are developed to assist terminal operators' decision-making. Moreover, this study develops an optimal procedure that terminal operators are to use to optimally run as for various statistics processes including exponential, deterministic, and others, seeking a solution that is beneficial for both terminal operators and truckers [7].

As a result of this research of the additional cargo turnaround time for port security delay, the following conclusion can be reached. The average additional delay time in the inspection station is very dependent on the inspection rate of the lower stage. The higher weighted inspection time based on raising security level allows less number of trucks to be inspected, which will derive high delay in the inspection station. Increase of Green Lane usage rate will allow a decrease in the arrival rate. This may lead to the improvement of inspection equipment efficiency and average delay time at the inspection station.

This study contributes to a grasp of the way in which design of terminal security inspection systems need not create excessive delay in LSCM inspection security. It can be beneficial to both public and business sectors such as customs border protection agencies, coast guards, port terminal officers, international freight shippers, transport vehicles carriers, and freight forwarders.

2. THEORETICAL BACKGROUND

Gim and Kim [5] expound that the significance of global SCSS has not been limited to the security system of port container terminals but extending to final consumers from original producers, which requires a comprehensive review of a whole range of LSCM security system. This system requires the integrity security procedure in LSCM activities from the beginning procedures to the end consumers in global seaborne trade and the world economy. In practice, the procedures in six base models developed in this paper are applicable to port container terminals and within the related fields. The scope of this study is limited to the scope of port container terminals to which the developed base models are applicable in this paper. Although this does not cover the entire areas outside of container terminals, that is, from producers/consumers to the terminals and vice versa, which are gaps to be overcome.

Table I shows the summary of major existing studies related to the aforementioned literature. Looking into the relevant contents, some of them include departure/output process of an M/M/1 and M/M/c queue following a Poisson process, resulting in a Poisson probability distribution for the number of container arrivals [8,9]. Another study contains two common measures that terminal operators seek to reduce the cargo turnaround time at seaport container terminals [7]. Further relevant contents appeared in "Toll Plaza Capacity and Level of Service" with respect to deterministic probability distribution [10] and the origin of NIMO [4]. Moreover, the ISPS code-related new requirements have changed the structure of global SCSS extending to that of shipping port LSCM [2], and the related contents are to be shown even in the scope of LSCM security system [5]. Further relevant information on the SCM security in port can be seen in such references as Andrea *et al*. [11], Aron [12], Asokan *et al*. [13], Backer and Christer [14], Hamid *et al*. [15], Lewis *et al*. [16], and Vis and De Koster [17].

With the continuous increase of international trade, there is a greater opportunity for terrorists to conceal their attack materials within commercial cargo and containers. This requires a range of sophisticated analytical computer databases to gamma ray and X-ray imaging systems, radiation isotope identifiers, explosive detectors, as well as sensors and cameras located along isolated stretches of the national border, especially in the container terminal.

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Table I. Summary of the major existing studies.

Author(s), year	Major contents of literature review
[8,9]	The departure/output process of an M/M/1 and M/M/c queue follows a Poisson process. This results in a Poisson probability distribution for the number of container arrivals to the second inspection stage.
[4]	Today's rapidly changing security environment's circumstances have expedited changes of the NIMO that was originated from changes of the shipping port dynamic activities.
[2,3]	The ISPS code-related new requirements have changed the structure of global supply chain security system extending to that of shipping port LSCM.
[5]	Global supply chain security system has brought about the increase of a significant role for world seaborne trade. Especially, the importance of this system has not been limited to the security system of port container terminals but extending to consumers from producers that require a comprehensive review of an entire range of LSCM security system.
[7]	There are two common measures that terminal operators are looking to reduce the cargo turnaround time at seaport container terminals. One is adding yard cranes and the other is employing a truck appointment system. This study developed methodologies to assist terminal operators in evaluating and applying the cargo turnaround time reducing measures.
[10]	Toll plaza capacity and level of service with deterministic probability distribution.

NIMO, new international maritime order; ISPS, International Ship and Port Facility Security; LSCM, Logistics and Supply Chain Management.

With the increase of the requests of shippers and customers for the timely delivery of international goods and containers, even a little delay in the time needed to inspect the containers in a security station at the seaport could result in serious economic disadvantage for each country. Customs is thus exploring several measures to minimize the potential costs and delays including the use of a "Fast Lane" that would allow precertified cargoes and containers to pass freely or pass through the terminal without the need for checking them. This approach would reduce cargo turnaround time within the port terminal.

To address the security inspection concerns, Korea is taking the initiative to provide a framework for security requirements that daily port operations must meet. These initiatives aim at moving part of such security efforts overseas, where goods are prepared for shipping into Korea. One example is the container security initiatives (CSI) that is a program intended to help increase security for containerized cargo shipped to the United States from around the world. CSI addresses the threat to border security and global trade posed by the potential for terrorist use of a maritime container to deliver a weapon and implemented by the US Customs in January 2002. Fifty eight of the largest seaports in 2008, in terms of containerized exports to the United States, have implemented bilateral agreements that would permit preshipment screening by the countries involved.

Another security agreement is the Customs-Trade Partnership Against Terrorism (C-TPAT), a voluntary government–business agreement made by importers, exporters, carriers, brokers, and warehouse operators of the LSCM. Under this agreement, customs officers are stationed overseas to work in foreign ports, thus ensuring the overall security level of containers from transmarine areas. To participate in these programs, seaports need to add container inspection processes into the daily terminal operations without interrupting port productivity.

This literature review provides background information on seaport container terminal operations, container security measures, container inspection procedures, and a review of previous studies dealing with seaport security and cargo turnaround time. An understanding of these operations of a container terminal is necessary before discussing the remaining sections.

The radiation portal monitor is a typical first stage detection device that provides customs with a passive, nonintrusive means to screen trucks, cargo containers, rail cars, passenger vehicles, and other conveyances for radiation emanating from nuclear devices, dirty bombs, special nuclear materials, natural sources, and isotopes commonly used in medicine and industry. Customs installed these radiation portal monitors nationwide—at seaports, land border ports of entry and crossings, including rail crossings, international airports, and international mail and express consignment carrier facilities in an effort to screen 100% of all incoming goods, people, and conveyances for radiation.

Large-scale gamma ray/X-ray imaging systems are typical second stage devices. Customs officers analyze the general images to determine where there are anomalies associated with the cargo listed

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on the manifest. There are 166 systems in use, with more to be added. Gamma ray/X-ray imaging should be useful for detection of weapons of mass destruction (either uranium or plutonium-based) in loaded containers, even if shielding is present. With both gamma ray and high-energy X-ray screening, any attempt to shield a device from the portal monitors will make it even more easily seen in the image. The speed of this inspection is limited by the flux from normally available gamma ray sources. About 20 containers per hour can be processed using today's gamma ray/X-ray systems. Because the average rate through a large port is several hundred containers per hour, this approach clearly can only inspect a small fraction of the containers. Because gamma ray/X-ray systems are commonly used at most ports, this explains why only a small percentage of containers is screened currently [20].

3. PORT SECURITY AND INSPECTION TIME

3.1. *Cargo inspection time*

Cargo inspection time with respect to port security is the time it takes a truck to complete a transaction such as picking up an import container or dropping off a container at the port terminal. Usually, before the inspection station, there are four activities that can affect the cargo turnaround time. These activities include the gate-in process, yard crane process, inner transport vehicle (Automated Guided Vehicle (AGV) or Straddle Carrier (SC)) process, and gate-out process. Huynh *et al*. [7] addressed two common measures terminal operators are looking to reduce the cargo turnaround time at seaport container terminals. One is adding yard cranes and the other is employing a truck appointment system. This study developed methodologies to assist terminal operators in evaluating and applying the cargo turnaround time reducing measures. To assist terminal operators in deciding whether or not to purchase additional cranes and to determine the number to purchase, this study developed a methodology to study the availability of cranes versus cargo turnaround time. In addition, this study developed a framework that terminal operators could use to optimally run the truck appointment system. The study sought a solution that was beneficial for both the terminal operator and truckers. Moreover, the formulation accounted for truckers with appointments showing up late or not showing up at all [21].

To study the availability of cranes versus truck turnaround time, the approach taken was to employ statistical models. The models included multiple regression models, polynomial regression models, and nonlinear in parameter regression models. The nonlinear in parameter model yielded the best fit. Through the estimating procedure, it was identified that truck turnaround time is primarily affected by the ratio of road moves to be performed to the number of yard cranes available.

The expectation of $E(S)$ for the nonlinear in parameter model is actually the sum of two parts including the expected number of cargos that are in queue, waiting to be inspected and the expected inspection time determined as

$$E(S) = \frac{P_O(I\rho)^I\rho}{I!(1-\rho)^2}\left[1-\rho^{U-I+1}-(1-\rho)(U-I+1)\rho^{U-1}\right]+I-P_0\sum_{k=0}^{k=I-1}\frac{(I-k)(\rho I)^k}{k!} \tag{1}$$

where

ρ = ratio of road moves
k = number of cargos in the system
I = number of cranes
U = the upper limit on the maximum number of cargos in the yard

where

$$P_0 = \left[\sum_{k=0}^{k=I-1}(1/k!)(\lambda/\mu)^k + \left\{(\lambda/\mu)^I/I!\right\}\left\{\left(1-\rho^{U-I+1}\right)/(1-\rho)\right\}\right]^{-1} \tag{2}$$

Six base models for the prediction of additional truck turnaround time[a] and determining the number of inspection units at an inspection station are developed and used in this research. The models include

[a]Additional truck turnaround time means the inspection time at security station added to time for truck from gate-in to gate-out.

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a single M/M/1 model (SMM), a multiple M/M/c model (MMM), a single channel and multiple stages model (SCMSM), and three multiple channel and multiple stages model (MCMSM) including MCMSM-Single And Multiple (MCMSM-SM), MCMSM-Multiple And Single (MCMSM-MS), and MCMSM-Multiple And Multiple (MCMSM-MM). Each of the models is used under various layouts, inspection policies, security levels of the container seaport, and government agencies. There are various critical parameters including the container arrival rate. This arrival rate varies by season, year, level of security, oil price, trade negotiation, market trend, weather, and other issues. Another variable is the inspection rate. The inspection rate depends on the type of equipment, number of equipment units, equipment technology, and level of security.

Moreover, the rate of using the Green Lane is a critical parameter. This rate is the rate of arrival of containers stuffed by a C-TPAT certified shipper. The container must have originated from a CSI port and ISPS-certified ports, container carried by C-TPAT certified rail/truck/ocean carriers, container delivered to C-TPAT importer, and level of security. Furthermore, this research can provide the additional truck turnaround time at a seaport container terminal in terms of several of the aforementioned variables. The developed SMM, MMM, SCMSM, and MCMSM models are described in the following sections.

3.2. *Departure and arrival pattern between stages*

According to Burke [8] and Reich [9], the departure (or output) process of an M/M/1 and M/M/c queue follows a Poisson process. This results in a Poisson probability distribution for the number of container arrivals to the second inspection stage.

If the departure distribution is split into half from the first stage of an M/M/1 or M/M/c queue, the distribution will end up at the next stage of exponential servers with the Poisson arrival rate halved. Poisson processes may be evenly separated and combined. In the first stage, every container truck has to get radioactive inspection, but in the second stage, only container trucks that need extra inspection need to get X-ray/Gamma ray inspection. So, the arrival rate of the trucks from the first and second stage might be different. The methodology can apply to all usage rate of the Green Lane and at the first and second stage between 0 ($\lambda = 0$) and 100% ($\lambda = 100$). The sum of two Poisson processes (λ_1, λ_2) produces a Poisson process with $\lambda = \lambda_1 + \lambda_2$. Furthermore, a Poisson process (λ) may be split into two Poisson processes (λ_1, λ_2) having $\lambda = \lambda_1 + \lambda_2$. "Figure 1 shows the departure rate in the SCMSM with the same arrival rate λ in each stage of the M/M/1 as well as in the exit of the inspection station if the arrival rate is less than the inspection rate at the first stage".

Jackson [18] developed a product-form solution for the steady-state probability $P(s_1, s_2)$ in tandem queues. This solution describes that the probability of a specific number of containers is in the first stage (s_1) and a specific number of containers in the second stage (s_2) shown in Equation (3).

$$P(s_1, s_2) = (1 - \rho_1){\rho_1}^{s_1} * (1 - \rho_2){\rho_2}^{s_2} \tag{3}$$

where

$$\rho_1 = \frac{\lambda}{\mu_1} \tag{4}$$

and

$$\rho_2 = \frac{\lambda}{\mu_2} \tag{5}$$

According to Jackson's theorem, the numbers of containers at each stage in the SCMSM are independent of each stage and the following equations apply. (Table II)

Figure 1 shows the diagram of departure rate in single channel and multiple stages model.

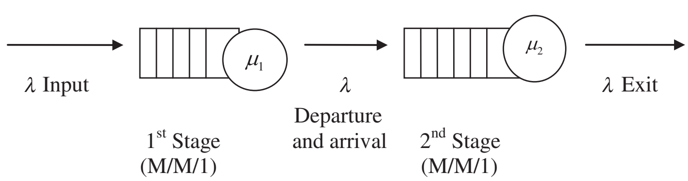

Figure 1. Diagram of departure rate in single channel and multiple stages model.

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Table II. Nomenclature table.

λ_1	Average container/cargo arrival rate at first stage
λ_2	Average container/cargo arrival rate at second stage
μ	Average service rate at inspection station
t	Inspection time
n	Number of truck
s_1	First Stage
s_2	Second Stage
p	Utilization rate
T_{1s}	Average number of trucks at the first stage of the inspection system
$ATTT_{1s,\text{ SCMSM}}$	Average additional truck time at the first stage of the inspection system
T_{2s}	Average number of trucks at the second stage of the inspection system
$ATTT_{2s,\text{ SCMSM}}$	Average additional truck time at the second stage of the inspection system
k	Number of cargos in the system
I	Number of cranes
U	The upper limit on the maximum number of cargos in the yard
$E(S)$	Delay time for the nonlinear in parameter model
θ	Container percentage

The average number of trucks at the first stage of the inspection system (T_{1s}) is

$$T_{1s} = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n{\rho_{1s}}^n(1-\rho_{1s}) = \frac{\rho_{1s}}{1-\rho_{1s}} \tag{6}$$

where

n = number of truck

The average additional truck time at the first stage of the inspection system ($ATTT_{1s,\text{ SCMSM}}$) is

$$ATTT_{1s,\text{SCMSM}} = \frac{T_{1s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n{\rho_{1s}}^n(1-\rho_{1s})}{\lambda} = \frac{1}{\mu_{1s}(1-\rho_{1s})} \tag{7}$$

The average number of trucks at the second stage of the inspection system (T_{2s}) is

$$T_{2s} = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n{\rho_{2s}}^n(1-\rho_{2s}) = \frac{\rho_{2s}}{1-\rho_{2s}} \tag{8}$$

The average additional truck time at the second stage of the inspection system ($ATTT_{2s,\text{ SCMSM}}$) is

$$ATTT_{2s,\text{SCMSM}} = \frac{T_{2s}}{\lambda} = \frac{\sum_{n=0}^{\infty} n{\rho_{2s}}^n(1-\rho_{2s})}{\lambda} = \frac{1}{\mu_{2s}(1-\rho_{2s})} \tag{9}$$

On the basis of Jackson's theorem, an SCMSM model can be used to analyze the inspection station as though each stage of the inspection is isolated from all the others.

Therefore, the total additional truck turnaround time ($ATTT_{\text{SCMSM}}$) at the inspection system can be obtained as a sum of the additional truck turnaround time at each stage as follows:

$$ATTT_{\text{SCMSM}} = ATTT_{1s,\text{SCMSM}} + ATTT_{2s,\text{SCMSM}} \tag{10}$$

The MCMSM can be divided into three submodels including MCMSM-SM, MCMSM-MS, and MCMSM-MM. "These submodels' layouts are shown in Figure 2".

4. SENSITIVITY ANALYSIS

The queuing models presented earlier will be used to analyze and evaluate the cargo turnaround time at container seaport inspection stations. The rate of containers entering into the inspection station is dependent on several variables such as the season, year, level of security, level of oil prices, market trends, weather, and political issues. The inspection rate is dependent on the equipment technology, number of equipment units, and level of security required.

Figure 2 shows six different types of diagram of the queuing models.

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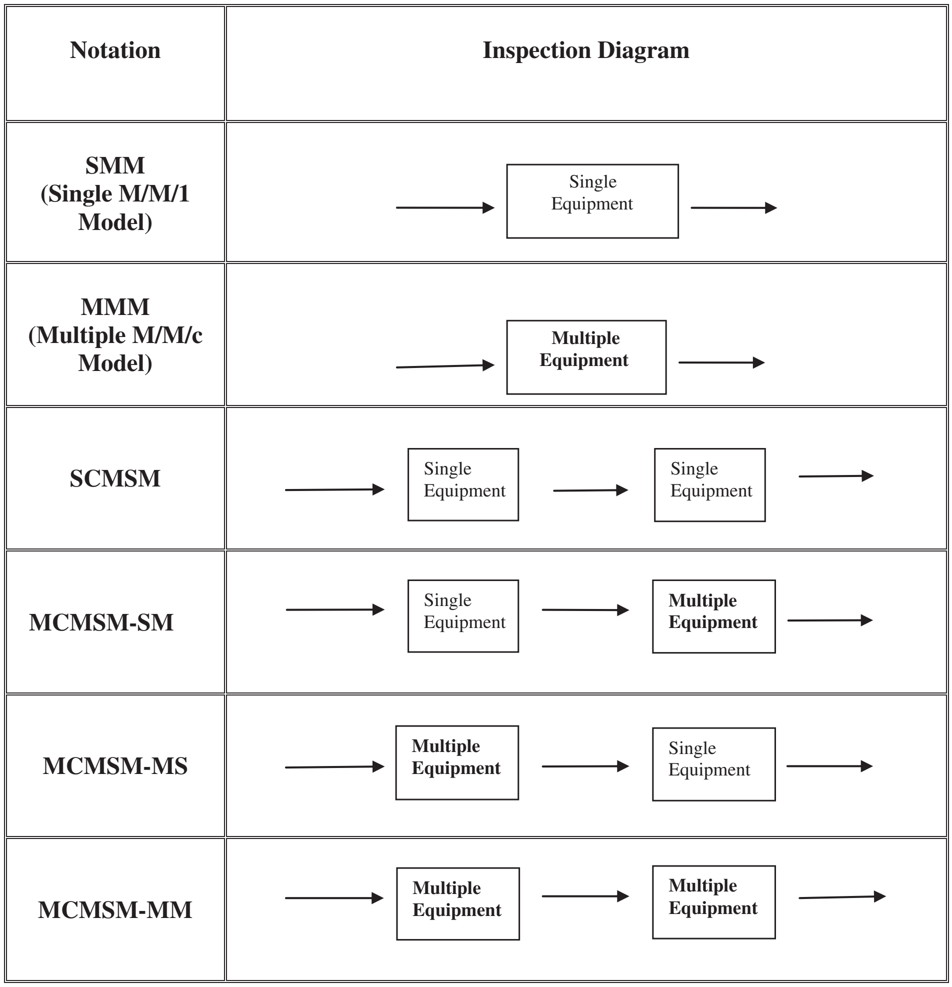

Figure 2. Diagram of queuing models.

In the United States, changes in the security level of the nation, issued by the Department of Homeland Security, will affect the inspection rate of containers entering the country. Inspection time intervals may be fixed or weighted. Fixed inspection time intervals mean that there is fixed increment in the inspection rate as the security level increases. For example, at a "guarded" security level, the inspection rate is 30 seconds higher than the inspection rate at a low security level. The inspection rate is also 30 seconds higher for the next higher or "elevated" security level. A 60-second increment between security levels is used for active inspection systems.

When using weighted inspection time intervals, in addition to the fixed time interval, an increment is added, which is equal to an additional time multiplied by the numerical difference between the prevailing security level and the low security level. For example, for an elevated security level (3) and an incremental time of 10 seconds, the additional weighted time to be added to the fixed time will be 10 $(3-1)=20$ seconds. Figure 3 shows the impact that various security levels have on the system's throughput for various weighted time intervals.

Figure 4 shows the assumed inspection time interval between security levels as a weighted time interval of 5, 10, and 15 seconds. The figure demonstrates that the higher the weighted inspection time the fewer the trucks that can be inspected, resulting in high delay at the inspection station.

5. THE ACADEMIC AND MANAGERIAL IMPLICATIONS OF THE RESEARCH

The academic and managerial implications of this research and how the methodology can be applied effectively in practice are summarized here.

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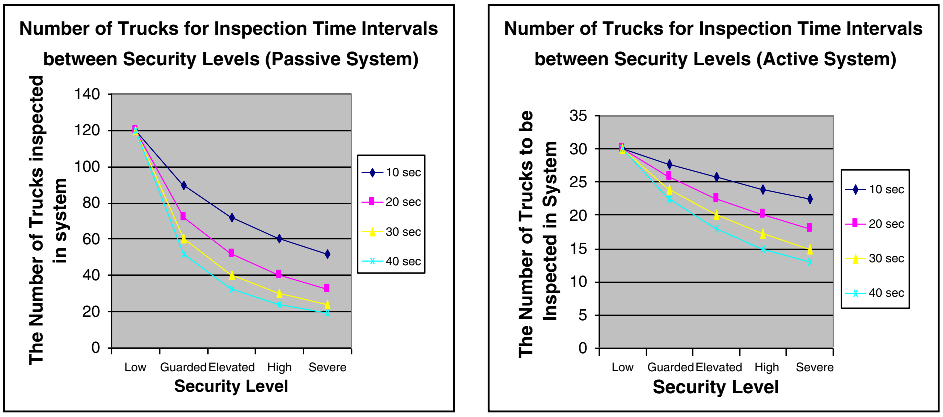

Figure 3. Sensitivity analysis of inspection rates with fixed time interval. Source: author based on Department of Homeland Security.

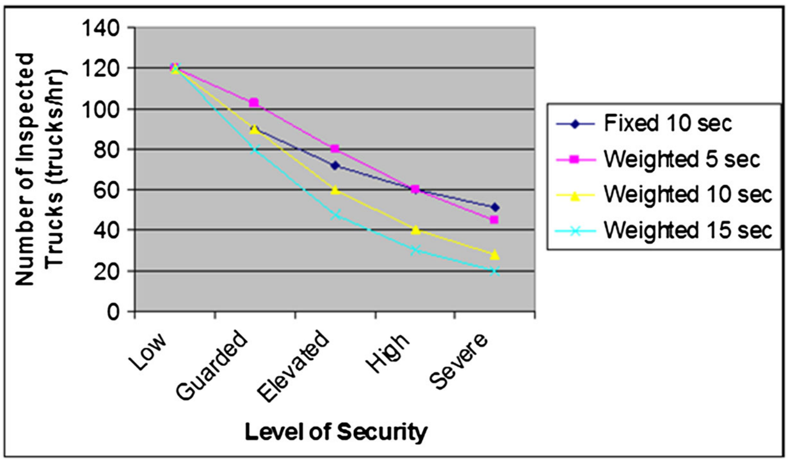

Figure 4. Sensitivity analysis of inspection rates with weighted time interval.

In Figure 5, actual arrival rate equals to total arrival rate minus Green Lane usage rate and actual inspection rate affected from inspection rate, equipment factor, security factor, and inspection time interval. The actual arrival rate over the inspection rate becomes the offered rate (OR). If the OR is greater than 1, the use of an MMM model is required. If the OR is less than 1, an SMM model will be used.

After determining the number of inspection units and using either the SMM or MMM model at first stage, the percentage (θ) of containers to be inspected at the second stage is used to determine the actual arrival rate at that stage. The equipment factor for X-ray/Gamma ray inspection units, security factor, and fixed and/or weighted time interval are used to determine the actual arrival rate (λ_{2s}) and inspection rate (μ_{2s}) at the second stage. If there is an SMM at the first stage, the procedure follows the left hand side at the second stage in Figure 5. If there is an MMM at the first stage, the procedure follows the right hand side. If the OR at the second stage is greater than 1, the MMM formulation will be used to obtain the minimum number of inspection units needed at the second stage. If the OR is less than 1, the SMM formulation will be used.

The bottom portion of Figure 5 shows the final procedure for determining the best layout and model of the six models including SMM, MMM, SCMSM, MCMSM-SM, MCMSM-MS, and MCMSM-MM.

On the basis of the final procedure for determining the best layout and model including SCMSM (if there are SMM models used at both first and second stages), MCMSM-SM (if there is an SMM

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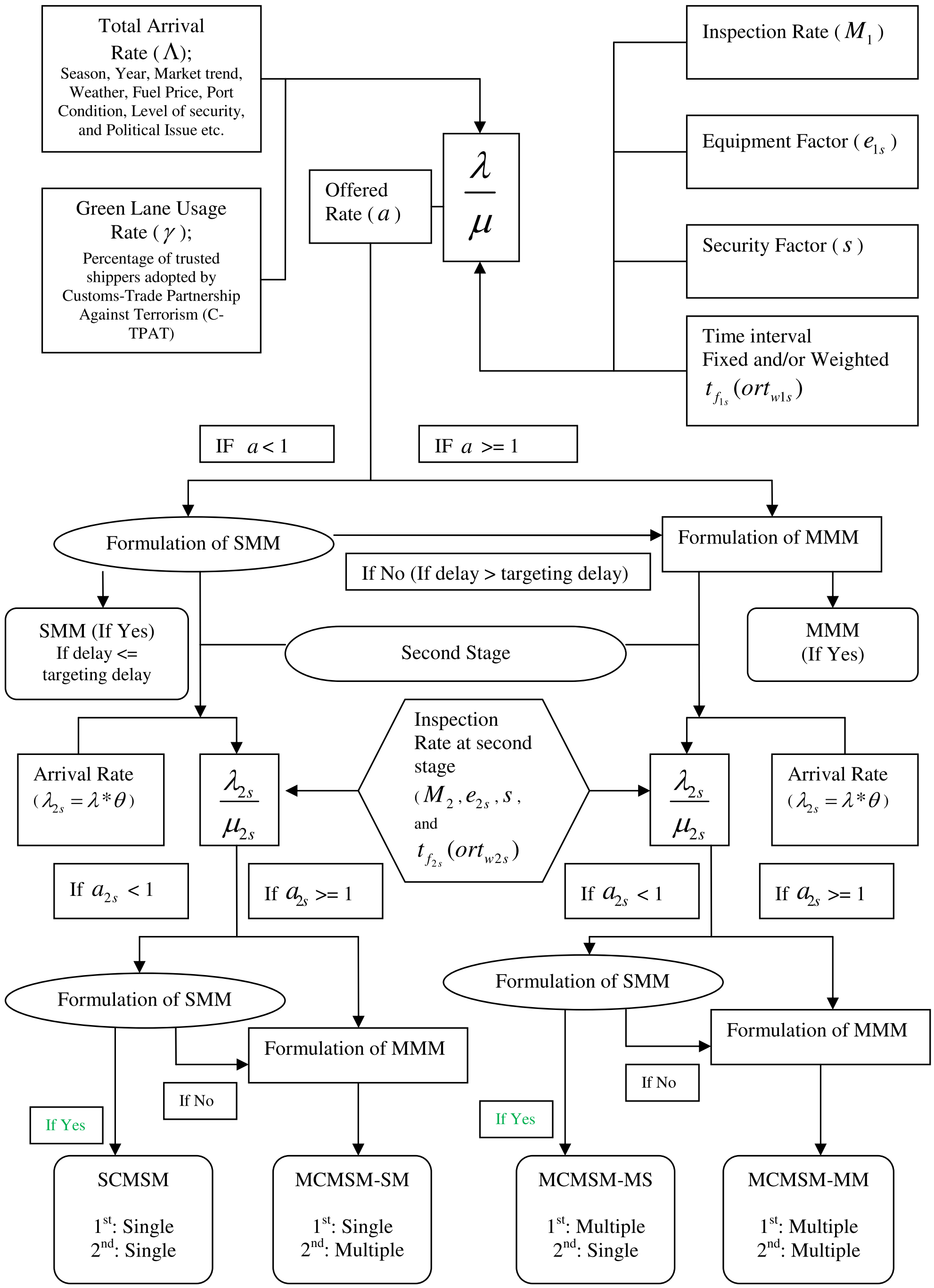

Figure 5. Flow diagram: procedure for identifying inspection needs.

model at the first stage and an MMM model at the second stage), MCMSM-MS (if MMM is used at the first stage and SMM at the second stage), and MCMSM-MM (if MMM is used at both stages), it may apply to port queuing system-related costs in terms of service cost and waiting cost in Figure 6. Optimal service should be at the point that total cost is in minimum [22].

Lastly, this research has demonstrated the simulation by computer software for a seaport in South Korea. Figure 7 showed the result of an experimental trial of a real case scenario and showed that after more than 550 000 cargoes coming into the station, the total cost increased dramatically. Therefore, to keep standing on less than 0.6 ratio of utilization that means 1–2 minutes in first stage and 5–10 minutes

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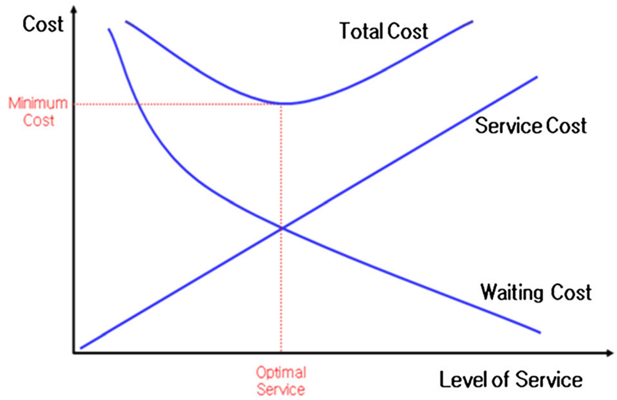

Figure 6. Port queuing system-related costs.

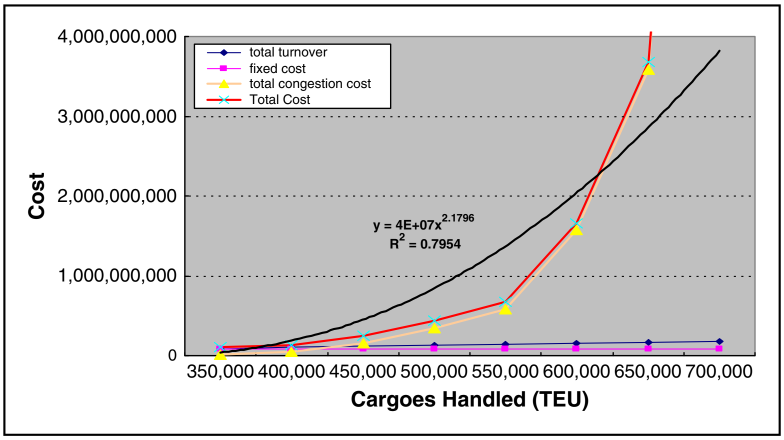

Figure 7. Relationship between turnover and cargo waiting/backlog-related costs.

in second, the port applied from SCMSM model to MCMSM-MM model by adding six and three more inspection capacities and labors at the first and second stage, respectively, at the cost of $80m.

Finally, by this research, it can be effectively analyzed and implicated the delay time in port security station in both academic and managerial fields in terms of traffic, procedure of security, usage of Green Lane, number of the equipment and efficiency, and so on.

6. CONCLUSION

The tragic events of 11 September 2001 lead to the adoption of the ISPS Code and SOLAS Amendments to enhance maritime security. These new requirements have changed the structure of the global SCSS extending to the global shipping port LSCM. It has expedited changes in the NIMO, and special attention has been given to the vulnerability of containers to terrorist activities. This fact necessitated the installation of an inspection station at port container terminals whose practice resulted in additional truck turnaround time at the terminals. Six base models were developed to optimize the relationship between the additional truck turnaround time and the required number of container inspection units.

As a result of this examination of the cost of delay and additional cargo turnaround time for security checks, the following conclusion can be drawn and made. The average additional delay time in the inspection station is very dependent on the inspection rate of the lower stage. The higher weighted inspection time based on rising security levels allows fewer trucks to be inspected, deriving high delay in the inspection station. A procedure for identifying inspection needs was used to determine the

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minimum number of inspection units required. An increase in the rate of Green Lane usage allows an increase in the arrival rate, resulting in the improvement of inspection unit efficiency and the decrease of average delay time at the inspection station. In a multiple stage model, total number of trucks and delay time very closely follow those of low inspection stage rate and number of inspection units. Free Lane is to be followed by C-TPAT and standardization of customs, packing, loading and unloading, documents, procedure, and exchange working in each country, especially in Asian countries.

This study contributes to an understanding of the way in which design of terminal security inspection systems need not create excessive delay in LSCM inspections security. It can be beneficial to both public bodies and business parties as in the fields of coast guards, customs border protection agencies, port terminal officers, international freight shippers, and transport vehicles carriers.

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