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A Study for a Methodology to Analyze Container Delays versus Security

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보안대비 컨테이너 지연분석을 위한 방법론적 연구

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ABSTRACT: *After September 11, 2001, the United State's Customs and Border Protection (CBP) has set up inspection stations in seaport terminals. The inspection station, however, may directly and indirectly affect delay time in the seaports, increasing by especially high and severe level of security. This paper studies for a methodology to analyze container delays versus security incurring by the various layouts of the inspection station in the United States.*

KEY WORDS: Marine Security, Layout, Queuing Theory, Inspection Station, Container Terminal.

요　약 : 2001년 9월 11일 World trade center 테러이후, 미국세관 및 국경 경비대는 미국에 있는 모든 컨테이너 터미널에 inspection station을 설치하였다. 이 인스펙션은 container의 추가적인 지연을 직·간접적으로 유발하고 있다. 이에 본 연구는 이 지연을 분석하기위하여 대기이론을 이용하여 방법론적 연구를 제시하였다.

핵심용어 : 해상보안, 배치, 대기이론, 검사소, 컨테이너 터미널

1. Introduction

After September 11, 2001, container transportation has become very vulnerable to terrorist activities for the use of dirty materials. This fact has made it impossible for the United States to ignore potential terrorists' dangers and threats and the potential use of dangerous goods such as nuclear and radiological weapons at seaport container terminals (Srinivasan, 2002). As international trade continues to increase, there are much more opportunities for terrorists to conceal their attack materials within commercial cargo and containers. In this paper, a methodology is focused to analyze delay time by using queuing theory.

2. Fundamental Factors to Analyze Delay Time

A queuing model is used to mathematically analyze waiting lines or queues. All queuing models have three factors including: (1) a random arrival process, (2) a probabilistic service time distribution function, and (3) a deterministic number of available servers.

In the queuing models of this research, the arrival process is the Poisson process. In this case, the times between successive arrivals of containers are exponentially distributed. The Poisson arrival process is routinely described by the letter **M**.

The inspection times are random in terms of the container's risk and security levels and the present inspection time does not affect future inspection time. Hence, in the queuing models of this research, these services times are exponentially distributed and they are also memoryless between inspection times. The letter **M** is also used to symbolize the service time distribution functions. Finally, the non-stochastic number of servers is typically denoted by some positive integer and describes the number of inspection equipment.

There are various critical parameters including the container arrival rate. This arrival rate varies by season, year, level of security, oil price, trade negotiation,

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market trend, weather, and other issues. Another variable is the inspection rate (Chatterjee, 2003). The inspection rate depends on the type of equipments, number of equipments, equipment technology, and level of security. The rate of using the Green lane[1] * is also a critical parameter. This rate is the rate of arrival of containers stuffed by a Customs Trade Partnership Against Terrorism (C-TPAT) certified shipper. The container must have originated from Container Security Initiative (CSI) port and International Ship and Port Facility Security (ISPS)-certified ports, container carried by C-TPAT certified rail/truck/ocean carriers, container delivered to C-TPAT importer, and level of security.

2.1 Arrival Pattern

In the queuing model, the arrival pattern is represented by a probability distribution function in terms of the number of arrivals in a particular interval of time (number of inter-arrival time), while the service pattern represented by a probability distribution function in terms of the number of service completed in a particular interval of time (Bish et. al. 2001). It is assumed that a probability distribution for the number of container arrivals in a particular interval of time at the first stage in this inspection station follows a Poisson distribution determined as:

$$P(x,\lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!} \qquad (1)$$

where, λ = average container arrival rate; and

x = number of container arrival.

Since the Poisson distribution has a same birth-rate during the same time period, the inter-arrival time follows an exponential distribution (Cheng et al. 2005).

2.2 Inspection Pattern

The inspection time refers to the length of time that a customer spends in the inspection station. The inspection pattern can be described as a probability distribution in terms of the number of containers served in a particular interval of time. The inspection rate of μ is exponentially distributed with a mean rate $1/\mu$, because the present inspection rate does not affect future rates. This exponential distribution is the only continuous distribution having a memoryless property (Collins et al. 2005). Therefore, it can be assumed that a probability distribution for the number of containers served in a particular interval of time at both the first inspection stage and the second inspection stage follows an exponential distribution determined as:

$$f(t) = \mu e^{-\mu t} \quad (if, t \geq 0) \qquad (2)$$

where, t = inspection time; and

μ = average inspection rate.

The probability to complete the inspection within the interval time t is determined as:

$$P(T \leq t) = 1 - e^{-\mu t} \qquad (3)$$

2.3 Departure and Arrival pattern Between Stages

According to Burke (1956) and Reich (1957), the departure (or output) process of an M/M/1 and M/M/c queue follows a Poisson process. This result in a Poisson probability distribution for the number of container arrivals in a particular interval of time from the first stage to the second stage in this inspection station is occurred. The Poisson process has the property that if the distribution is separated probabilistically, it will still end up with the Poisson process. Thus, if the departure distribution is spilt into half from the first stage of M/M/1 or M/M/c queue, the distribution will still end up at the next stage of exponential servers with the Poisson arrival rate halved. Conversely, the Poisson process also has the property that if it is combined two or more Poisson processes, it will end up with a Poisson process again.

3. Methodology

Six base models for the prediction of additional delay time at an inspection station are used and

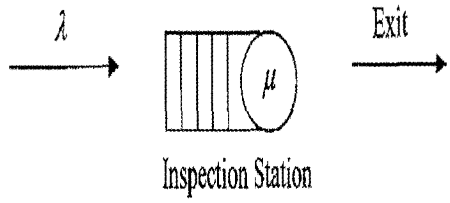
1. CBP's commissioner Bonner (2005) stated the Green lane as an advanced CBP's policy that in the lane containers would be immediately released without inspection for trusted shippers that adopt the highest levels of security controls by C-TPAT.

developed in this research. The queuing models are used to mathematically analyze waiting lines or queues. The models include 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−Multiple and Single, and MCMSM−Multiple and Multiple. Each of the models is applied under various layouts, inspection policies, security levels of the container seaport and government agencies. The developed SMM, MMM, SCMSM and MCMSM models are described as follows.

3.1 Single M/M/1 Model (SMM)

In this paper, a single M/M/1 model is used for a single inspection station. It is assumed that containers are served on a first come first served basis, and assigned to equipment of inspection randomly. The queuing system of this single inspection station (SMM) can be summarized as shown in Fig.1.

Fig.1. A SMM at Single Inspection Station.



where, λ = average container arrival rate

μ = average service rate at inspection station

Average additional delay time at the queue ($AADT_{q,SMM}$) is shown as:

$$AADT_{q,SMM} = \frac{L_q}{\lambda} = \frac{\sum_{n=1}^{\infty}(n-1)P_n}{\lambda} = \frac{\psi}{\mu(1-\psi)} \tag{4}$$

where,

$$P_n = \frac{\prod_{i=0}^{n-1}\lambda_i}{\prod_{i=1}^{n}\mu_i}P_0 = (1-\frac{\lambda}{\mu})(\frac{\lambda}{\mu})^n = (1-\psi)\psi^n, \quad (n \geq 0) \tag{5}$$

and,

$$P_0 = \left[1+\sum_{n=1}^{\infty}\left\{\frac{\prod_{i=0}^{n-1}\lambda_i}{\prod_{i=1}^{n}\mu_i}\right\}\right]^{-1} = \left[\sum_{n=0}^{\infty}\left(\frac{\lambda}{\mu}\right)^n\right]^{-1} = 1-\frac{\lambda}{\mu} = 1-\psi, \text{ and } \psi = \frac{\lambda}{\mu} \tag{6}$$

If utilization rate of the equipment (ψ) is close to 1 that the arrival rate is equal to the service rate, a small increase in the truck arrival rate (or a small decrease in the inspection rate) will cause the time of average additional delay time at the inspection equipment ($AADT_{q,SMM}$) to increase dramatically. Therefore, the number of inspection equipment will affect the ability to minimize the delay time at a container seaport terminal. This model can also be applied at a SCMSM and MCMSM Model with single equipment.

3.2 Mutiple M/M/c Model (MMM)

Some container terminals have a single inspection station with multiple inspection equipment. Therefore, the second analysis used in this paper is the study of the inspection station as a queuing model with multiple servers at one stage. This inspection station layout is shown as follows:

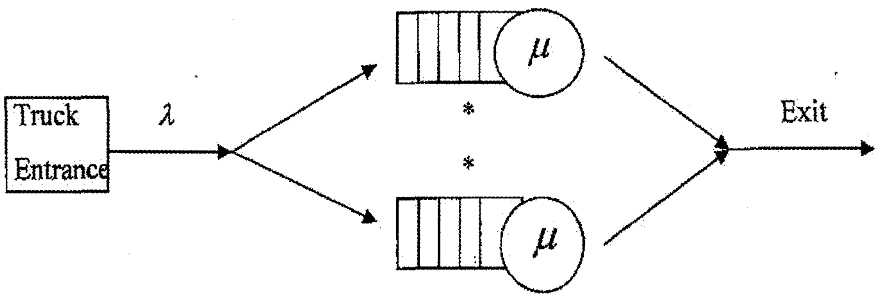
Where, the steady-state probability (P_n) at each state is shown in equations 6 and 7.

$$P_0 = \left[\sum_{k=0}^{c-1} \frac{a^k}{k!} + \frac{a^c}{c!} * \frac{1}{(1-\psi)} \right]^{-1} \tag{8}$$

where, $\psi = \frac{\lambda}{c\mu}$, $a = \frac{\lambda}{\mu}$

$$P_n = \begin{cases} \frac{(c\psi)^n}{n!} * P_0 \ (1 \le n \le c-1) \\ \frac{(c\psi)^c}{c!} * \psi^{n-c} P_0 \ (n \ge c) \end{cases} \tag{9}$$

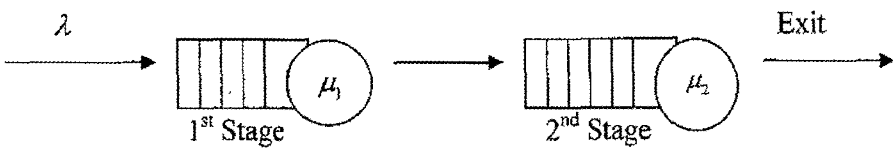
Fig.2. A MMM at Single Inspection Station.



The average additional delay time at the inspection system ($AADT_{MMM}$) in the MMM is as follows:

$$AADT_{MMM} = \frac{\sum_{n=c}^{\infty}(n-c)P_n}{\lambda} + \frac{1}{\mu} = \frac{\frac{(c\psi)^c}{c!} * \frac{\psi}{(1-\psi)^2} P_0}{\lambda} + \frac{1}{\mu} = \frac{\frac{\psi}{(1-\psi)^2} P_c}{\lambda} + \frac{1}{\mu} \tag{7}$$

Fig.3. A diagram of SCMSM at Inspection Station.



Where, λ = average container arrival rate

μ_1 = average service rate at 1st Stage

μ_2 = average service rate at 2nd Stage

This model can be applied at each stage with multiple equipment in Multiple Channels and Multiple Stages Model Single and Multiple (MCMSM-SM), Multiple Channels and Multiple Stages Model Multiple and Single (MCMSM-MS), and Multiple Channel and Multiple Stages Model Multiple and Multiple (MCMSM-MM).

3.3 Single Channel and Multiple Stages Model (SCMSM)

Some container seaports have especially high volumes of containers from risky foreign countries. These containers must pass through multiple inspection stages including a first and second stage at an inspection station. The first stage includes passive inspection and the second stage includes active inspection. Even if each port has different layouts for the stages of the inspection station, a SCMSM can be applied to the port having multiple stages in order to analyze the impact of the layout on delay time. Truck delays at inspection stations in seaport container terminals are caused by several factors including the type and number of inspection equipment and the inspection procedure. This model breaks the inspection process into two parts including the first stage and at the second stage. During the first stage, all containers entering into the U.S. should be inspected in this stage. During the second stage, some of containers which failed inspection or inspected as an unreliable container during the first stage needs an inspection at the second stage with an imaging system.

The SCMSM is the approach to determine expected delays for a variety of truck flow rates, service rates and inspection procedures. The delay time includes the additional time required by trucks at each stage of the inspection process due to the inspection process. These additional times are combined for each stage in order to obtain the additional delay time due to the inspection station. The queuing system of this model can be summarized as shown in Fig. 3.

In this figure, the container has an arrival rate λ . At the first and second stages the service rates are μ_1 and μ_2 respectively. It is assumed that there is an infinite waiting area in both stages. Based on Jackson's theorem, a 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 delay time ($AADT_{SCMSM}$) by the inspection system can be obtained as a sum of the additional delay time at each stage as follows:

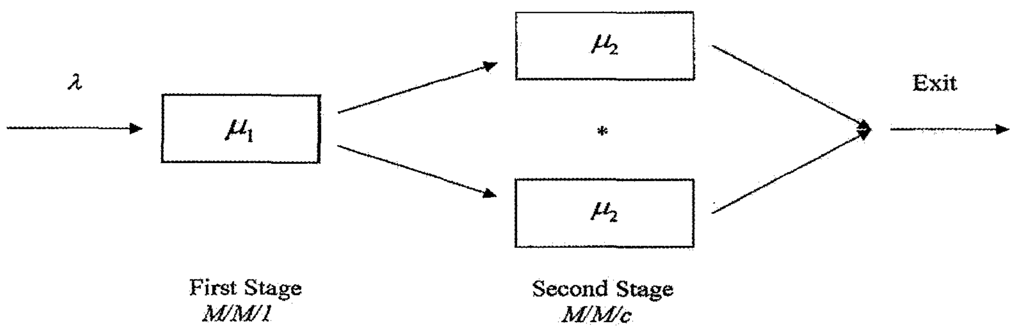
$$AADT_{SCMSM} = AADT_{1s,SMM} + AADT_{2s,SMM} \tag{10}$$

3.4 Multiple Channels and Multiple Stages Model (MCMSM)

The MCMSM can be divided into three sub−models including MCMSM−Single and Multiple (MCMSM−SM), MCMSM−Multiple and Single (MCMSM−MS) and MCMSM−Multiple and Multiple (MCMSM−MM). The MCMSM−MS is used to determine the expected delay time by applying one equipment at the first stage denoted as a M/M/1 and multiple equipment having identical inspection rates at the second stage denoted as a M/M/c.

On the contrary, the MCMSM−MS is the approach used to determine the delay time by applying multiple equipment having identical inspection rate at the first stage denoted as a M/M/c, and one equipment at the second stage denoted as a M/M/1 for a variety of truck flow rates, service rates and the rate of Green lane usage, while a MCMSM−MM uses multiple equipment for both the first and second stages. Trucks arriving to the inspection station will be inspected at one of idle equipment. The queuing system for these models can be summarized as shown in Fig. 4, 5 and 6.

Fig.4. A diagram of MCMSM-SM at Inspection Station.



Where, λ = average container arrival rate
μ_1 = average inspection rate at first stage
μ_2 = average inspection rate at second stage

Fig.5. A diagram of MCMSM-MS at inspection station.

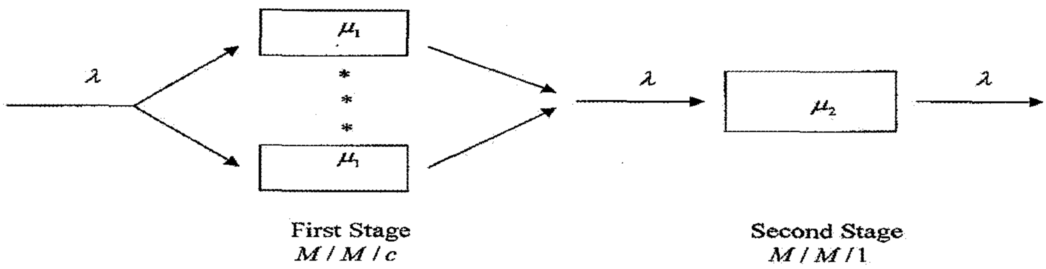
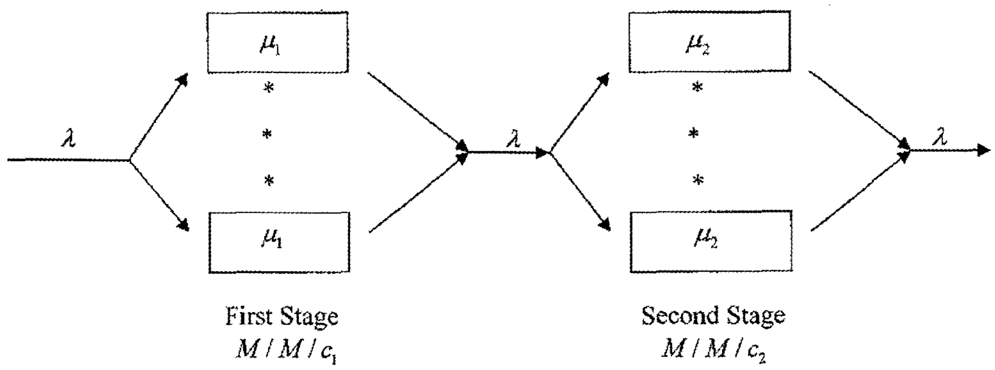


Fig.6. A diagram of MCMSM-MM at inspection station.



This model of MCMSM−MS includes a multiple M/M/c Model at the first stage and a single M/M/c model at the second stage.

This model of MCMSM−MM includes a multiple M/M/c model at both the first and second stages. Based on Jackson's (1957) theorem, the number of containers at each stage in the MCMSM is independent. The following equations describe the Multiple Channel and Multiple Stage Model Multiple and Single (MCMSM MS) and Multiple Channel and Multiple Stage Model Multiple and Multiple (MCMSM MM). Therefore, the total delay times ($AADT_{MCMSM-MS}$) by the inspection system in an MCMSM−MS and $AADT_{MCMSM-MM}$ in MCMSM−MM can be obtained by summing each stage as follows:

$$AADT_{MCMSM-SM} = AADT_{1s,SMM} + AADT_{2s,MMM} \tag{11}$$

$$AADT_{MCMSM-MS} = AADT_{1s,MMM} + AADT_{2s,SMM} \tag{12}$$

$$AADT_{MCMSM-MM} = AADT_{1s,MMM} + AADT_{2s,MMM} \tag{13}$$

4. Conclusion

After September 11, 2001, the movement of containers has become very vulnerable for terrorist and for the use of dirty materials. This fact allows the United States to set up inspection stations in seaport container terminals. However, it derives a result of additional delay time at the terminals. In this study, this queuing models are applied in order to analyze the delay time at inspection station as a methodology. That is, six base models are developed in this research depending on the various layouts including 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 channels and multiple stages model (MCMSM) for prediction of additional delay time at an inspection station in the USA. As a result of the review of the six models, the average additional delay time (AADT) in the six models for the inspection station is very dependent on the stage at low inspection rate with inappropriate number of inspection equipment. In addition, if utilization rate of the equipment (Ψ) is close to 1, a small increase in the container's arrival rate (or a small decrease in the inspection rate) will allow the delay time at the inspection equipment to increase dramatically.

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