科技部補助專題研究計畫成果報告
期末報告

邊境安全檢查之等候模型與計算(第 2 年)

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執 行 單 位 ：國立政治大學應用數學學系

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報 告 附 件 ：移地研究心得報告
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中 華 民 國 104 年 02 月 05 日

中文摘要： 在機場或國際邊界的安全檢查經常會導致個人，行李，包裹或車輛長時間排隊等候。一般情況下，因為人（或車輛）不會於固定的時間間隔依序到達，因此要保證安全等待時間似乎並不那麼容易，更不要說因為安全需要增加必要的檢查造成服務的過程中更多的不確定性。

這項計畫的目的是構建一個排隊模型，以協助海關人員了解如何設計和管理同時俱備安全與最高等候時間的排隊環境，例如正常的等待時間不超過 30 分鐘。為了考慮在實踐中的真實情況，如在各種安全階段的檢查，我們用類 Coxian 分佈服務時間的排隊模型。雖然類 Coxian 分佈計算非常複雜，但其估計值比傳統的模型好。經由這種模型，它既能保持安全級別，又可以舒緩在機場，或國際邊界之安全檢查點上時間緊張的壓力。這項計畫預期在第一年完成基本模型和它的計算公式；第二年則根據實務的需要做相對應的參數調整，以期達到實用價值。

中文關鍵詞： 類生死過程之馬可夫鏈, 等候理論, 安全檢查, Coxian 分佈

英文摘要： Security access control and security screening (“search“) applications in airports or international borders will routinely cause a waiting line by people, baggage, packages or vehicles. Generally, finding out the average security wait time is not as easy as it appears. This is because people (or vehicles) do not arrive at the queue on a precise schedule, not to mention the need for security check which makes the service process more involved.

The objective of this proposal is to construct a queueing model to assist the Transportation Security Office understand how to design and manage the security wait environment with customers‘ satisfaction, e.g. the normal wait time is no more than 30 minutes. To accommodate the seurity conditions in practice, such as check in various security stages, we use a queueing model with service time of semi-Coxian distributions. The semi-Coxian distribution in fact complicates the computation but reflects relatively better estimation than a traditional model. Thus, it is useful both to maintain the security level and to release the tense in the security check points in airports, or international borders. The basic computable model will be built in the first year and further investigation for implementation issues and verification will be conducted in the second year.

英文關鍵詞： QBD Markov Chain, Queueing, Security Check, Coxian Distribution.

行政院國家科學委員會補助專題研究計畫成果報告

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計畫類別：☑ 個別型計畫 ☐ 整合型計畫

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執行單位：國立政治大學應用數學系

中 華 民 國 103 年 10 月 15 日

行政院國家科學委員會專題研究計畫成果報告
邊境安全檢查之等候模型與計算
Computing the waiting time in a security check system

計畫編號: **NSC 101-2221-E-004 -002 -MY2**
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Abstract. This project studies the performance analysis and trade-off between security and cargo service goals of a security-check system during the global supply chain. There are relatively fewer studies on security-check waiting lines using analytical models. We address the important tradeoff issue between the security screening effectiveness and the supply chain efficiency, i.e., the two main goals of a security-check system while considering the global supply chain management. A multiple servers security system is considered in this report. Stationary probabilities are fundamental in response to various measures of performance in queueing networks. Solving stationary probabilities in Quasi-Birth-and-Death (QBD) type Markov Chain normally are dependent on the structure of the queueing network. In this report, a new computing scheme is developed for attaining stationary probabilities in queueing networks of the multiple servers security systems. Our approach is to develop a stylized queueing model with the novel features pertaining to the real system. The goal of this report is to provide a modelling framework to understand the economic tradeoffs embedded in container-inspection decisions and to use this framework to analyze policy initiatives.

1 Introduction

The motivation of this study arises from a U.S. law enacted in August 2007, "Implementing Recommendations of the 9/11 Commission Act of 2007" [4], popularly called the 9/11 Commission Act. The law requires that, before any cargo bound for the United States is loaded onto a ship at an international port, it must be scanned using Non-Intrusive Imaging (NII) and radiation detection technology to detect radiological contraband. The deadline for compliance with this law is July 1, 2012, unless the Secretary of Homeland Security grants extensions, which can be offered in two-year increments [4].

A U.S. law mandating non-intrusive imaging and radiation detection for 100% of U.S.-bound containers at international ports has provoked widespread concern that the resulting congestion would hinder trade significantly. The consensus among security experts is that the most probable way that Americans would be targeted by a nuclear weapon would be for al-Qaeda or a future adversary to smuggle it into the United States. The millions of shipping containers that are used to transport goods in ocean-going vessels provide terrorists with one promising way to hide a nuclear device destined for U.S. shores. By using a container, terrorists can potentially achieve mass disruption of global supply chains: widespread public anxiety that other containers may contain nuclear devices would result in stepped-up inspections that would cause congestion throughout the global intermodal transportation system.

To counter the threat of nuclear terrorism, the United States has initiated various security measures, both at domestic and foreign ports. These measures can require the cooperation of foreign nations, trading companies, terminal operators, customs brokers, trucking companies, ocean carriers, and other participants in the maritime supply chain. In this report, we focus on security initiatives implemented at international ports, namely, the Container Security Initiative (CSI) and the Secure Freight Initiative (SFI). These constitute only 2 out of nearly 25 to 30 U.S. and international initiatives and legislations directed at enhancing maritime security.

CSI is a security program administered by the U.S. Bureau of Customs and Border Protection (CBP), an agency that falls within the Department of Homeland Security. The program, announced in January 2002, uses an "automated targeting system" (ATS) that employs rules-based software to identify containers bound for the United States that are at risk of being tampered with by terrorists. A key input to this system is the container's shipping manifest, which contains information about the container's sender, recipient, and contents. CBP's "24-hour rule" mandates that an ocean carrier transporting a container to the United States forward manifest information to CSI officials at least 24 hours prior to the container's lading onto a vessel that will call on a U.S. port. The most common concern is that the congestion that would result from this security requirement will substantially increase the cost of doing business and hurt commerce.

Stank and Crum [23] suggested that border crossings create delays in transportation and add uncertainty to transit times as customs clearance, traffic congestion, and other operating procedures are often highly variable with respect to time. The interval that a vehicle spends at a border impacts a wide range of carrier and shipper tactical and operational plans, including driver staffing, warehouse usage, vehicle routing and scheduling, and total cost. Taylor et al. [24, 25] estimated that, in 2003, the overall annual cost to carriers and shipper of crossing between Canada and the U.S.A. was about 6.3 billion, with the costs of transit time and uncertainty being about 4.0 billion of that total.

The U.S. Office of Freight Management and Operations [26] concluded that the number of inspection and processing booths open at each point-of-entry at any given time had a significant influence on the variability of travel time and delay. Goodchild et al. [27] reported that there was a direct correlation between delays and the number of customs/immigration booths open—the greater the number of booths open, the shorter the delay. Taylor et al. [25] stated that the most common cause of current delays and uncertainty related to the number of available customer primary inspection booths and the staffing of those booths, and the staffing of customs secondary inspection yards. They ranked staffing at border crossings as a most severe cause of border delays. Although many models for staff planning have been proposed (e.g., Edwards [28], Ernst et al. [29], and references therein), few of these models have been applied to border staffing and, more specifically, to the question of how many booths or lanes to have open at a crossing or how many truck inspectors to have on duty.

A key first step in planning responses to border delays is estimating how long a driver and vehicle will require to cross (or often, wait) at a border crossing. When studying queueing systems, it is important to predict their performance. Common performance measures include the average time that containers spend in the inspection system, the average number of containers in the system, and the maximal service rate at which the custom can inspect containers.

2 Research background

This project is prepared as a basic model of conducting queueing analysis for waiting time in security applications such as search and screening checkpoints.

Security access control and security screening ("search") applications will routinely cause a waiting line as the people, baggage, packages or vehicles begin to enter for "processing." The processing time is the period from the moment a person leaves the head of the queue and enters the security checkpoint process, until that person has completed the security procedure and been released to proceed freely within the secured area. Processing time depends primarily upon the tasks that are performed, for example check photo I.D., items through x-ray, person through magnetometer, etc. A simple and common security process would be the swiping of an access control card at a card reader that then releases a mechanical or optical turnstile. A more complex security process would be baggage x-ray screening and weapons or explosives scan, and other measures such as a vehicle search.

Each task and/or instrument utilized in the security process consumes time. The processing time for each individual is translated into the maximum number that can be "processed" per minute or per hour. This is commonly referred to as the "throughput". While actual security processing time can vary widely depending upon the tasks to be performed and the actual instruments in use, some examples may be helpful. A typical screening configuration consisting of 2 x-ray machines with a walk-through magnetometer ("metal or weapons detector") can process about 3 to 4 persons per minute realistically. A vehicle search lane with multiple security personnel can properly process a vehicle in approximately 45 to 60 seconds. Generally, increasing throughput by adding additional "lanes" is the method used to reduce wait time.

Most security managers and others that have addressed this issue raise its importance as seriously as the travellers do. In practice, some operations will "monitor" the queue in order to make rapid adjustments such as opening additional lanes when the queue becomes excessive. For example, people have become accustomed to long waits at airport security screening while the security check may have been conducted by using corner surveillance monitor to check the traveller in line. But no person desires to stand in line for more than 30 minutes although it is likely to be less than many people might expect in today's airport environment. In general, the delay occurring in the airport is restrained by the boarding time by which a aircraft is set to take off. It is necessary for the security client to first determine a TARGET average waiting period as the maximum time in queue, in order for security consultants to determine the necessary configuration. The object of this proposal is to built up a queueing model for waiting analysis at security checkpoints.

A security-check system such as border-crossing station can be modeled as a two-stage queueing system. A certain proportion (q) of customers (either cars or persons) are selected for further inspection and rest of customers will leave without going through further inspection after asking some questions and a brief visual inspection. The security-check level depends on two parameters $-$ q, the proportion of further inspection customers, and S the average time of the further inspection (mean service time of the second stage). As the waiting space is limited in the second stage and we must check all customers in this stage, the probability that the number of customers is above a certain limit (waiting space limit) must be small enough (such as less than 0.01). Thus the tail probability smaller than an upper bound is used as a service capacity requirement for a given security level (q_0, S_0). On the other hands, we must ensure that average customer waiting time is kept no more than a limit, say 30 minutes or minimized subject to the security level constraint. The tradeoff between ensuring sufficient security level and achieving good customer service must be made in such a service system. Waiting time in security applications or any other similar application in control could simply provide just one lane and one server or multiple lanes with several servers.

3 System Description and Model Formulation

Consider a two-stage queueing model as shown in Figure 1. This model is for a selective inspection system that often is in operation for an international border-crossing station or a security-check point at airport. In such a system, there are two stages for inspection: the waiting space at the first stage is fairly and is assumed to be infinite; but at the second stage is the waiting space is quite limited due to the service capacity B which is expandable with a significant cost per spot. In the first stage service, customers after initial screen are either transferred immediately to the second stage further inspection with probability q or continues to the routine check and leaves the system. The first year provides a system description and model formulation with analytic solution. The second year will focus on determining the optimal staffing and inspection strategy for a given security-check level.

We consider the queueing system for the security-check waiting lines, where customers arrive according to a Poisson process with mean arrival rate λ. There are c_1 servers in this system, and each one provides a preliminary first phase of the first-stage inspection (Phase 1) to all arriving customers. The average service time of first-phase inspection is exponentially distributed with rate μ_1 of each server. As soon as the first phase is completed, the customer may be provided with a second-phase service at the first-stage inspection with probability $1-q$ $(0 \le q \le 1)$, where the average service rate of each server is μ_2, or may enter the second-stage inspection with probability q. Assuming that the average service rate of the second-stage inspection is ν of each server. Those service times are mutually independent and follow exponential distributions.

For constructing a queueing model, consider a two-stage $M/Cox(2)/c_1 \to /M/c_2/B$ system. First stage has c_1 servers and a buffer of infinite capacity and second stage has c_2 servers and a buffer of finite capacity of $B - c_2$. First, we define the system state as (n, i, j, m), where n denotes the number of customers at the first stage, m denotes the number of customers at the second stage, i and j denote the total number of customers in phase 1 and in phase 2 at the first stage, respectively. Then we have the state space

$$\mathbf{S} = \{(n, i, j, m)|\ i + j = n, \text{if } n < c_1;\ i + j = c_1, \text{if } n \ge c_1, i,\ j,\ n \in \{0\} \cup \mathbb{N},\ m \in \{0, 1, 2, \ldots, B\}\}.$$

Denote $\overline{n}$ as the system state vector for $n = 1, 2, \ldots$, where state

$$\overline{1} = \{(1, 0, 1, 0), (1, 1, 0, 0), (1, 0, 1, 1), (1, 1, 0, 1), \ldots, (1, 0, 1, B), (1, 1, 0, B)\}$$

$$\overline{2} = \{(2, 0, 2, 0), (2, 1, 1, 0), (2, 2, 0, 0), (2, 0, 2, 1), (2, 1, 1, 1), (2, 2, 0, 1), \ldots, (2, 0, 2, B), (2, 1, 1, B), (2, 2, 0, B)\}$$

Figure 1: A security check queue model

$\overline{1}$ is of dimension $2(B+1)$. Given $n < c_1$, any combination of n servers gives the same pattern of service speed since the servers are homogeneous, which is independent of m. For example, the service rate at state $(1,1,0,B)$ is the same as at $(1,0,1,B)$, while that at $(1,1,0,2)$ is the same as that at $(1,0,1,3)$. thus, state $\overline{n}$ is of dimension $(n+1)(B+1)$, when $0 < n < c_1$, and $\overline{n}$ is of $(c_1+1)(B+1)$ when $n \geq c_1$. A picture of possible transitions is drawn in Figure 2.

The infinitesimal generater $\mathbf{Q}$ is of the block-tridiagonal form and written as follows

$$\mathbf{Q} = \begin{bmatrix} \mathbf{B}_0 & \mathbf{C}_0 & & & & & \\ \mathbf{A}_1 & \mathbf{B}_1 & \mathbf{C}_1 & & & & \\ & & \ddots & \ddots & \ddots & & \\ & & & \mathbf{A}_{c_1-1} & \mathbf{B}_{c_1-1} & \mathbf{C}_{c_1-1} & \\ & & & & \mathbf{A} & \mathbf{B} & \mathbf{C} \\ & & & & & \ddots & \ddots & \ddots \end{bmatrix}$$

where the submatrices $\mathbf{A}_n$, $\mathbf{B}_n$ and $\mathbf{C}_n$ are dimensional of $((n+1)(B+1) \times (n)(B+1))$, $((n+1)(B+1) \times (n+1)(B+1))$, and $((n+1)(B+1) \times (n+2)(B+1))$ for $0 < n \leq c_1$ respectively, but $\mathbf{A} = \mathbf{A}_{c_1}$, $\mathbf{B} = \mathbf{B}_{c_1}$ and $\mathbf{C} = \mathbf{C}_{c_1}$ for $n > c_1$.

Define

$$\mathbf{A}_n = \begin{bmatrix} \bar{\boldsymbol{\alpha}} & \boldsymbol{\alpha} & & & \\ & \bar{\boldsymbol{\alpha}} & \boldsymbol{\alpha} & & \\ & & \ddots & \ddots & \\ & & & \ddots & \boldsymbol{\alpha} \\ & & & & \bar{\boldsymbol{\alpha}} \end{bmatrix}$$

where $\boldsymbol{\alpha}$ and $\bar{\boldsymbol{\alpha}}$ are the size of $(n+1) \times n$ for $0 < n \leq c_1$ and of $(n+1) \times (n+1)$ for $n > c_1$, respectively, i.e.,

$$\bar{\boldsymbol{\alpha}} = \begin{bmatrix} a_n & & & & \\ & a_{n-1} & & & \\ & & \ddots & & \\ & & & a_2 & \\ & & & & a_1 \\ 0 & & & & 0 \end{bmatrix}$$

and for $n > c_1$

$$\bar{\boldsymbol{\alpha}} = \begin{bmatrix} 0 & a_n & & & & \\ \vdots & & a_{n-1} & & & \\ & & & \ddots & & \\ & & & & a_2 & \\ & & & & & a_1 \\ 0 & \cdots & & & & 0 \end{bmatrix}$$

where $a_k = k\mu_2$ if $k < c_1$; $a_k = c_1\mu_2$ otherwise; for $0 < n \leq c_1$

$$\boldsymbol{\alpha} = \begin{bmatrix} 0 & 0 & & \\ qb_1 & & & \\ & qb_2 & & \\ & & \ddots & \\ & & & qb_n \end{bmatrix}$$

Figure 2: TEST

and for $n > c_1$

$$\bar{\boldsymbol{\alpha}} = \begin{bmatrix} 0 & \cdots & & & 0 \\ 0 & qb_1 & & & \\ \vdots & & qb_2 & & \\ & & & \ddots & \\ 0 & & & & qb_n \end{bmatrix}$$

where $b_k = k\mu_1$ if $k < c_1$; $b_k = c_1\mu_1$ otherwise.

Define

$$\mathbf{B}_n = \begin{bmatrix} \bar{\boldsymbol{\beta}} & & & & & & \\ \tilde{\boldsymbol{\beta}}_1 & \bar{\boldsymbol{\beta}} & & & & & \\ & \ddots & \ddots & & & & \\ & & \tilde{\boldsymbol{\beta}}_k & \bar{\boldsymbol{\beta}} & & & \\ & & & \ddots & \ddots & & \\ & & & & \tilde{\boldsymbol{\beta}}_B & \bar{\boldsymbol{\beta}} \end{bmatrix}$$

$\tilde{\boldsymbol{\beta}}_k$ and $\bar{\boldsymbol{\beta}}$ are the size of $(n+1) \times (n+1)$.

$$\bar{\boldsymbol{\beta}} = \begin{bmatrix} \delta_n & & & & \\ (1-q)b_1 & \delta_{n-1} & & & \\ & & \ddots & & \\ & & & (1-q)b_n & \delta_0 \end{bmatrix}$$

$\tilde{\boldsymbol{\beta}}_k = k\nu\mathbf{I}_{n+1}$ if $k < c_2$; $\tilde{\boldsymbol{\beta}}_k = c_2\nu\mathbf{I}_{n+1}$ otherwise.

Define

$$\mathbf{C}_n = \begin{bmatrix} \bar{\mathbf{c}} & & & \\ & \bar{\mathbf{c}} & & \\ & & \ddots & \\ & & & \bar{\mathbf{c}} \end{bmatrix}$$

where $\bar{\mathbf{c}} = \lambda[I_n, \mathbf{0}]$ is the size of $(n+1) \times (n+2)$. The solution of this model is not easy to obtain because of its highly dependent state relation and complicated stationary probability structure resulting ill-conditioned matrices. Due to the nature of the Coxian service, any sub-outflows of c_1 can be considered. With probability $1-q$, the customer leaves the system after two phases of the service time (stage 1). This output flow becomes the input flow of the second stage inspection (service). With probability q, the customer continues to complete the second phase of the service time. However, the service at stage 2 is independently carried out for its security check by each continuing customer which makes the computational procedure intricate and intractable.

To simplify the analysis, we first investigate a stylized one stage queueing model with c_1 servers but of which an additional phase of service rate ν is made similarly as a security check in phase 2. It is certainly an approximation of the proposed model (a multi-server system for both stages).

Once we have our $\mathbf{Q}$ matrix, the next step is to obtain some steady state results. The steady-state probabilities for this queue satisfy $\overline{\pi}\mathbf{Q} = \mathbf{0}$ and $\overline{\pi}\mathbf{1} = 1$, where $\overline{\pi} \geq \overline{0}$ is partitioned into blocks corresponding to the states for 0 customer, 1 customer, 2 customers, ..., etc. That is, $\overline{\pi} = (\overline{P}_0, \overline{P}_1, \overline{P}_2, \ldots)$. Using the block probabilities and the elements of the $\mathbf{Q}$ matrix, we need to find the $\overline{P}_n$'s that satisfy:

$$\overline{P}_0\mathbf{B}_0 + \overline{P}_1\mathbf{A}_1 = \mathbf{0}, \tag{3.1}$$

$$\overline{P}_n\mathbf{C}_n + \overline{P}_{n+1}\mathbf{B}_{n+1} + \overline{P}_{n+2}\mathbf{A}_{n+2} = \mathbf{0}, \quad \text{for } n = 0, 1, \ldots, c-1, \tag{3.2}$$

$$\overline{P}_n\mathbf{C} + \overline{P}_{n+1}\mathbf{B} + \overline{P}_{n+2}\mathbf{A} = \mathbf{0}, \; n = c, c+1, \ldots. \tag{3.3}$$

From (3.3), the matrix geometric procedure gives the vector solution

$$\overline{P}_n = \overline{P}_c \mathbf{R}^{n-c},\ n = c, c+1, \ldots, \tag{3.4}$$

where $\mathbf{R}$ is the matrix solution of the equation

$$\mathbf{C} + \mathbf{R}\mathbf{B} + \mathbf{R}^2\mathbf{A} = \mathbf{0}.$$

Nuets [9] showed that the iteration

$$\mathbf{R}_i = -(\mathbf{C} + \mathbf{R}_{i-1}^2\mathbf{A})\mathbf{B}^{-1},\ i = 1, 2, \ldots,$$

converges to the solution $\mathbf{R}$ starting with $\mathbf{R}_0 = \mathbf{0}$. Using the recurrence relation (3.4) in equations (3.1), (3.2) and the normalization equation $\overline{\pi}\mathbf{1} = 1$, we can determine the steady state probability vector $\overline{\pi}$.

For example, we solve a special case of $c_1 = 2$, i.e., $M/Cox(2)/2$ queueing model for security-check waiting lines. Suppose that customers arrive the system according to a Poisson process with mean arrival rate λ. There are two servers (named server I and server II) in this system, and each one provides a preliminary first phase of the first-stage inspection (Status 1) to all arriving customers. The average service time of first-phase inspection is exponentially distributed with rate μ_1. As soon as the first phase is completed, the customer may be provided with a second-phase service of the first-stage inspection (Status 2) with probability $1-q$ $(0 \le q \le 1)$ or may enter the second stage (Status 3) with probability q. Assuming that the average service rate of the second-phase service is μ_2, and the average service rate of the second-stage inspection is ν. Those service times are mutually independent and follow exponential distributions.

First, we define the system state as (n, i, j), where n represents the number of customers in the system, i represents the status of service in the server I, j represents the status of service in the server II. Then we have the state space

$$\mathbf{S} = \{(n, i, j)|\ n \in \{0\} \cup \mathbb{N},\ i \in \{0, 1, 2, 3\},\ j \in \{0, 1, 2, 3\}\}.$$

Denote $\overline{n}$ as the system state vector, where

$$\begin{aligned}
\overline{0} &= \{(0,0,0)\},\\
\overline{1} &= \{(1,1,0),(1,2,0),(1,3,0),(1,0,1),(1,0,2),(1,0,3)\},\\
\overline{n} &= \{(n,1,1),(n,2,1),(n,3,1),(n,1,2),(n,2,2),(n,3,2),(n,1,3),(n,2,3),(n,3,3)\},
\end{aligned}$$

for $n = 2, 3, \ldots$. The multi-dimensional states $\overline{n}$ correspond to the number of customers in the system, the status of server I and the status of server II.

The infinitesimal generator matrix has the following structure:

$$\mathbf{Q} = \begin{array}{c|cccccccc}
 & \overline{0} & \overline{1} & \overline{2} & \overline{3} & \overline{4} & \overline{5} & \cdots & \cdots \\
\hline
\overline{0} & \mathbf{B}_{00} & \mathbf{C}_{01} & 0 & 0 & \cdots & \cdots & \cdots & \cdots \\
\overline{1} & \mathbf{A}_{10} & \mathbf{B}_{11} & \mathbf{C}_{12} & 0 & 0 & \cdots & \cdots & \cdots \\
\overline{2} & 0 & \mathbf{A}_{21} & \mathbf{B} & \mathbf{C} & 0 & \cdots & \cdots & \cdots \\
\overline{3} & 0 & 0 & \mathbf{A} & \mathbf{B} & \mathbf{C} & 0 & \cdots & \cdots \\
\overline{4} & 0 & 0 & 0 & \mathbf{A} & \mathbf{B} & \mathbf{C} & 0 & \cdots \\
\vdots & & & & \ddots & \ddots & \ddots & \ddots &
\end{array}$$

where those sub-matrices are

$$\mathbf{B}_{00} = [-\lambda],$$

$$\mathbf{C}_{01} = \begin{bmatrix} \frac{\lambda}{2} & 0 & 0 & \frac{\lambda}{2} & 0 & 0 \end{bmatrix},$$

$$\mathbf{A}_{10} = \begin{bmatrix} 0 \\ \mu_2 \\ \nu \\ 0 \\ \mu_2 \\ \nu \end{bmatrix},$$

$$
\mathbf{B}_{11} = \begin{bmatrix}
-(\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 & 0 & 0 & 0 \\
0 & -(\mu_2+\lambda) & 0 & 0 & 0 & 0 \\
0 & 0 & -(\nu+\lambda) & 0 & 0 & 0 \\
0 & 0 & 0 & -(\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 \\
0 & 0 & 0 & 0 & -(\mu_2+\lambda) & 0 \\
0 & 0 & 0 & 0 & 0 & -(\nu+\lambda)
\end{bmatrix},
$$

$$
\mathbf{C}_{12} = \begin{bmatrix}
\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 \\
\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0
\end{bmatrix},
$$

$$
\mathbf{A}_{21} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \mu_2 & 0 & 0 \\
0 & 0 & 0 & \nu & 0 & 0 \\
\mu_2 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_2 & 0 & 0 & \mu_2 & 0 \\
0 & 0 & \mu_2 & 0 & \nu & 0 \\
\nu & 0 & 0 & 0 & 0 & 0 \\
0 & \nu & 0 & 0 & 0 & \mu_2 \\
0 & 0 & \nu & 0 & 0 & \nu
\end{bmatrix},
$$

$$
\mathbf{A} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\nu & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_2 & 0 & \mu_2 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \mu_2 & \nu & 0 & 0 & 0 & 0 & 0 \\
\nu & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \nu & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 \\
0 & 0 & \nu & 0 & 0 & 0 & \nu & 0 & 0
\end{bmatrix},
$$

$$
\mathbf{B} = \begin{bmatrix}
-(2\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 & (1-p)\mu_1 & 0 & 0 & p\mu_1 & 0 & 0 \\
0 & -(\mu_1+\mu_2+\lambda) & 0 & 0 & (1-p)\mu_1 & 0 & 0 & p\mu_1 & 0 \\
0 & 0 & -(\nu+\mu_1+\lambda) & 0 & 0 & (1-p)\mu_1 & 0 & 0 & p\mu_1 \\
0 & 0 & 0 & -(\mu_1+\mu_2+\lambda) & (1-p)\mu_1 & p\mu_1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -(2\mu_2+\lambda) & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -(\nu+\mu_2+\lambda) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -(\nu+\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -(\nu+\mu_2+\lambda) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -(2\nu+\lambda)
\end{bmatrix},
$$

$$
\mathbf{C} = \begin{bmatrix}
\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda
\end{bmatrix}.
$$

4 Anticipated resultants in the first year

4.1 The Matrix Geometric Solution

Once we have our $\mathbf{Q}$ matrix, the next step is to obtain some steady state results. The steady-state probabilities for this queue satisfy $\overline{\pi}\mathbf{Q} = \overline{0}$ and $\overline{\pi}\overline{1} = 1$, where $\overline{\pi} \geq \overline{0}$ is partitioned into blocks corresponding to the states for 0 customer, 1 customer, 2 customers, etc., in the system. That is, $\overline{\pi} = (\overline{P}_0, \overline{P}_1, \overline{P}_2, \ldots)$. Using the block probabilities and the elements of the $\mathbf{Q}$ matrix, we need to find the $\overline{P}_n$'s that satisfy:

$$\overline{P}_0\mathbf{B}_0 + \overline{P}_1\mathbf{A}_{10} = \overline{0} \tag{4.1}$$

$$\overline{P}_0\mathbf{C}_0 + \overline{P}_1\mathbf{B}_{11} + \overline{P}_2\mathbf{A}_2 = \overline{0} \tag{4.2}$$

$$\overline{P}_1\mathbf{C}_1 + \overline{P}_2\mathbf{B} + \overline{P}_3\mathbf{A} = \overline{0} \tag{4.3}$$

$$\overline{P}_{n+2}\mathbf{C} + \overline{P}_{n+3}\mathbf{B} + \overline{P}_{n+4}\mathbf{A} = \overline{0},\ n = 0, 1, 2, \ldots \tag{4.4}$$

From (4.4), the matrix geometric procedure gives the vector solution

$$\overline{P}_n = \overline{P}_2\mathbf{R}^{n-2},\ n = 3, 4, \ldots, \tag{4.5}$$

where $\mathbf{R}$ is the matrix solution of the equation

$$\mathbf{C} + \mathbf{RB} + \mathbf{R}^2\mathbf{A} = \overline{0}.$$

Nuets [9] showed that the iteration

$$\mathbf{R}_i = -(\mathbf{C} + \mathbf{R}_{i-1}^2\mathbf{A})\mathbf{B}^{-1},\ i = 1, 2, \ldots$$

converges to the solution $\mathbf{R}$ starting with $\mathbf{R}_0 = \overline{0}$. Using the recurrence relation (4.5) in equations (4.1), (4.2), (4.3) and the normalization equation $\overline{\pi}\overline{1} = 1$, we can determine the steady state probability vector $\overline{\pi}$.

We will use the first moment of the queue length (or waiting time) of M/G/2 queue to study the performance of stage 1 queue as follows. Since the departure of stage 1 is the arrival to stage 2 queue, we adopt the renewal process approximation (see Whitt 1983) to obtain the LST of the interarrival time for the second stage queue. Our approximation is based on the following assumption: When the server is busy, the departure process is determined by assuming that the service is continuous and no idle period occurs. When the server is idle, the departure process is determined by assuming that the every service is separated by an idle period. Assume that the stage 1 service time follows a Coxian-2 distribution with μ_1 and μ_2 as the parameters of the exponentially distributed phase 1 and phase 2 durations. Let $X(s) = \mu_1/(\mu_1 + s)$ and $Y(s) = [\mu_1/(\mu_1 + s)][\mu_2/(\mu_2 + s)]$. Let $L(2)$ be a random number of customers in the queue where there are 2 servers in the model. By the proposed matrix computation in the project and [**?**], we are able to give an analysis of the stationary probability of $\overline{P}_n,\ n = 0, 1, 2, \cdots$.. It is the work of the proposal to investigate the following two theorems.

Theorem 4.1 *Suppose $W(2)$ is a random variable of waiting time in the queue when there are two servers. There exists a stationary distribution of $Pr\{W(2) < t\}$*

Based on $W(2)$, we may derive the following theorems.

Theorem 4.2 *Given an $\epsilon > 0$, there exists a number N such that $Pr\{L(2) > N\} < \epsilon$*

According to Theorem 4.2, one may choose an optimal N by which when the number customers is no larger than this threshold number, the waiting time of each customer is able to control under 30 minutes with a guaranteed probability. However, it is only for the model $M/Cox(2)/2$. Our goal of this research, by extending the results of Theorems **??**, is to obtain the similar the waiting time distribution and optimal control for performance of $M/Cox(2)/c_1 \to /M/c_2/B$. In other words, the proposed research will focus on analyzing service systems in a stochastic environment with highly complicated matrix. It is obvious that matrix geometric solution plays an essential role to design better systems or systems control policies, e.g. choosing an optimal N. Since N could be used as a signal to guarantee the waiting time for most customers, it is sufficient to apply for $M/Cox(2)/c_1 \to /M/c_2/B$. Moreover, what if the congestion occurs and the number of waiting customers is more than N, is it the moment to add an additional server? To answer this question, it can be accomplished by using queueing models 3 as outlined in this proposal, treating c_1 and c_2 as the control variables. Thus, to continue with Theorems **??** by considering multiple servers in both stages, we need derive the stationary probability by using the matrix geometric solution for 3, which will be carried out to the second year research and investigation of this project.

5 Anticipated resultants in the second year

5.1 Determining the Staffing Level of the Second Stage

Suppose the proportion for the second stage check q_0 and the required mean service time at the second stage is S_0, which are considered as the security level. Given (q_0, S_0) a security level (q_0, S_0), the minimum arrival rate to the second stage is λq_0 and the minimum mean service time is $S_0 = 1/\nu$. Assume that there are c_2 servers in the second stage. We have an $GI/M/c_2$ model with $A(s)$ as the LST of the arrival process. The stationary distribution of the queue length, denoted by m_j, can be obtained as

$$m_j = K r_0^j \quad \text{for } j \geq c_2$$

where r_0 is the root of $A[c_2\nu(1-z)] = z$. The constant K and the m_j $(j = 0, 1, ..., B-c_2)$ must be determined from the normalization condition $\sum_{j=0}^{\infty} q_j = 1$ and the the stationary probability balanced equations, using the transition probability formulas given in 3. A recursive relation for m_j, when $j < c_2$ can be developed as standard results for $GI/M/c$ queue. Suppose that the waiting space for the second stage inspection is limited by size $B-c_2$. Then the tail probability of queue length exceeding N_0 is defined as $\alpha_0 = \sum_{j=N_0+1}^{B-c_2} m_j$. For a given λ, q_0, S_0, there is a minimum requirement $x(\alpha)$ for the system that guarantees the minimum waiting, that is $\lambda q_0 S_0/c_2 < x(\alpha)$ or $c_2 > \lambda q_0 S_0/x$, which gives the range of c_2 for a guaranteed waiting time. We need to find an appropriate initial c_2 such that a feasible range of $q \geq q_0$ and $S \geq S0$ with $\alpha < \alpha_0$ exists. This initial feasible staffing level denoted by c_2^0 can be obtained by numerical search over (q, S) subject to the constraint $\alpha < \alpha_0$. Obviously, the larger the c_2^0, the larger the feasible region of (q, S). Note that as c_2 increases, the feasible region of $\alpha < \alpha_0$ will expand. For a given S, we can determine the maximum feasible $q_m ax$. Thus the feasible q should be in $(q_0, q_{\max})$.

Optimization Problem: The main issue in a two-stage security-check system is to determine the staffing level for a required security check level and the optimal policy parameter to minimize the average customer waiting time. Let $E(W_i)$ be the expected waiting time in stage i queue, where $i = 1, 2$. For a set of feasible $c_2 > c_0^2$ and $S > S_0$, our problem of finding the optimal (c_1, c_2) can be written as

$$\min_{c_1, c_2} E(W) = (1-q)E(W_1) + q[E(W_1) + E(W_2)] = E(W_1) + qE(W_2).$$

Subject to $q_0 < q < q_{\max}$. It is very interesting to see that $E(W_1)$ is determined by μ_1, μ_2, and q, the parameters of the Coxian distribution of service time at Stage 1.

Proposition 1: $E(W_1)$ can be written as

$$E(W_1) = \frac{\frac{\lambda}{\mu_1^2} + (1-q)(\frac{\lambda}{\mu_2^2} + \frac{\lambda}{\mu_1\mu_2})}{1 - \frac{\lambda}{\mu_1} - (1-q)\frac{\lambda}{\mu_2}}.$$

Numerically, we can demonstrate that $E(W)$ is a unimodal function of q with a single minimum. Based on the properties of the system performance measures, we develop a procedure of determining the optimal staffing level (c_1, c_2) and the inspection policy (q). There are two possible cases for the expected waiting time minimization: (Case 1) for a security check feasible case; and (Case 2) for a security check infeasible case.

A Search Procedure for Finding the Optimal Feasible q^*:

Step 1 : For a given traffic demand and a security check requirement (q_0, S_0), find an initial staffing level c_1, c_2 for the security inspection based on the tail probability constraint of $\alpha < \alpha_0$.

Step 2 : Compute $E(W)$ for $q > q_0$. If for $q_2 > q_1$, $E(W(q_2)) < E(W(q_1))$, based on the unimodual property of $E(W)$, it is Case 1. Thus, q is security-check feasible and can be used as the proportion of customers selected for the second stage inspection with the expected waiting time $E(W(q^*))$. Stop, (c_1, c_2, q) is the policy with optimum. Otherwise, it is Case 2, go to the next step.

Step 3 : If $q^* < q_0$, any increase in q will increase $E(W(q))$. This is a case where an increased staffing level with a feasible q^* for the second stage inspection should be considered. For

an increased pair $(\acute{c}_1, \acute{c}_2) > (c_1^0, c_2^0)$ such that q^*, q_0, $E(W(q))$ curve will shift so that the optimal q^* may become feasible. To indicate the dependence on (c_1, c_2), we denote the expected waiting time by $E(W(q)|(c_1, c_2))$.

Theorem 5.1 ***Suppose the waiting cost rate is h_1 and the staffing cost rate is h_2, a policy (c_1^0, c_2^0, q_0) is said to be dominated, if there exits a policy $(\acute{c}_1, \acute{c}_2, q_0^*)$ so that $h_1\{E(W(q_0)|(c_1^0, c_2^0)) - E(W(q^*)|(\acute{c}_1, \acute{c}_2))\} > h_2\{(\acute{c}_1 + \acute{c}_2) - (c_1^0 + c_2^0)\}$.***

Continuing from the previous project, the contribution of this research is twofold: (1) it shall give a more efficient solution approach for certain applications and provide students with capability of queueing analysis and modelling skills; (2) it shall enhance the international collaboration and reputation.

6 International Cooperation

The most practical method of obtaining reasonably accurate results for use in security planning and design for an acceptable wait time in queue, is through computer modeling. Working in international cooperation is important while the results will only be as good and as accurate as the data that was entered into the program to start with. As described, the service time data can have many significant variables and the length of time any given person must wait in the queue line depends upon how many people are ahead of them in that line. One of tasks in the project is to collect data and make observations from the real cases. Although some has been done during the prior collaboration with Prof. Zhang under his project NSERC Number: RGPIN197319 at a border-crossing with security concerns, the new security queue projects, conducting such an investigation of matrix geometric solutions with a more completed system will be substantive. The data must be produced reflecting real situations and experience which should be used in creating the queueing model and probability distributions. A short visit to Prof. Zhang, for the security check at the airport and Canada-USA borders is scheduled during the research project.

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出國報告審核表

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<tr><td>出國人姓名（2 人以上，以 1 人為代表）</td><td>職稱</td><td>服務單位</td></tr>
<tr><td>陸行</td><td>教授</td><td>政治大學應用數學系</td></tr>
<tr><td colspan="2">出國期間：2014 年 8 月 18 日至 2014 年 8 月 21 日</td><td>報告繳交日期：　年　月　日</td></tr>
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行政院科技部補助國內專家學者出席學術會議報告

報告人姓名	陸　　行	服務機構 及職稱	政大應數系教授
時間 會議 地點	Aug. 18-21, 2014 Bellingham，USA	本會核定 補助文號	
會議 名稱	（中文）第九屆國際等候理論與網路應用會議 （英文）9Th International Conference on Queueing Theory and Network Applications		
發表 論文 題目	(中文) (英文)		

一、內容摘要

The 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) 於2014年8月18日至8月21日於美國西華盛頓大學舉行，會議為期4天。

本人是本次會議的論文審查委員。另外，因為會議的主辦人(Professor George Zhe Zhang)是本人專題研究計畫的研究夥伴，因此，參加本次會議的目的有二：

(1) 審查會議論文和安排相關審查與會場議題秩序的工作；

(2) 實地連繫Prfessor Zhang 強化研究成果，同時建立主辦學校與台灣政治大學的合作關係。

本次會議受到主辦學校高度重視，除了副校長致歡迎詞外，院長和系主任全程參與，希望能與臺灣、日本、韓國、中國和其他國家研究等候系統的學者專長們建立合作關係，本人因此特別向院長和副校長表示合作的意願, 以及可以合作的項目。在雙方積極連絡下，西華盛頓大學特別派英語學程的代表Miss Ting Hsien 於九月十一日來政大說明，招幕新生。

二、重要結論或研究成果（中英文論文、期刊、光碟、出版或獲校外研究經費補助）

這次的研討會相當成功，不但認識新的研究議題，更加深國際間的交流和合作。關於研究方面，也有進展，重要結論詳截如論文最後。

附件：

(1) 附研討會議程。

(2) Professor George Zhe Zhang的邀請函如後。

(3) 研究論文。

三、建議

四、相關聯結(活動網頁、與本學術活動有關聯結…)

The 9th International Conference on Queueing Theory and Network Applications (QTNA2014)

Western Washington University, Bellingham, USA

August 18-21, 2014

Edited by

Zhe George Zhang, Western Washington University, USA
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Preface

The 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) is held at Western Washington University in Bellingham, Washington, USA, on August 18-21, 2014. The conference is a continuation of a series of successful conferences: QTNA 2006 (Seoul, Korea), QTNA 2007 (Kobe, Japan), QTNA 2008 (Taipei, Taiwan), QTNA 2009 (Singapore), QTNA 2010 (Beijing, China), QTNA 2011 (Seoul, Korea), QTNA 2012 (Kyoto, Japan), and QTNA 2013 (Taichung, Taiwan). The aim of this series is to bring together international researchers and practitioners to share critical issues in queueing theory and network applications. It is our goal to work together to discover pioneering solutions to these issues. While all previous conferences in this series have been hosted in Asian cities, QTNA 2014 (Bellingham) is the first to be held in America.

All accepted papers will be included in the proceedings in USB. Selected papers from those presented at the conference will be considered for *Journal of Industrial and Management Optimization* (JIMO), *Quality Technology and Quantitative Management* (QTQM) and *International Journal of Operations Research* (IJOR).

We hope that this conference offers an excellent forum to exchange the latest research accomplishments among academia and industries. Furthermore, it is hoped that this conference will cultivate mutual friendship among professionals and researchers from different countries.

We would like to thank the speakers and attendees for making this conference a great success. The conference would not be successful without your support and participation. We would also like to thank the members of the Organizing Committee and the Technical Program Committee for their great support.

George Zhang, Craig Tyran
Co-Chairs
Organizing Committee

Wuyi Yue, Yutaka Takahashi, Hsing Paul Luh, Jau-Chuan Ke
Co-Chairs
Technical Program Committee

Message from Organizing Committee Chairs

On behalf of the organizing committee, we cordially welcome you to the 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) held at Western Washington University in beautiful Bellingham.

QTNA has been firmly supported by leading international researchers in Queueing Theory and Network Applications. This year's QTNA has the first to come from Asia to America. It offers an excellent open forum to exchange the latest research accomplishments among academia and industries, and also to cultivate a mutual friendship among professionals and researchers from the world.

We would like to take this opportunity to thank the following sponsors:
·Center for Operations Research and Management Science (CORMS), Western Washington University, USA
·College of Business and Economics, Western Washington University, USA
·School of Management, Lanzhou University, China

We would like to thank members of Technical Program Committee for their time and dedication to develop this conference program. Many thanks go to all active members of QTNA2014.

Finally, we wish this year's QTNA conference great success and every participant a very enjoyable stay in Bellingham and the State of Washington.

George Zhang (Co-Chair), Western Washington University
Craig Tyran (Co-Chair), Western Washington University

Message from Technical Program Committee Chairs

We welcome everyone to the 9th International Conference on Queueing Theory and Network Applications (QTNA2014). It is very enthusing that many researchers from Asia, Europe, and North America have participated in QTNA 2014. So far about 30 contributions submitted from the USA, Canada, Taiwan, Japan, Korea, China and Europe have been selected to be presented at the QTNA2014 conference. This conference disseminates the latest results in several research fields such as performance modeling and analysis of telecommunication networks, retrial and vacation queueing models, optimization of queueing system, matrix analytic methods, probability generating function method, and other areas such as reliability engineering and supply chain management.

Building upon the success of the previous years, we hope to provide a significant opportunity for researchers of all backgrounds to share their achievements and discoveries, collaborate on studies, and create new friendships to drive the future development of our shared fields.

We would like to acknowledge all the members of the Program Committee of QTNA2014 for their extremely valuable support. We also thank the authors who attend for their excellent technical contributions and new theoretical results.

We express gratitude to the Organizing Committee for their work in organizing this event, Co-Chairs Professor George Zhang and Professor Craig Tyran, and leading members of the organizing committee Professor Jianming Bai, and Ms Racheal Scholler for their hard work throughout the process of planning and putting together the meeting. We hope that this year's conference will be full of new findings and interesting experiences for all involved.

Finally, we hope all the participants enjoy this fascinating and fruitful conference. We wish all the participants enjoy their stay in Bellingham and Washington State.

Wuyi Yue (Co-Chair), Konan University, Japan
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Hsing Paul Luh (Co-Chair), National Chengchi University, Taiwan
Jau-Chuan Ke (Co-Chair), National Taichung University of Science and Technology, Taiwan

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Zhaosong Lu (Simon Fraser University, Canada)

Events

August 18 (Monday)
16:00-18:00 Registration

August 19 (Tuesday)
Registration in Morning Hours
08:30-09:00 Light Breakfast
09:00-09:40 Opening Ceremony and Photo
09:40-10:30 Plenary Speaking
10:30-10:50 Coffee Break
10:50-12:20 Session 1
12:20-13:30 Lunch
13:30-15:30 Session 2
15:30-16:00 Coffee Break
16:00-18:00 Session 3
18:00-20:00 Welcome Dinner

August 20 (Wednesday)
Registration in Morning Hours
08:30-09:00 Light Breakfast
09:00-10:30 Session 4
10:30-11:00 Coffee Break
11:00-12:30 Session 5
12:30-13:30 Lunch
13:30-15:30 Session 6
15:30-16:00 Coffee Break
16:00-17:30 Session 7
18:00-20:30 Banquet and Closing Ceremony

August 21 (Thursday)
09:00-16:00 Meetings of Committees and Discussion about Next QTNA

Conference Venue
Viking Union, Western Washington University

Welcome Dinner
Anthony's Hearthfire Grill

Banquet and Closing Ceremony
Viking Union, Western Washington University

Program Overview

August 19 (Tuesday)	
08:30-09:00	**Light Breakfast**
09:00-09:40	**Opening Ceremony** (Room: VU 462) Dr. Bruce Shepard President of Western Washington University Dr. Craig Dunn Dean of College of Business and Economics **Photo**
09:40-10:30	**Plenary Speaking** (Room: VU 462) Phase-Type Representation, Coxianization, and Majorization Dr. Qi-Ming He, University of Waterloo, Canada
10:30-10:50	**Coffee Break**
10:50-12:20	**Session 1** (Room: VU 567) Breakdown Models
12:20-13:30	**Lunch**
13:30-15:30	**Session 2** (Room: VU 567) Network Models
15:30-16:00	**Coffee Break**
16:00-18:00	**Session 3** (Room: VU 567) Vacation Models
18:00-20:00	**Welcome Dinner**

August 20 (Wednesday)	
08:30-09:00	**Light Breakfast**
09:00-10:30	**Session 4** (Room: VU 567) Optimization
10:30-11:00	**Coffee Break**
11:00-12:30	**Session 5** (Room: VU 567) Reliability Models
12:30-13:30	**Lunch**
13:30-15:30	**Session 6** (Room: VU 567) Queueing Models
15:30-16:00	**Coffee Break**
16:00-17:30	**Session 7** (Room: VU 567) Queueing Applications
18:00-20:30	**Banquet and Closing Ceremony**

August 21 (Thursday)	
09:00-16:00	**Meetings of Committees and Discussion about Next QTNA** (Room: TBA)

August 19 (Tuesday) Morning Sessions

09:00-09:40
Opening Ceremony (Room: VU 462)
Dr. Bruce Shepard, President of Western Washington University, USA
Dr. Craig Dunn, Dean of College of Business and Economics, Western Washington University, USA

Photo

09:40-10:30
Plenary Speaking (Room: VU 462)
Phase-Type Representation, Coxianization, and Majorization
Dr. Qi-Ming He, University of Waterloo, Canada

10:30-10:50
Coffee Break

10:50-12:20
Session 1 Breakdown Models (Room: VU 567)
Session Chair: Yutaka Takahashi

1. Optimal Control of the Machine Repair Problem with Removable Repairman Subject to Working Breakdowns
   Wen-Kuang Chou (Huanghuai University)
   Haitao Wu (Huanghuai University)
   Kuo-Hsiung Wang (Providence University)
   Tseng-Chang Yen (National Chung-Hsiung University)

2. Extended Optimal Replacement Policy for a Two-Unit System under Cumulative Damage Model
   Shey-Huei Sheu (Providence University)
   Tzu-Hsin Liu (Providence University)
   Zhe George Zhang (Western Washington University)

3. Maximum Entropy Analysis to the *N* Policy M/G/1 Queue with Working Breakdowns
   Jia-Yu Chen (National Chung-Hsiung University)
   Kuo-Hsiung Wang (Providence University)
   Shin-Pyng Sheu (National Chung-Hsiung University)
   Wen-Kuang Chou (Providence University)

August 19 (Tuesday) Afternoon Sessions

13:30-15:30
Session 2 Network Models (Room: VU 567)
Session Chair: Hsing Paul Luh

1. Performance Analysis of MAC Protocol of EDCA on Common Channel and Reservation on Service Channels for IEEE 802.11p/1609.4 WAVE
   Bong Dae Choi (Sungkyunkwan University)
   Yun Han Bae (Sangmyung University)
2. Call Blending Retrial Queue with Gated Type Incoming Call Service
   Zsolt Saffer (Budapest University of Technology and Economics)
   Wuyi Yue (Konan University)
3. Performance Analysis of Energy-Saving Server Scheduling Mechanism for Large-scale Data Centers
   Masataka Kato (Kyoto University)
   Hiroyuki Masuyama (Kyoto University)
   Shoji Kasahara (Nara Institute of Science and Technology)
   Yutaka Takahashi (Kyoto University)
4. Performance Analysis of the Gate-Polling Spectrum Access Strategy in Cognitive Radio Networks
   Shunfu Jin (Yanshan University)
   Wuyi Yue (Konan University)
   Zsolt Saffer (Budapest University of Technology and Economics)

15:30-16:00
Coffee Break

16:00-18:00
Session 3 Vacation Models (Room: VU 567)
Session Chair: Jau-Chuan Ke

1. Fluid Model Modulated by an M/M/1 Working Vacation Queue with Negative Customer
   Xiuli Xu (Yanshan University)
   Xianying Wang (Yanshan University)
2. Analysis of Decision-Making Behavior in Geo/G/1 Queues with Vacations
   Jihong Li (Shanxi University)
   Qingqing Ma (Shanxi University)

3. Equilibrium in Vacation Queueing System with Complementary Service
   Yan Ma (Central South University)
   Ben Fu (Simon Fraser University)
   Zaiming Liu (Central South University)
   Zhe George Zhang (Western Washington University, Simon Fraser University)
4. Analysis of an M/M/1 Queue with Vacations and Impatient Time which Depends on the Server's States
   Dequan Yue (Yanshan University)
   Wuyi Yue (Konan University)
   Guoxi Zhao (Yanshan University)

August 20 (Wednesday) Morning Sessions

09:00-10:30
Session 4 Optimization (Room: VU 567)
Session Chair: Zhe George Zhang

1. Supply Chain Cooperative Advertising Based on Advertising Efforts and Price Discount
   Lihong He (Lanzhou University)
   Jianzu Wu (Lanzhou University)
   Zhe George Zhang (Western Washington University, Simon Fraser University)
   Peter Haug (Western Washington University)
2. Resource Renting Problem in Project Scheduling with Self-Owned Resources, Multi-mode, and Penalty for Tardiness
   Guorong Chai (Lanzhou University)
   Yana Su (Lanzhou University, Lanzhou Polytechnic College)
   Shengliang Zong (Lanzhou University)
   Chun Yuan (Lanzhou University)
3. Optimization of Production with Green-Awareness Demands
   Zhaofu Hong (Lanzhou University)

10:30-11:00
Coffee Break

11:00-12:30
Session 5 Reliability Models (Room: VU 567)
Session Chair: Dequan Yue

1. Availability of the Series System with Unreliable Server and Imperfect Coverage
   Ching-Chang Kuo (National Taichung University of Science and Technology)
   Jau-Chuan Ke (National Taichung University of Science and Technology)
   Fu-Min Chang (Chaoyang University of Technology)
2. Availability of Machine Repairing System with Unreliable Server and Switching Failure
   Ching-Chang Kuo (National Taichung University of Science and Technology)
   Jau-Chuan Ke (National Taichung University of Science and Technology)
   Jyh-Bin Ke (National Chung-Hsing University)
3. Analysis of Type III System Model with Failed Service in Star Networks
   Sun Lijun (Qingdao University of Science and Technology)
   Qiao Yongjuan (Qingdao University of Science and Technology)
   Zhao Yue (Qingdao University of Science and Technology)

August 20 (Wednesday) Afternoon Sessions

13:30-15:30
Session 6 Queueing Models (Room: VU 567)
Session Chair: Bong Dae Choi

1. A Composite Priority Queue with Binomial Gated Polling Groups and Priority Groups
   Tetsuji Hirayama (University of Tsukuba)
2. Fluid Vacation Model with Markov Modulated Load and Gated Discipline
   Zsolt Saffer (Budapest University of Technology and Economics)
   Miklós Telek (Budapest University of Technology and Economics)
3. Analysis of the MMPP/G/1/K Queue with a Modified State-Dependent Service Rate
   Doo Il Choi (Halla University)
   Bokeun Kim (Korea Advanced Institute of Science and Technology)
   Dae Eun Lim (Baekseok University)
4. Stochastic Analysis of an Impatient Retrial Queue due to Preemptive Priority
   Shan Gao (Beijing Jiaotong University, Fuyang Normal College)
   Jinting Wang (Beijing Jiaotong University)
   Tien Van Do (Budapest University of Technology and Economics)

15:30-16:00
Coffee Break

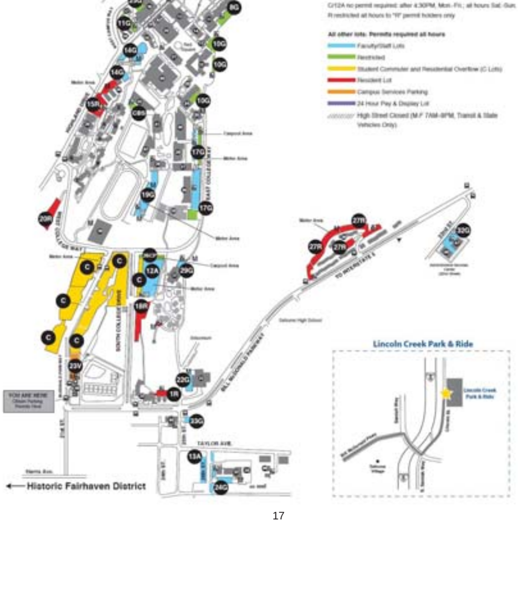
16:00-17:30
Session 7 Queueing Applications (Room: VU 567)
Session Chair: Wuyi Yue

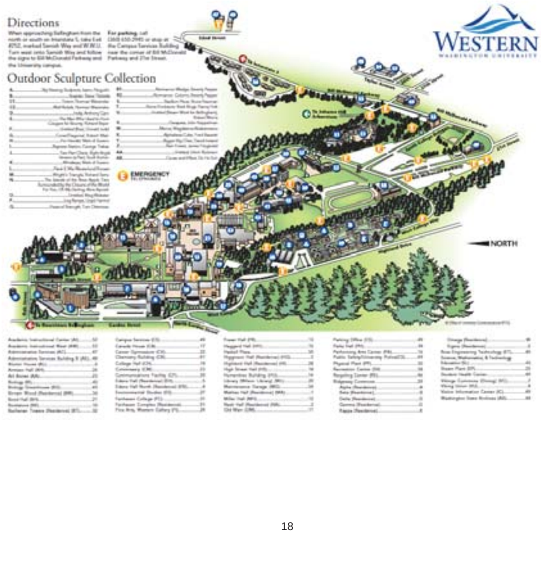
1. An Analysis on the CSAR (Combat Search and Rescue) Operation using Queue with Impatient Customers
   Bong-Kyoo Yoon (Korea National Defense University)
   Sung-Woo Kim (Korea National Defense University)
   Sungjune Park (University of North Carolina at Charlotte)
2. Tail Asymptotics of Heavy-Tailed Random Sums and its Applications to Distributed Server Systems
   Byeongchan Lee (Korea Advanced Institute of Science and Technology)
   Jonghun Yoon (Korea Advanced Institute of Science and Technology)
   Yang Woo Shin (Changwon National University)
   Ganguk Hwang (Korea Advanced Institute of Science and Technology)

3. Game Analysis in a Dual Channels System with Different Power Structures and Service Provision
    Guoxing Zhang (Lanzhou University)
    Shuai Fang (Lanzhou University)

August 21 (Thursday)

09:00-16:00
Meetings of Committees and Discussion about Next QTNA (Room: TBA)





The 9th International Conference on

Queueing Theory and Network Applications

(QTNA 2014)

Western Washington University, Bellingham, WA, USA

August 18-21, 2014

Abstracts

Optimal Control of the Machine Repair Problem with Removable Repairman Subject to Working Breakdowns

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Abstract

This paper deals with a single removable repairman in the machine repair problem with warm standbys and working breakdowns. We assume that the repairman can be subject to working breakdowns only when there is at least one failed machine in the system. Applying the matrix-analytic method, we develop the steady-state probabilities of the number of failed machines in the system as well as several system performance measures. We construct a cost model to compute the optimal threshold N, and the joint optimal values for the fast and slow service rates simultaneously by two-stage optimization method whose effectiveness is proved by numerical results. Moreover, we also analyze the sensitivity with numerical illustration based upon different system parameter values.

Extended Optimal Replacement Policy for a Two-Unit System under Cumulative Damage Model

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Abstract

In this article, we consider a system consisting of two major units (A and B), which is subject to two types of shocks that occur according to a non-homogeneous Poisson process. The probabilities of these two shock types are age-dependent. Each type I shock causes a minor failure of unit A, which also results in an amount of damage to unit B. The damages to unit B are accumulated to trigger a preventive replacement or a corrective replacement action. In addition, a minor failure for unit B with cumulative damage of z will occur with probability $\pi(z)$ at a unit A failure instant. A type II shock is a major one and the system is replaced at its occurrence. We consider a more general replacement policy where the system is replaced at age T, or at the time which the total damage to unit B exceeds a pre-specified level Z (but less than the failure level K) or at any type II shock or when the total damage to unit B exceeding a failure level K, whichever occurs first. The expected cost per unit time is formulated by introducing relative costs.

Maximum Entropy Analysis to the *N* Policy M/G/1 Queue with Working Breakdowns

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Abstract

This paper deals with the N policy M/G/1 queue with working breakdowns. In this queueing system, the steady-state probabilities cannot be derived explicitly. We employ maximum entropy approach with several constraints to develop the approximate formulae for the steady-state probability distributions of queue length and the expected waiting time in the queue. We perform a comparative analysis between the approximate results and established exact results for three different service time distributions, such as exponential, 2-stage Erlang, and deterministic. We demonstrate that the maximum entropy approach is quite accurate for practical purpose and is useful for complex queueing systems solving.

Performance Analysis of MAC Protocol of EDCA on Common Channel and Reservation on Service Channels for IEEE 802.11p/1609.4 WAVE

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Abstract

The IEEE 1609.4 for Wireless Access in Vehicular Environment (WAVE) network is designed to support both safety applications (e.g., emergency service) and non-safety applications (e.g., data service) for Intelligent Transportation System (ITS). The Wave operates on multi-channels consisting of one control channel (CCH) and 6 service channels (SCHs). In this paper, we propose and analyze a MAC protocol consisting of Enhanced Distributed Channel Access (EDCA) on the CCH and reservation on SCHs in IEEE 802.11p/1609.4 WAVE. Specifically, emergency packets and status packets for safety service, and request for service (RFS) packets to reserve a SCH for non-safety service are transmitted on the common channel by contention-based EDCA scheme. Non-safety applications such as information and commercial data file are transmitted on SCHs by contention-free scheme after reserving with RFS packet. We assume that an out-dated safety packet is replaced by the new one and a RFS packet is generated after previous service file is completed successfully. On board unit (OBU) in a vehicle is assumed to have dual radios in order to utilize the full capacity of channels. We assume that only the road-side unit (RSU) sends acknowledgment (ACK) message to the broadcasted packet, to improve the successful delivery probability of safety packets. We present mathematical models of our proposed MAC protocol. From the mathematical model, various performance measures such as successful delivery probability, delay of packet and throughput are obtained. Numerical results show that 98 percent successful delivery probability and less than 100 ms delay of safety packet can be achieved.

Call Blending Retrial Queue with Gated Type Incoming Call Service

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Abstract

In this paper we consider call blending retrial queue with gated type incoming call service. Call blending is a way of mixing incoming and outgoing call activities in call centers, which is applied mainly in order to increase the operator utilization and thus also the overall productivity. The incoming calls waiting in the orbit perform retrial with constant rate. We apply a gated-type balancing mechanism in order to achieve a kind of fairness between the incoming and outgoing calls. The methodology used in this paper differs from the usual ones applied in retrial queue context. This analysis consists of two steps. In the first one steady-state relationships are established among quantities at characteristic embedded epochs. Then they are used for the derivation of the results at arbitrary epoch in the second step. The main results are the probability-generating function and the mean of the number of incoming calls at arbitrary epoch. We also discuss the steps of the numerical solution.

Performance Analysis of Energy-Saving Server Scheduling Mechanism for Large-Scale Data Centers

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Abstract

Large-scale data centers for cloud computing services consist of a number of commodity servers, resulting in a huge amount of power consumption. In order to save this consumption, BEEMR (Berkeley Energy Efficient MapReduce), a MapReduce workload manager, is developed. In a BEEMR-based data center, servers are classified into the interactive and batch zones. Arriving jobs with a small size are immediately processes in the former zone, while large-sized jobs are queued and served simultaneously at every fixed service period in the latter zone. In this paper, we evaluate the effect of BEEMR-type job scheduling on the power consumption. We consider two queueing models for the interactive and batch zones. The interactive zone is modeled as a single-server queueing system with processor-sharing (PS) service. In terms of the batch zone, we consider a queueing system with gated service in which arriving jobs are queued and served at every fixed service period. For these models, the time-average power consumption and the mean response time are derived as the performance measures. Numerical examples show that the power consumption is significantly affected by the number of servers in the batch zone, while the power consumption is insensitive to the length of the batch-service period.

Performance Analysis of the Gate-Polling Spectrum Access Strategy in Cognitive Radio Networks

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Abstract

In this paper, we present a novel centralized spectrum access strategy with a gate-polling mechanism by considering the fairness of spectrum usage. Accordingly, we build a gated vacation queueing model with non-zero switchover procedure and interrupted service. By applying the method of a regeneration cycle, the performance of the proposed spectrum allocation strategy is evaluated analytically, the formulas for the system measures in terms of the delay jitter of the SU packets and the spectrum switching ratio are derived. We also present a method to optimize the arrival rate of the licensed users with a cost function. Numerical results with analysis are provided in order to investigate the system performance on different parameters in cognitive radio networks such as delay jitter of the SU packets, spectrum ratio and optimal cost.

Fluid Model Modulated by an M/M/1 Working Vacation Queue with Negative Customer

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Abstract

This paper investigates a fluid model driven by an M/M/1 queue with working vacations and RCE (Removal of customer in the end) policy of negative customer. In the external environment, the negative customer is not served by the server and only removes the positive customer in the end one-to-one. We establish a fluid flow model based on this stochastic process, and obtain the mean buffer content and the probability of empty buffer for this fluid queue using the LT (Laplace transform) method. Moreover, several special cases of the model here are obtained. Finally, some numerical examples are presented to demonstrate the effects of parameters on the performance indices of the fluid model.

Analysis of Decision-Making Behavior in Geo/G/1 Queues with Vacations

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Abstract

In this paper, the decision-making behavior is introduced into Geo/G/1 queueing models. Starting from the customer to maximize his benefit, the customer optimal behavior in the single-server discrete-time Geo/G/1 queues with generally distributed service and vacation times has been studied. In the unobservable queue, the overall profit function about the individual customer and the whole customers are constructed by a method of mean value analysis, then the customer equilibrium balking strategies and socially optimal balking strategies are analyzed. Further, the almost observable case is considered and equilibrium strategies are determined within the parameters of different ranges. At last, the results are improved by empirical analysis and numerical simulations.

Equilibrium in Vacation Queueing System with Complementary Service

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Abstract

This paper studies a vacation queue where customers need complementary services. The main service provider or the queue server may become absence when the system is empty or adopts multiple vacation policy, which is more common in practice. The secondary service provider offers instantaneous service (no queue). The two services are complementary and a customer has no benefit from obtaining just one of them. We investigate the equilibrium solutions in time-based fee model under competition and monopoly cases, respectively. A flat fee model is also analyzed.

Analysis of an M/M/1 Queue with Vacations and Impatient Time which Depends on the Server's States

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Abstract

In this paper, we consider an M/M/1 queueing system with vacations and impatient customers. Whenever a customer arrives at the system, it activates a random "impatience timer." If the customer's service has not been completed before the customer's impatient timer expires, the customer abandons the queue, and never to return. It is assumed that customers have different impatience timers in server's busy period and server's vacation period. By using the probability generating functions method, we obtain explicit expressions for various performance measures such as the mean system sizes when the server is either on vacation or busy, the proportion of customers served, and the average rate of abandonments due to impatience.

Supply Chain Cooperative Advertising Based on Advertising Efforts and Price Discount

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Abstract

When market demand is sensitive to sales price and the advertising efforts, both manufacturer and retailer in a supply chain system must make decisions on their advertising effort levels and price discount. In this paper, we develop two models to study how to make such decisions. The first one is a non-cooperative Stackelberg advertising model, in which a manufacturer is a Stackelberg leader and the ratailer is a follower and the second one is a Partnership co-operative advertising (PCA) model. The optimal advertising and pricing strategies, such as the levels of national advertising effort and local advertising effort, the share rate of advertising, and the price discount, are theoretically obtained in the two models. The results reveal that the levels of advertising effort by both a manufacturer and retailer in the PCA strategy are greater than those in the Stackelberg equilibrium; the manufacturer provides a higher price discount in the PCA strategy than in Stackelberg equilibrium; thus, the profit of a supply chain using the PCA strategy is greater than that in the Stackelberg equilibrium. Besides, we also find that there is a negative nonlinear correlation between the price discount offered by the manufacturer to customers and the manufacturer's sharing rate for the retailer's local advertising cost. And there is a positive linear correlation between the retailer's advertising cost and the manufacture's one. Specifically, the former is twice as much as the latter. Finally, we examine the Pareto improvement to coordinate the supply chain. It has been found that the Pareto efficient cooperation can be achieved in distributing the supply chain extra profit between the manufacturer and the retailer in the PCA strategy.

Resource Renting Problem in Project Scheduling with Self-Owned Resources, Mmulti-Mode, and Penalty for Tardiness

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Abstract

In this paper, we present a resource renting problem with self-owned resources and penalty for tardiness (RRP-SP) based on the resource renting problem (RRP). In many real-life projects, the contractors only rent bottleneck resources other than their self-owned resources, so we introduce self-owned resources into the RRP. And the clients often set up a tardicost per tardiness from the due date of the project to encourage the contractor to fulfill the project on time, so we permit tardiness with penalty in the model. For more practical significance we divide the object cost into two parts: working cost and renting cost. Then, we give a genetic algorithm for the RRP-SP and test our algorithm by some numerical instances. We also analysis how the project instance itself and rent level affect renting strategy.

Optimization of Production with Green-Awareness Demands

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Abstract

This paper studies the production decision problem of a manufacturer considering green-awareness demands and carbon emission regulations. Carbon emissions generated in production are limited by a mandatory emission cap imposed by governments, under which both regular and green technologies are equipped by the manufacturer to comply emission regulations. Customers in retail markets are heterogeneous and sensitive on the price and the carbon footprint of products. The manufacturer pursues maximal profit by optimizing his decisions on the carbon footprint, the wholesale price, the usage of the technologies and the retailer selection. The problem is formulated as a two-stage Stackelberg game model, where the manufacturer acts as the leader and determines the carbon footprint and the wholesale price while the retailers act as the followers and determine their retail price and the willingness to cooperation. The decision problem is proven to be NP-hard and a hybrid algorithm combining dynamic programming algorithm, analytical method and genetic algorithm is developed to efficiently solve the model.

Availability of the Series System with Unreliable Server and Imperfect Coverage

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Abstract

In this paper, we discuss the steady-state availability of three different series system configurations with unreliable server and imperfect coverage. The primary and standby components are included in each of three different series system configurations, and the repair time of standby components are exponentially distributed with respective parameter and λ , α . When the server goes to repair, it is subjected to active breakdown, and its breakdown time is assumed to have exponential distribution with parameter γ . When the primary components fail, the standby components replace the primary components right away. The switch from standby to active is perfect. The coverage factors for a primary component failure and for a warm standby component failure are assumed to be the same as *c*. The repair time of the failed components and the repair time of the breakdown server are generally distributed. Here we use supplementary variable method and integro-differential equations to obtain the steady-state availability $A(\infty)$ of these three different series system configurations. In the end, we compare the cost/benefit between the three configurations with given to the distribution parameters, and to the cost of the primary and standby components.

Availability of Machine Repairing System with Unreliable Server and Switching Failure

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Abstract

This paper studies the machines' repairing steady-state availability of two different series system configurations with an unreliable server and switching failure. Each of two different series system configurations includes the main and standby components, and the repair time of standby components are exponentially distributed with respective parameter and λ, α. The server subjects to active breakdown when he is repairing. The server's breakdown time is also assumed to have exponential distribution with parameter γ. When the main components fail, the standby components replace the main components successfully with rate 1-*q*. The repair time of the failed components and the repair time of the breakdown server are generally distributed. Further, we use supplementary variable method and integro-differential equations to obtain the steady-state availability $A(\infty)$ of these two different series system configurations. Finally, we compare the cost/benefit between the two configurations with given to the distribution parameters, and to the cost of the primary and standby components.

Analysis of Type III System Model with Failed Service in Star Networks

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Abstract

Contention-Collision Cancellation (C-CC) access control mode is an important access control mode in star network, and it was divided into six system models, whose mathematical modeling have been almost finished for star network with one server. However, due to the difficulty and complexity of the type III system model, its analysis was based on a simplified model, in which all services were considered as successful. In this paper, the complete type III system model under general circumstances, i.e. service failure situation included, is discussed, and the customer state transfer probability, average queue length, and the average service time are given. At last, we evaluate the performance of this system through the numerical calculation. The conclusion not only consummates the mathematical modeling for single-star network, but also provides the overall reliable theoretical foundation to the application of star network.

A Composite Priority Queue with Binomial Gated Polling Groups and Priority Groups

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Abstract

We consider a multiclass queueing system with two categories of customer groups: ordinary and priority. The system has a global priority mechanism where customers in the priority groups can always begin service before customers in the ordinary groups begin. In real communication networks with various classes of traffic, composite scheduling mechanisms are often used that combine priority queueing for important classes and weighted round robin queueing for normal classes. Then we also consider the following composite mechanism in addition to the global priority. Local priority is introduced into the priority groups, and a local polling mechanism is introduced into the ordinary groups where each group is served by a binomial gated discipline, which is a variation of weighted round robin mechanism. We analyze the average sojourn times in the system by the functional computation method (FCM), which we have been developing in order to provide a framework for analysis of various multiclass M/G/1 type queueing systems.

Fluid Vacation Model with Markov Modulated Load and Gated Discipline

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Abstract

In this paper we analyze a fluid vacation model with gated discipline. The fluid source is modulated by a background continuous-time Markov chain. The fluid is removed during the service period by constant rate. We adapt the descendant set approach used in polling models to the continuous fluid model. This enables to establish the steady-state relationship on Laplace transform level among the joint distributions of the fluid level and the state of the modulating Markov chain at end of vacation and at start of vacation. The main results of the paper are the steady-state vector LT and mean of the fluid level at arbitrary epoch in terms of the previously determined quantities at the vacation end and vacation start epochs. We present numerical examples to illustrate the numerical solution.

Analysis of the MMPP/G/1/K Queue with a Modified State-Dependent Service Rate

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Abstract

We analyze an MMPP/G/1/*K* queue with a modified state-dependent service rate. The service time of customers upon service initiation is changed if the number of customers in the system reaches a threshold. Then, the changed service time is continued until the system becomes empty completely, and this process is repeated. We analyze this system using an embedded Markov chain and a supplementary variable method, and present the queue length distributions at a customer's departure epochs and then at an arbitrary time.

Stochastic Analysis of an Impatient Retrial Queue due to Preemptive Priority

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Abstract

This paper deals with a preemptive priority M/G/1 retrial queue with impatient customers. If a new arrival finds the server idle, he begins his service immediately, otherwise, with probability α he will preempt the customer being served to commence his service or with probability $1-\alpha$ join the waiting queue. We assume that the preempted customer may leave the service area with probability p to join a retrial queue and repeats the attempts to get service in random intervals or with probability $1-p$ leaves the system forever (called impatient customer). For classical retrial policy and general retrial policy, by using embedded Markov chain technique and the supplementary variable method, we find the necessary and sufficient condition for the system to be stable and discuss the joint distribution of the server state, the numbers of customers in service area and retrial group in the steady state.

An Analysis on the CSAR (Combat Search and Rescue) Operation using Queue with Impatient Customers

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Abstract

Since pilots are highly valuable asset, it is important to manage CSAR (Combat Search and Rescue) operations in an efficient way. In CSAR operation, key decision variables are the number of rescue teams and the probability that the rescue is successful. Meanwhile, since pilots could leave the place where they sent the distress call or be captured by enemy force, it is imperative to include so called impatient customer phenomena to the model for analyzing CSAR operation. This paper suggests a model to derive key performance measures for CSAR such as the success probability of the rescue operation using queue with impatient customers. In addition, this paper shows that the key performance measures for CSAR could be derived in an easier way by the concept of phase-type distribution.

Tail Asymptotics of Heavy-Tailed Random Sums and its Applications to Distributed Server Systems

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Abstract

The appearance of heavy-tailedness in users' traffic significantly degrades the performance of communication systems, and a distributed server system is considered as a good solution to this problem because of its distributed service characteristic by multiple servers. So we tackle the question in this paper that a distributed server system can alleviate heavy-tailedness, so that users experience good QoS as if there were no heavy-tailedness. To this end, we first mathematically model a distributed server system and obtain a heavy-tailed random sum with the help of the theory of perturbed random walk. We then analyze the tail asymptotic of the heavy-tailed random walk to find a condition with which the distributed server system can alleviate heavy-tailedness.

Game Analysis in a Dual Channels System with Different Power Structures and Service Provision

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Abstract

This paper studies a dual channel supply chain in which a manufacturer sells products to a retailer as well as to customers who are sensitive to both channel price and the retail service. Three game models (Manufacturer Stackelberg, Retailer Stackelberg and Vertical Nash) are built according to members' different bargaining power in a dual channels system. We show that consumers can receive lower channel price and higher retail service level when channel members possess equal bargaining power (e.g. Vertical Nash), however, when the retailer occupies the market leadership (e.g. Retailer Stackelberg), consumers always receive the least welfare because of the higher channel price and lower retailer service. Interestingly, the retailer can take advantage of market leadership to make more profits, while the manufacturer is more willing to give up its power and act as a Stackelberg follower. Furthermore, Manufacturer Stackelberg and Vertical Nash is a strictly dominated strategy for the retailer and the manufacturer respectively.

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July 14, 2014

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Dear Prof. Luh,

I am pleased to invite you cordially of visiting Western Washington University from August 17 to August 23. During your visit, besides your attending QTNA 2014 conference, I expect you to meet some leaders at departmental, college, and university levels to discuss further collaboration between your university and Western Washington University. In addition, we may also discuss the on-going joint research projects while you are at our university.

Please do not hesitate to contact us if you have any queries regarding our invitation. My e-mail address is George.Zhang@wwu.edu.

We are looking forward to meeting you at Western Washington University

Yours Sincerely

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A Computing Approach to Two Competing Services with a Finite Buffer Effect

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Abstract

This paper studies a two-tier service queueing model, where one service provider offers service with unlimited waiting space and the other offers a finite waiting space. Due to the two-dimensional state space, the queueing system is formulated as a state dependent quasi-birth-and-death (QBD) process. For a large size QBD process, it is an important issue to solve the stationary distribution efficiently. Depending on the special structure of the infinitesimal generator matrix, we propose a more efficient and innovative algorithm for computing the stationary distribution. As the buffer size increases, the accuracy and computational efficiency of the proposed **K**-matrix method increases significantly. We draw a conclusion that the proposed approach is a more efficient algorithm than Geometric-Matrix method for solving this two-tier service queueing model, especially when the buffer size is large.

finite buffer queue, two service channels, quasi-birth-death process

1 Introduction

In this paper, we consider a queueing system with two service providers (SP) for customers to select. One SP offers service with unlimited waiting space and the other SP offers guaranteed delay time with a finite waiting space. There are different waiting costs for customers in both lines. We develop a computational model for evaluating the impact of the congestion on the performance measures. Based on customer-choice behavior, we formulate a state dependent quasi-birth-and-death (QBD) process. By exploring the structure of the problem with finite buffer, a new and innovative K-matrix based algorithm is proposed for computing the stationary distribution and related performance measures more efficiently and accurately compared with the classical rate matrix iteration algorithms. The result shows how eigenvalues may take place in this problem for efficient computation and how the finite buffer as a decision variable affects the customer's choice according to the numerical test demonstration.

2 A Two-tier Service Model

Suppose the customers arrive at the system following a Poisson Process with rate λ_{all} and customers' service time follows exponential distributions. Consider a state dependent quasi-birth-and-death (QBD) process where customers' arrival depends on states of the system when it is not congested. Let queue 1 denote the one that offers service without limited waiting space and queue 2 denote the other that offers guaranteed delay time with a finite waiting space, M. Let $X_1(t)$ and $X_2(t)$ be the queue lengths (including the customer in service) of queue 1 and queue 2, respectively. The system state is defined as $(X_1(t), X_2(t))$ on the state space

$$\mathbf{S} = \{(i,j)|\ i = 0, 1, \ldots;\ j = 0, 1, \ldots, M\}.$$

At state (i, j), suppose that a customer chooses queue 1 with a probability results in a state-dependent arrival rate $\lambda_1^{(i,j)}$ while there is an state-dependent arrival rate $\lambda_2^{(i,j)}$ at queue 2. Note that $\lambda_1^{(i,j)} + \lambda_2^{(i,j)} = \lambda_{all}$ for all i, j. In general, we may assume the service rates are different, denoted by μ_1 and μ_2 respectively. The states of the system can be classified into three categories based on the arriving customer's choice behavior: the states in region I are "all join queue 1" states; the states in region II are "join queue 1 or queue

2" states; and the states in region III are "all join queue 2". Based on the classification of the states, we specify the infinitesimal generator matrix $\mathbf{Q}$ for the QBD process as follows:

$$\mathbf{Q} = \begin{bmatrix} \mathbf{C}_{0,0} & \mathbf{A}_{0,1} & & & & & \\ \mathbf{D} & \mathbf{C}_{1,1} & \mathbf{A}_{1,2} & & & & \\ & \mathbf{D} & \mathbf{C}_{2,2} & \mathbf{A}_{2,3} & & & \\ & & \ddots & \ddots & \ddots & & \\ & & & \mathbf{D} & \mathbf{C}_{M,M} & \mathbf{A}_{M,M+1} & \\ & & & & \mathbf{D} & \mathbf{C} & \mathbf{A} \\ & & & & & \ddots & \ddots & \ddots \end{bmatrix},$$

where all elements are $(M+1) \times (M+1)$ matrices. We have

$$\mathbf{C}_{0,0} = \begin{bmatrix} -\lambda_{all} & & & \\ \mu_2 & -(\lambda_{all} + \mu_2) & & \\ & \ddots & \ddots & \\ & & \mu_2 & -(\lambda_{all} + \mu_2) \end{bmatrix},$$

$$\mathbf{A}_{0,1} = \begin{bmatrix} \lambda_{all} & & \\ & \ddots & \\ & & \lambda_{all} \end{bmatrix} = \lambda_{all} I,$$

$$\mathbf{D} = \begin{bmatrix} \mu_1 & & \\ & \ddots & \\ & & \mu_1 \end{bmatrix} = \mu_1 I$$

and

$$\mathbf{A} = \begin{bmatrix} 0 & \cdots & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots \\ \vdots & \cdots & 0 & 0 \\ 0 & \cdots & 0 & \lambda_{all} \end{bmatrix}.$$

For simplicity, let $\Theta = \lambda_{all} + \mu_2 + \mu_1$, we have

$$\mathbf{C} = \begin{bmatrix} -(\mu_1+\lambda_{all}) & \lambda_{all} & 0 & \cdots & \cdots & \cdots & 0 \\ \mu_2 & -\Theta & \lambda_{all} & 0 & \cdots & \cdots & \vdots \\ 0 & \mu_2 & -\Theta & \lambda_{all} & 0 & \cdots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \cdots & 0 & \mu_2 & -\Theta & \lambda_{all} & 0 \\ \vdots & \cdots & \cdots & 0 & \mu_2 & -\Theta & \lambda_{all} \\ 0 & \cdots & \cdots & \cdots & 0 & \mu_2 & -\Theta \end{bmatrix}.$$

In addition, for $i = 1, \ldots, M$, we have $\mathbf{C}_{i,i} =$

$$\begin{bmatrix} -(\mu_1+\lambda_{all}) & \lambda_2^{(i,0)} & 0 & \cdots & \cdots & \cdots & 0 \\ \mu_2 & -\Theta & \lambda_2^{(i,1)} & 0 & \cdots & \cdots & \vdots \\ 0 & \mu_2 & -\Theta & \lambda_2^{(i,2)} & 0 & \cdots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \cdots & 0 & \mu_2 & -\Theta & \lambda_2^{(i,i-2)} & 0 \\ \vdots & \cdots & \cdots & 0 & \mu_2 & -\Theta & \lambda_2^{(i,i-1)} \\ 0 & \cdots & \cdots & \cdots & 0 & \mu_2 & -\Theta \end{bmatrix}$$

and

$$\mathbf{A}_{i,i+1} = \begin{bmatrix} \lambda_1^{(i,0)} & & & & & \\ & \ddots & & & & \\ & & \lambda_1^{(i,i-1)} & & & \\ & & & \lambda_{all} & & \\ & & & & \ddots & \\ & & & & & \lambda_{all} \end{bmatrix}.$$

Under the stability condition, the stationary probability vector is defined as $\boldsymbol{\pi}_n = [\pi_{n0}, \pi_{n1}, ..., \pi_{nM}]$,We know that when $n \geq M$, the matrix geometric solution for such a QBD process is given by

$$\boldsymbol{\pi}_{n+1} = \boldsymbol{\pi}_n \mathbf{R}, \tag{1}$$

where $\mathbf{R}$ is the rate matrix. For $0 \leq n \leq M$, the probability vector $\boldsymbol{\pi}_n$ can be obtained by solving a set of equations.

Proposition 1 *The service system reaches the steady state if*

$$\mu_1 > \frac{\left(1 - \frac{\lambda_{all}}{\mu_2}\right)\left(\frac{\lambda_{all}}{\mu_2}\right)^M \lambda_{all}}{1 - \left(\frac{\lambda_{all}}{\mu_2}\right)^{M+1}}. \tag{2}$$

Note that, when $M \longrightarrow \infty$, the condition (2) is reduced to more intuitive stability conditions.

Corollary 2 *As $M \longrightarrow \infty$, we have*

(i.) the stability condition $\mu_1 > 0$ if $\lambda_{all}/\mu_2 \leq 1$;

(ii.) the stability condition $\mu_1 + \mu_2 > \lambda_{all}$ if $\lambda_{all}/\mu_2 > 1$.

Like any regular QBD process, the rate matrix $\mathbf{R}$ should satisfy $\mathbf{R}^2\mathbf{D} + \mathbf{RC} + \mathbf{A} = \mathbf{0}$ and can be solved by using one of many known algorithms (see Neuts 1981, Bright and Taylor 1995, and Latouche and Ramaswami 1999). From $\boldsymbol{\pi}\mathbf{Q} = \mathbf{0}$ and (1), the state vectors $\boldsymbol{\pi}_0$, $\boldsymbol{\pi}_1$, ..., and $\boldsymbol{\pi}_M$ can be derived from the boundary conditions

$$\boldsymbol{\pi}_0\mathbf{C}_{0,0} + \boldsymbol{\pi}_1\mathbf{D} = \mathbf{0}, \tag{3}$$

$$\boldsymbol{\pi}_0\mathbf{A}_{0,1} + \boldsymbol{\pi}_1\mathbf{C}_{1,1} + \boldsymbol{\pi}_2\mathbf{D} = \mathbf{0}, \tag{4}$$

$$\boldsymbol{\pi}_1\mathbf{A}_{1,2} + \boldsymbol{\pi}_2\mathbf{C}_{2,2} + \boldsymbol{\pi}_3\mathbf{D} = \mathbf{0}, \tag{5}$$

$$\vdots$$

$$\boldsymbol{\pi}_{M-2}\mathbf{A}_{M-2,M-1} + \boldsymbol{\pi}_{M-1}\mathbf{C}_{M-1,M-1} + \boldsymbol{\pi}_M\mathbf{D} = \mathbf{0}, \tag{6}$$

$$\boldsymbol{\pi}_{M-1}\mathbf{A}_{M-1,M} + \boldsymbol{\pi}_M(\mathbf{C}_{M,M} + \mathbf{RD}) = \mathbf{0}, \tag{7}$$

and the normalization condition

$$\boldsymbol{\pi}_0\mathbf{1} + \boldsymbol{\pi}_1\mathbf{1} + \cdots + \boldsymbol{\pi}_M(\mathbf{I} - \mathbf{R})^{-1}\mathbf{1} = 1. \tag{8}$$

After the stationary distribution is computed, we can obtain the major performance measures of the service system. To model a realistic system, M can be quite large and this is particularly true when we analyze a large scale system with heavy traffic intensity. Such a large M results in a large number of boundary states and a large number of phases of the QBD process which greatly increase the computational complexity and may cause the ill-conditioned matrices of the traditional iterative algorithm for the rate matrix. To overcome this challenge, using the special structure of the infinitesimal generator matrix $\mathbf{Q}$, we propose a more efficient and innovative algorithm for computing the stationary distribution. Compared with the traditional matrix geometric solution algorithm, our so-called $\mathbf{K}$-matrix based algorithm is faster, more numerically stable and accurate, and can be applied to solving large scale problems.

3 A Solution Approach

In this section, we develop the $\mathbf{K}$-matrix algorithm to solve the stationary probability $\boldsymbol{\pi}$. We define

$$\mathbf{\Phi} \begin{bmatrix} 0 & \cdots & 0 & \mu_1 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & 0 & \mu_1 \end{bmatrix}$$

and let $\mathbf{K} = -[\mathbf{C} + \mathbf{\Phi}]\mathbf{D}^{-1}$, which is an $(M+1) \times (M+1)$ matrix.

We start to observe its element structure by visualization from a small one. Denote by $\mathbf{K}_m$ a square matrix with m rows and m columns where $1 \leq m \leq (M+1)$. It is easy to check that $\mathbf{K}_3$ and $\mathbf{K}_4$ are expressed respectively, by

$$\mathbf{K}_3 = \begin{bmatrix} \frac{\lambda_{all}+\mu_1}{\mu_1} & \frac{-\lambda_{all}}{\mu_1} & -1 \\ \frac{-\mu_2}{\mu_1} & \frac{\lambda_{all}+\mu_1+\mu_2}{\mu_1} & \frac{-\lambda_{all}-\mu_1}{\mu_1} \\ 0 & \frac{-\mu_2}{\mu_1} & \frac{\lambda_{all}+\mu_2}{\mu_1} \end{bmatrix}$$

and

$$\mathbf{K}_4 = \begin{bmatrix} \frac{\lambda_{all}+\mu_1}{\mu_1} & \frac{-\lambda_{all}}{\mu_1} & 0 & -1 \\ \frac{-\mu_2}{\mu_1} & \frac{\lambda_{all}+\mu_1+\mu_2}{\mu_1} & \frac{-\lambda_{all}}{\mu_1} & -1 \\ 0 & \frac{-\mu_2}{\mu_1} & \frac{\lambda_{all}+\mu_2+\mu_1}{\mu_1} & \frac{-\lambda_{all}-\mu_1}{\mu_1} \\ 0 & 0 & \frac{-\mu_2}{\mu_1} & \frac{\lambda_{all}+\mu_2}{\mu_1} \end{bmatrix}.$$

In order to find an eigenvalue of $\mathbf{K}$ which is located between 0 and 1, we need to consider the determinant of $\mathbf{K}$. Let $\ell(x)$ be the characteristic polynomial defined as $\ell(x)\langle \mathbf{K}-x\mathbf{I}\rangle$ where $\langle\cdot\rangle$ denotes determinant of a matrix and $\mathbf{I}$ is an identity matrix with a proper size. We need to show $\ell(0)\times\ell(1) < 0$ as well as there is one $x \in (0,1)$ such that $\ell(x) = 0$, i.e., $\langle \mathbf{K}\rangle \times \langle \mathbf{K}-\mathbf{I}\rangle < 0$.

Lemma 3 *The eigenvalues of matrix* $\mathbf{K}$ *are positive.*

It suffices to show that $\mathbf{K}$ is positive definite. Note that $\mathbf{K} = -[\mathbf{C}+\mathbf{\Phi}]\mathbf{D}^{-1}$

$$= \begin{bmatrix} \frac{\mu_1+\lambda_{all}}{\mu_1} & \frac{-\lambda_{all}}{\mu_1} & & & -1 \\ \frac{-\mu_2}{\mu_1} & \frac{\mu_1+\mu_2+\lambda_{all}}{\mu_1} & \ddots & & \vdots \\ & \ddots & \ddots & \ddots & -1 \\ & & \ddots & \frac{\mu_1+\mu_2+\lambda_{all}}{\mu_1} & \frac{-\mu_1-\lambda_{all}}{\mu_1} \\ & & & \frac{-\mu_2}{\mu_1} & \frac{\mu_2+\lambda_{all}}{\mu_1} \end{bmatrix}.$$

Since the diagonal entry of $\mathbf{K}$ is positive, we can choose a upper triangular matrix $\mathbf{U}$ and lower triangular matrix $\mathbf{L}$ such that $\mathbf{K} = \mathbf{L} + \mathbf{U}$ and the diagonal entry of $\mathbf{L}$ and $\mathbf{U}$ are positive. Clearly, $\mathbf{L}$ and $\mathbf{U}$ are positive definite because eigenvalue of $\mathbf{L}$ and $\mathbf{U}$ are diagonal entry. Since the addition of two positive define matrix is positive define, it concludes that $\mathbf{K}$ is also positive definite.

Lemma 4 *Under the stability condition, we have* $\ell(1) = \langle \mathbf{K}-\mathbf{I}\rangle < 0$.

It can be derived that $\langle \mathbf{K}-\mathbf{I}\rangle =$

$$\frac{-\mu_1(\lambda_{all}^M + \mu_2\lambda_{all}^{M-1} + \mu_2^2\lambda_{all}^{M-2} + \cdots + \mu_2^M) - \lambda_{all}^{M+1}}{\mu_1^{M+1}}$$

$$= \mu_2^M \times \frac{-\mu_1((\frac{\lambda_{all}}{\mu_2})^M + (\frac{\lambda_{all}}{\mu_2})^{M-1} + \cdots + 1) - (\frac{\lambda_{all}}{\mu_2})^M\lambda_{all}}{\mu_1^{M+1}}$$

$$= \mu_2^M[(\frac{\lambda_{all}}{\mu_2})^M + (\frac{\lambda_{all}}{\mu_2})^{M-1} + (\frac{\lambda_{all}}{\mu_2})^{M-2} + \cdots + 1] \cdot \frac{-[\mu_1 - \frac{(\frac{\lambda_{all}}{\mu_2})^M\lambda_{all}}{(\frac{\lambda_{all}}{\mu_2})^M + (\frac{\lambda_{all}}{\mu_2})^{M-1} + (\frac{\lambda_{all}}{\mu_2})^{M-2} + \cdots + 1)}]}{\mu_1^{M+1}}. \quad (9)$$

By the stability condition

$$\mu_1 > \frac{(\frac{\lambda_{all}}{\mu_2})^M \lambda_{all}}{[(\frac{\lambda_{all}}{\mu_2})^M + (\frac{\lambda_{all}}{\mu_2})^{M-1} + (\frac{\lambda_{all}}{\mu_2})^{M-2} + \cdots + 1]},$$

we know that the second term in (9) is negative but the first term is positive. Hence, their product makes $\langle \mathbf{K} - \mathbf{I} \rangle < 0$.

Consequently, we have $\ell(0)\ell(1) < 0$ and shown that there exists a eigenvalue of $\mathbf{K}$ in (0,1).

3.1 Location of the Eigenvalue

In sequel, we will only illustrate by construction of a Sturm sequence the uniqueness of such an eigenvalue without giving a complete proof since the uniqueness is not necessary when the existence appears critically in our approach. But the illustration shows the usefulness of this approach. First, from Grassman (2002), we know there are distinct $M+1$ positive eigenvalues of $\mathbf{K}$ of the birth-death Markov chain model as μ_1 and μ_2 are strictly positive. Then we shall construct a Sturm sequence to show that a unique eigenvalue between 0 and 1 (Theorem 1 in Grassman 2002). Let real coefficients a, b and c defined as

$$a\frac{\lambda_{all} + \mu_1 + \mu_2}{\mu_1}, \; b\frac{-\lambda_{all}}{\mu_1}, \; c\frac{-\mu_2}{\mu_1},$$

then we have a series of polynomials of x, $\{G_m(x), m = 0, 1, 2, \cdots, M+1\}$, as follows

$$G_0(x) = 1$$

$$G_1(x) = a - x - 1$$

$$G_2(x) = (a-x)(a-x-1) - bc + c$$

$$G_3(x) = (a-x)G_2(x) - bc\, G_1(x) + (-1)c^2 = \langle \mathbf{\Phi}_3 - x\mathbf{I} \rangle,$$

$$\begin{aligned} G_m(x) &= (a-x)G_{m-1}(x) - bc\, G_{m-2}(x) - (-c)^{m-1} \\ &= \langle \mathbf{\Phi}_m - x\mathbf{I} \rangle \end{aligned}$$

for $m = 4, 5, \cdots, M+1$. The last term is

$$G_{M+1}(x) = \langle \mathbf{\Phi}_{M+1} - x\mathbf{I} \rangle + c\langle \mathbf{\Phi}_M - x\mathbf{I} \rangle.$$

Apparently, $G_{M+1}(x) = \ell(x)$ which is the characteristic polynomial of $\mathbf{K}$. Following the Sturm sequence, we count the number of sign changes of the sequence $\{G_m(x), m = 0, 1, 2, \cdots, M+1\}$. For a real number r, define

$$S(r) = \{G_0(r), G_1(r), \cdots, G_{M+1}(r)\}$$

and $s(x)$ the sign changes in $S(x)$. Clearly, the number of sign changes $s(x)$ is 0 if $G_m(x) > 0$ for all m and $s(x) = M + 1$ if the sign changes every time. The value of $s(x)$ cannot change unless there exists a n such that $G_m(x)$ goes through zero meaning $G_{m-1}(x)G_m(x) < 0$.

One of the Sturm properties is that the number of sign changes $s(r)$ in $S(r)$ equals the number of eigenvalues of $\mathbf{K}$ less than r. Thus, if $G_m(x)$ forms a Sturm sequence, the number of roots of $\ell(x)$ in (0, 1) is $s(1) - s(0)$. We already know $s(0) = 0$, since it has been proved that $G_{M+1}(0) > 0$ and $G_m(0) > 0$ for all $m = 1, 2, 3, \cdots, M$.

In order to find a general form of $G_m(x)$, we consider an inhomogeneous second order difference equation, for $m \geq 3$,

$$g_m(x) - (a - x)g_{m-1}(x) + bcg_{m-2}(x) = -(-c)^{m-1},$$

where $g_0(x) = 1$ and $g_1(x) = a - x - 1$. First, we solve the homogeneous second order difference equation, namely, one of the form given above but where the righthand side is zero. In a specific case, when $x = 1$ one solves the following equation

$$y^2 + (b + c)y + bc = 0.$$

Thus, we have

$$y = \frac{-(b + c) \pm |b - c|}{2} = \begin{cases} -c & \text{if } \frac{\lambda_{all}}{\mu_2} = 1 \\ -c, \text{ or } -b & \text{if } \frac{\lambda_{all}}{\mu_2} \neq 1. \end{cases}$$

The particular solution of $g_m(1)$ when $\lambda_{all}/\mu_2 \neq 1$ is

$$g_m(1) = \alpha(-c)^m + \beta(-b)^m + \frac{m(-c)^m}{c - b},$$

where $\alpha = \frac{c^2 - bc - b}{(c-b)^2}$ and $\beta = \frac{b(1-c+b)}{(c-b)^2}$; or, the alternative solution with $b = c$ gives

$$g_m(1) = (\alpha + \beta m)(-c)^m + \frac{m^2(-c)^m}{2c},$$

where $\alpha = 1$ and $\beta = \frac{2c+1}{2c}$.

Lemma 5 *There exists $m_0 > 0$ such that $g_m(1) < 0$ for all $m > m_0$ if $g_{m_0}(1) < 0$.*

It is clear that

$$\begin{aligned} g_{m_0+1} &= \alpha(-c)^{m_0+1} + \beta(-b)^{m_0+1} + \frac{m_0+1}{c-b}(-c)^{m_0+1} \\ &= [\alpha + \beta(\frac{b}{c})^{m_0}(\frac{b}{c}) + \frac{m_0+1}{c-b}](-c)^{m_0+1}. \end{aligned}$$

To prove $g_{m_0+1} < 0$, it shall claim that

$$[\alpha + \beta(\frac{b}{c})^{m_0}(\frac{b}{c}) + \frac{m_0+1}{c-b}] < 0.$$

From $g_{m_0}(1) < 0$, by induction, suppose $k > m_0$ such that

$$\alpha(-c)^k + \beta(-b)^k + \frac{k}{c-b}(-c)^k < 0.$$

Next, we need to prove that

$$[\alpha(-c)^{k+1} + \beta(-b)^{k+1} + \frac{k+1}{c-b}(-c)^{k+1}] < 0.$$

Note that $\beta < 0$ because it can be derived that $\lambda < \mu_c + \mu_f$ implying $(c-b) < 1$.

(Case i.) If $c - b < 0$, then we have $0 < \frac{b}{c} < 1$. It can be derived that

$$[\alpha + \beta(\frac{b}{c})^k(\frac{b}{c}) + \frac{k+1}{c-b}] < 0$$

and

$$[\alpha + \beta(\frac{b}{c})^k + \frac{k}{c-b}] < 0$$

since $(\frac{b}{c}) > 0$. Thus, we have

$$[\alpha + \beta(\frac{b}{c})^k(\frac{b}{c}) + \frac{k+1}{c-b}](-c)^{k+1} < 0.$$

(Case ii.) If $c - b > 0$, then it is clear that $\frac{b}{c} > 1$. Thus, there exists a sufficiently large $m_0 \gg 0$ such that

$$[\alpha + \beta(\frac{b}{c})^{m_0}(\frac{b}{c}) + \frac{m_0+1}{c-b}] < 0.$$

(Case iii.) In case of $b = c$, we consider $\frac{-m_0}{2c}$. There is a sufficiently large $m_0 > 0$ such that $1 < \frac{-m_0}{2c}$ because of the condition $c < 0$. Thus we have $1 < \frac{-m_0}{2c} - \frac{1}{2c}$, which implies for any $m > m_0$, and it provides

$$\begin{aligned}(-c)^m(1+m)(1+\frac{m}{2c}) &= (-c)^m[(1+m)+(1+m)\frac{m}{2c}] \\ &= (-c)^m[1+\beta m+\frac{m^2}{2c}] < 0\end{aligned}$$

Therefore, it proves $(1+\frac{m}{2c}) < 0$ for a large m and $g_m(1) < 0$, for all $m > m_0$.

Proposition 6 *There exists a unique eigenvalue of* $\mathbf{K}$ *between 0 and 1.*

(Case i.) Stating from the case of $b = c$, we compute $G_2(1) = (1+2\beta+2/c) < 0$ and $G_3(1) = (1+3\beta+\frac{9}{2c}) < 0$. Hence we have $G_m(1) < 0$ for all $m > 3$ and

$$\begin{aligned} & \mathbf{K}_{M+1}(1) \\ =\ & G_{M+1}(1) + cG_M(1) \\ =\ & (-c)^{M+1}(2+M)(1+\frac{M+1}{2c}) + c(-c)^M(M+1)(1+\frac{M}{2c}) \\ =\ & (-c)^{M+1}(1+M)(\frac{1}{c}+\frac{1}{M+1}).\end{aligned}$$

We find that $\mathbf{K}_{M+1}(1)$ is negative as M is sufficiently large since c is negative.

(Case ii.) Second, we consider $b \neq c$. It can be derived that

$$\begin{aligned}\mathbf{K}_{M+1}(1) &= G_{M+1}(1) + cG_M(1) \\ &= (-c)^{M+1} + \beta(-b)^{1+M} + (\frac{M+1}{c-b})(-c)^{M+1} \\ &\quad +\alpha c(-c)^M + \beta c(-b)^M + \frac{M}{c-b}(-c)^M c \\ &= (-c)^{M+1}[\beta(\frac{b}{c})^M(\frac{b}{c}-1) + \frac{1}{c-b}].\end{aligned}$$

If $b > c$ then $c - b < 0$ and $0 < b/c < 1$. In this case, the second term in the above equation is negative since $\beta < 0$, which implies $\mathbf{K}_{M+1} < 0$. On the other hand, if $b < c$ then $c - b > 0$ and $b/c > 1$. In this case, it is easy to check that $\mathbf{K}_{M+1} < 0$ when M is sufficiently large.

Consequently, we know that $s(1) = 1$ and $s(1) - s(0) = 1$, By the Sturm theorem, there is only one eigenvalue in $(0, 1)$.

Although the proposition has been proved completely, it is sufficient to provide the stationary probability solution through the existence of a real eigenvalue between 0 and 1. This is because the system is stable, and one can always use the normalization condition to justify the state balance equations with proper parameters at the boundary equations.

3.2 An Efficient Algorithm to Solve $\pi\mathbf{Q} = \mathbf{0}$

Without loss of generality, suppose σ between 0 and 1 is an eigenvalue of $\mathbf{K}$. Set

$$\mathbf{R}' = h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix},$$

where $h = \sigma / v(M+1)$ and $\mathbf{v}^T = (v(1), v(2), \cdots, v(M+1))$. Because of $\mathbf{R}'^2 = \sigma\mathbf{R}' = \mathbf{R}'\mathbf{K}$, it can be derived that $\mathbf{R}'$ is a solution of $\mathbf{A} + X\mathbf{C} + X^2\mathbf{D} = \mathbf{0}$.

Lemma 7 *The matrix $\mathbf{R}'$ is a solution of $\mathbf{A} + X\mathbf{C} + X^2\mathbf{D} = \mathbf{0}$.*

First, it follows that

$$\begin{aligned} \mathbf{R}'^2 &= h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix} \cdot h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix} \\ &= h \begin{bmatrix} \mathbf{0} \\ hv(M+1)\mathbf{v}^T \end{bmatrix} \\ &= hv(M+1)\mathbf{R}' \\ &= \sigma\mathbf{R}'. \end{aligned}$$

Next, we have

$$\begin{aligned} \mathbf{R}'\mathbf{K} &= h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix} (\mathbf{V}^T)^{-1}\mathbf{E}\mathbf{V}^T \\ &= h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix} \sigma(\mathbf{V}^T)^{-1}\mathbf{V}^T \\ &= \sigma\mathbf{R}'. \end{aligned}$$

Thus, we have

$$\mathbf{A} + \mathbf{R}'\mathbf{C} + \mathbf{R}'^2\mathbf{D}$$

$$
\begin{aligned}
&= \mathbf{A} + \mathbf{R}'\mathbf{C} + \mathbf{R}'\mathbf{K}\mathbf{D} \\
&= \mathbf{A} + \mathbf{R}'(\mathbf{C} - (\mathbf{C} + \mathbf{P})\mathbf{D}^{-1}\mathbf{D}) \\
&= \mathbf{A} - \mathbf{R}'\mathbf{P} \\
&= \mathbf{0}.
\end{aligned}
$$

Hence, it can be proved that $\mathbf{R}'$ is the solution of $\mathbf{A} + X\mathbf{C} + X^2\mathbf{D} = \mathbf{0}$.

Assuming π_n approaches to zero as $n \longrightarrow \infty$, it produces

$$
\pi_M \begin{bmatrix} 0 \\ \vdots \\ \lambda_{all} \end{bmatrix} + \pi_{M+1} \begin{bmatrix} -\mu_1 \\ \vdots \\ -\mu_1 \end{bmatrix} = 0. \tag{10}
$$

Substituting π_{M+1} by $\pi_M \mathbf{R}'$, it produces $\lambda_{all} = h\mu_1(\mathbf{v}^T\mathbf{1})$. Since $\mathbf{v}$ is a right eigenvector which can be normalized to 1 we may replace h by λ_{all}/μ_1. Moreover, consider σ is a function of the buffer size of the cost queue, M and denote it by $\sigma(M)$. We have the following proposition to further reduce the computational efforts in calculating the eigenvalue.

Proposition 8 *Under the stability condition, we have*

$$
\sigma(M) = \frac{\lambda_{all}}{\mu_1 + \mu_2} + o(M), \tag{11}
$$

which implies

$$
\lim_{M \to \infty} \sigma(M) = \frac{\lambda_{all}}{\mu_1 + \mu_2}. \tag{12}
$$

When M becomes very large, it will behave like a two-independent $M/M/1$ queues with utilization λ_1/μ_1 and λ_2/μ_2 respectively. In the long-run, it gives $\mu_1/(\mu_1 + \mu_2)$ and $\mu_2/(\mu_1 + \mu_2)$ for individual queues in average at the total service rates. Therefore the eigenvalue of a matrix associated with the QBD process for the system is the traffic intensity, which is

$$
\frac{\lambda_1}{\mu_1} \cdot \frac{\mu_1}{\mu_1 + \mu_2} + \frac{\lambda_2}{\mu_2} \cdot \frac{\mu_2}{\mu_1 + \mu_2} = \frac{\lambda_{all}}{\mu_1 + \mu_2}.
$$

It was easily proved that the traffic intensity is the eigenvalue of an $M/M/1$ QBD matrix. Note that, in general, $\sigma(M)$ closes to the limit when M is more than 10 in our numerical tests.

Let $\boldsymbol{\pi} = (\boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \boldsymbol{\pi}_2, \ldots)$, where

$$\boldsymbol{\pi}_0 = (\boldsymbol{\pi}_0(0), \boldsymbol{\pi}_0(1), \ldots, \boldsymbol{\pi}_0(M)). \tag{13}$$

We define the matrix $\mathbf{T}_i$ as follows

$$\begin{aligned}
\mathbf{T}_0 &= \mathbf{I}, \\
\mathbf{T}_1 &= -\mathbf{C}_{0,0}\mathbf{D}^{-1}, \\
\mathbf{T}_i &= -(\mathbf{T}_{i-2}\mathbf{A}_{i-2,i-1} + \mathbf{T}_{i-1}\mathbf{C}_{i-1,i-1})\mathbf{D}^{-1},
\end{aligned}$$

for $2 \leq i \leq M$.

Proposition 9 *The stationary probability $\boldsymbol{\pi}_0(0)$ satisfies the following two equations:*

(i.) $\boldsymbol{\pi}_0(\mathbf{T}_{M-1}\mathbf{A}_{M-1,M} + \mathbf{T}_M(\mathbf{C} + \mathbf{R}'\mathbf{D})) = \mathbf{0}$, *where*

$$\mathbf{R}' = h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix}, \quad \mathbf{v}^T\mathbf{1} = 1;$$

(ii.)

$$\boldsymbol{\pi}_0 \left[\sum_{i=0}^{M-1} \mathbf{T}_i\mathbf{1} + \mathbf{T}_M \begin{bmatrix} 1 \\ \vdots \\ 1 \\ \bar{h} \end{bmatrix} \right] = 1,$$

where

$$\bar{h} = 1 + \frac{\lambda_{all}}{\mu_1(1-\sigma)}$$

and $\boldsymbol{\pi}_i = \boldsymbol{\pi}_0\mathbf{T}_i$, for $0 \leq i \leq M$.

The original balance equations are

$$\boldsymbol{\pi}_0(0)\mathbf{C}_{00} + \boldsymbol{\pi}_0(1)\mathbf{D} = \mathbf{0}, \tag{14}$$

$$\begin{aligned}
\boldsymbol{\pi}_0(n-1)\mathbf{C}_{n-1,n} + \boldsymbol{\pi}_0(n)\mathbf{C}_{n,n} + \boldsymbol{\pi}_0(n+1)\mathbf{D} = \mathbf{0}, \\
\forall\ 1 \leq n \leq M-2, \qquad (15) \\
\boldsymbol{\pi}_0(M-2)\mathbf{C}_{M-2,M-1} + \boldsymbol{\pi}_0(M-1)\mathbf{C}_{M-1,M-1} + \boldsymbol{\pi}_0(M)\mathbf{D} = \mathbf{0},
\end{aligned}$$

$$\boldsymbol{\pi}_0(M-1)\mathbf{C}_{M-1,M} + \boldsymbol{\pi}_0(M)(\mathbf{C} + \mathbf{R}'\mathbf{D}) = \mathbf{0}, \tag{16}$$

$$\boldsymbol{\pi}\mathbf{1} = 1. \tag{17}$$

Starting from equation (14), and $\mathbf{D} = \mu_1 \mathbf{I}$ being invertible, for $0 \leq n \leq M$, we have $\mathbf{T}_1 = -\mathbf{C}_{00}\mathbf{D}^{-1}$. Thus, repeating it in equation (15) until $n = M-1$ and together with equation (16), it gives

$$\boldsymbol{\pi}_0(0)(\mathbf{T}_{M-1}\mathbf{A}_{M-1,M} + \mathbf{T}_M(\mathbf{C}_{M,M} + \mathbf{R}'\mathbf{D})) = \mathbf{0}.$$

Since

$$(\mathbf{I} - \mathbf{R}')^{-1} = \mathbf{I} + \mathbf{R}' + \mathbf{R}'^2 + \cdots = \mathbf{I} + \frac{\mathbf{R}'}{1-\sigma}$$

equation (17) can be rewritten as

$$\boldsymbol{\pi}_0(0)\left[\sum_{i=0}^{M-1} \mathbf{T}_i \mathbf{1} + \mathbf{T}_M(\mathbf{I} - \mathbf{R}')^{-1}\mathbf{1}\right] = 1$$

which can be further simplified with $\mathbf{R}'$ and $c = \lambda_{all}/\mu_1$. Then we can solve $\boldsymbol{\pi}_0(0)$ with $(M+1)$ unknowns and $(M+1)$ independent equations.

Proposition 10 *The solution vector* $\boldsymbol{\pi} = (\boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \ldots)$ *of* $\boldsymbol{\pi}\mathbf{Q} = \mathbf{0}$ *can be obtained from*

$$\begin{aligned} \boldsymbol{\pi}_0(i) = &\quad \boldsymbol{\pi}_0(0)\mathbf{T}_i, \quad \forall 0 \leq i \leq M, \\ \boldsymbol{\pi}_{M+k} = &\quad \boldsymbol{\pi}_M \sigma^{k-1}\mathbf{R}', \quad \forall 1 \leq k. \end{aligned}$$

An Efficient Algorithm

Step 1. Set $\mathbf{K} = -[\mathbf{C} + \boldsymbol{\Phi}]\mu_1^{-1}$.

Step 2. Find an eigenvalue σ of $\mathbf{K}$ which is less than one, and has a corresponding right eigenvector $\mathbf{v}$, where $\mathbf{v}^T\mathbf{1} = 1$.

Step 3. Define $\mathbf{R}' = h \begin{bmatrix} \mathbf{0} \\ \mathbf{v}^T \end{bmatrix}$, where $h = \lambda_{all}/\mu_1$.

Step 4. Construct matrices $\mathbf{T}_0 = \mathbf{I}$, $\mathbf{T}_1 = -\mathbf{C}_{0,0}\mathbf{D}^{-1}$ and $\mathbf{T}_i = -(\mathbf{T}_{i-2}\mathbf{A}_{i-2,i-1} + \mathbf{T}_{i-1}\mathbf{C}_{i-1,i-1})\mathbf{D}^{-1}$ for $2 \leq i \leq M$.

Step 5. Determine $\boldsymbol{\pi}_0$ by solving

$$\boldsymbol{\pi}_0(\mathbf{T}_{M-1}\mathbf{A}_{M-1,M} + \mathbf{T}_M(\mathbf{C} + \mathbf{R}'\mathbf{D})) = \mathbf{0},$$

$$\boldsymbol{\pi}_0 \left[\sum_{i=0}^{M-1} \mathbf{T}_i \mathbf{1} + \mathbf{T}_M \left[\begin{array}{c} 1 \\ \vdots \\ 1 \\ \bar{h} \end{array} \right] \right] = 1,$$

and $\boldsymbol{\pi}_0(i) = \boldsymbol{\pi}_0(0)\mathbf{T}_i$, for $0 \leq i \leq M$.

Step 6. From $\boldsymbol{\pi}_{M+k} = \boldsymbol{\pi}_M \sigma^{k-1}\mathbf{R}'$, for $k \geq 1$, we obtain $\boldsymbol{\pi} = (\boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \boldsymbol{\pi}_2, \ldots)$.

4 Numerical Illustrations

In this section, we compare the numerical performance under two computing approaches, that is, Matrix-Geometric method versus **K**-matrix based algorithm. We use the computing language MATLAB to develop algorithm and compile these two computing approaches. The numerical experiments are run on the PC platform with Intel(R) Core(TM) i7-3770 CPU @ 3.40 GHz and 32 GB RAM. In the proposed two-tier service queueing model, we take $\lambda_{all} = 1$, $\mu_1 = 0.6$ and $\mu_2 = 0.6$ as an illustrative example. With the stationary distribution $\boldsymbol{\pi} = (\boldsymbol{\pi}_0, \boldsymbol{\pi}_1, \boldsymbol{\pi}_2, \ldots)$, we can determine the expected number of customers in queue 1, L_1, and the expected number of customers in queue 2, L_2.

Table 1 summarizes the numerical results obtained by Matrix-Geometric method and **K**-matrix method as the finite buffer size M varies from 5 to 95. Figure **??** shows the expected numbers of customers in queue 1 and queue 2, L_1 and L_2, individually. It can be found that, while the buffer size M increases, the average system size obtained by Matrix-Geometric method and **K**-matrix method would approach to the same value. Figure **??** compares the CPU time needed by Matrix-Geometric method and **K**-matrix method while solving two-tier service queueing model under the same parameters $\lambda_{all} = 1$, $\mu_1 = 0.6$ and $\mu_2 = 0.6$. We find that **K**-matrix based algorithm can save more CPU time than Matrix-Geometric method. As the buffer size M grows large, it can be observed that the computational efficiency of **K**-matrix based algorithm becomes more significant. Hence, it can be concluded that the **K**-matrix method is a more efficient algorithm than traditional Matrix-Geometric method for solving the proposed two-tier service queueing model.

5 Conclusions

In summary, we draw a conclusion that the **K**-matrix method is a more efficient algorithm than Geometric-Matrix method for solving this two-tier service queueing model, especially when the buffer size is large. As the buffer size M increases, the accuracy and computational efficiency of the **K**-matrix method increases significantly. The proposed approach depends on a right eigenvector and an eigenvalue which is simply $\lambda_{all}/(\mu_1 + \mu_2)$. It is also fairly simple to determine the matrix **K**, which only depends on the right eigenvector but can be determined in exact form. It can be found that, while the buffer size is large enough, the solutions obtained by **K**-matrix method approaches to the same value obtained by Matrix-Geometric method. We find that the computational complexity of **K**-matrix method is comparatively simple and low because it needs to solve the vector $\boldsymbol{\pi}_0$ with $M+1$ variables and the remaining probabilities are attained by substitution. The advantage of this approach is that the cost of computational efforts is not high, comparing with the traditional minimum nonnegative **R** matrix approach.

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Table 1: Numerical results obtained by Matrix-Geometric method and **K**-matrix method with parameters $\lambda_{all} = 1$ and $\mu_1 = \mu_2 = 0.6$.

	Matrix-Geometric Method			**K**-matrix Method		
M	L_1	L_2	CPU Time	L_1	L_2	CPU Time
5	3.6126	2.0068	0.3588	3.9458	2.1157	0.1560
15	3.1416	2.6050	0.7956	3.1848	2.6386	0.7020
25	3.1606	2.6475	2.0904	3.1634	2.6500	0.4212
35	3.1626	2.6501	12.6205	3.1627	2.6502	0.7644
45	3.1627	2.6502	24.8198	3.1627	2.6502	2.0436
55	3.1627	2.6502	42.8535	3.1627	2.6502	3.5256
65	3.1627	2.6502	86.7054	3.1627	2.6502	6.1152
75	3.1627	2.6502	159.7138	3.1627	2.6502	12.4333
85	3.1627	2.6502	305.6372	3.1627	2.6502	23.9306
95	3.1627	2.6502	542.7587	3.1627	2.6502	43.1499

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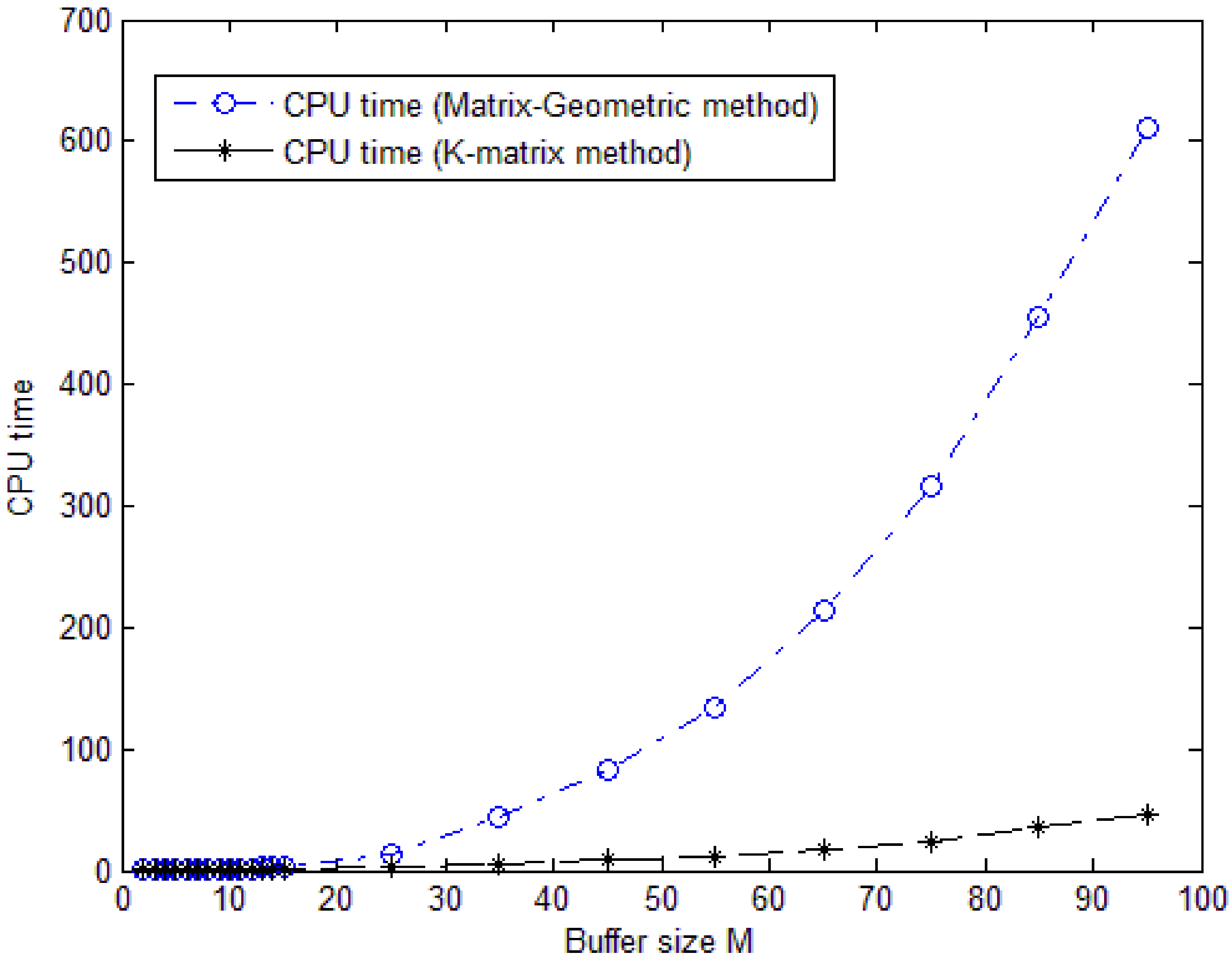
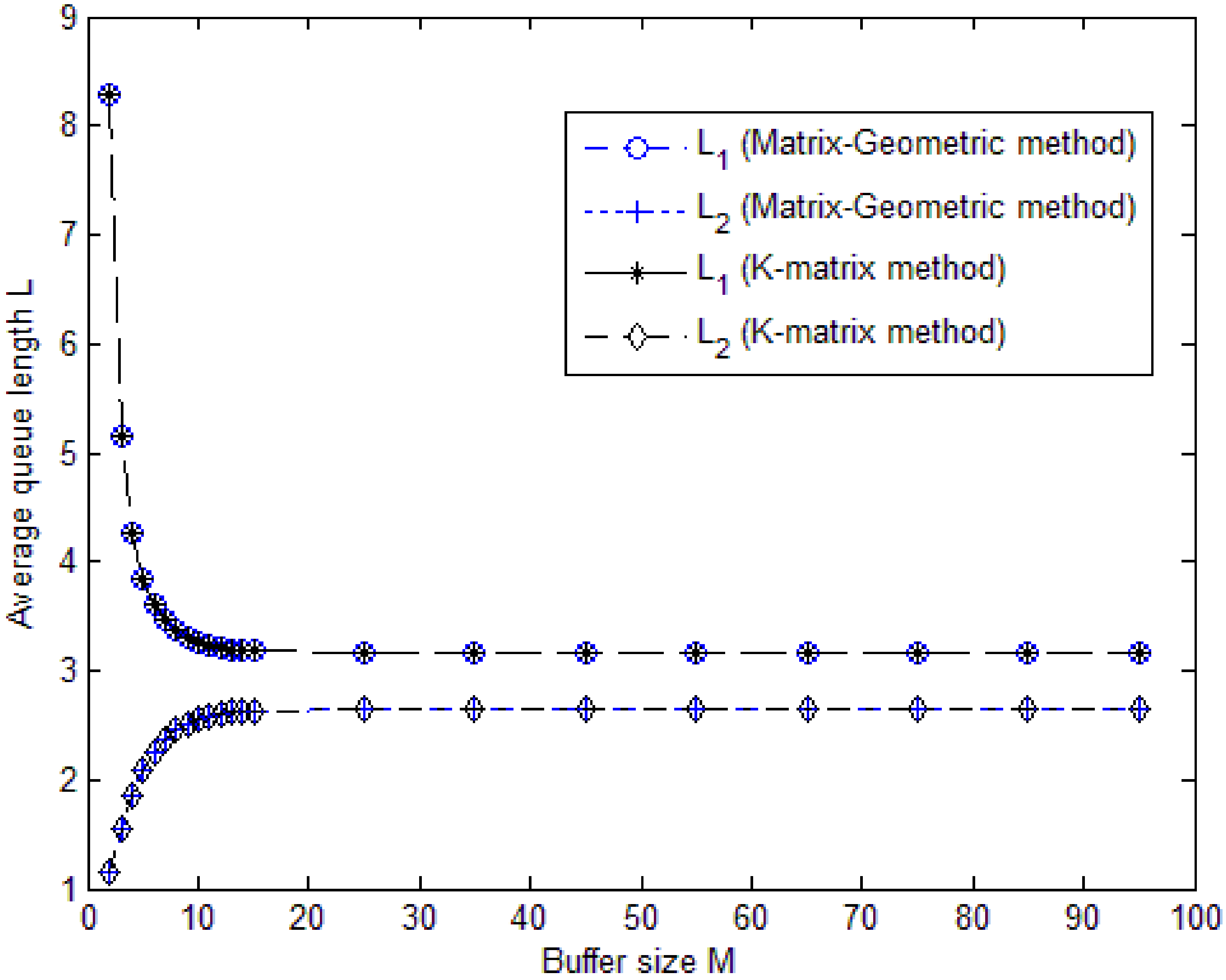
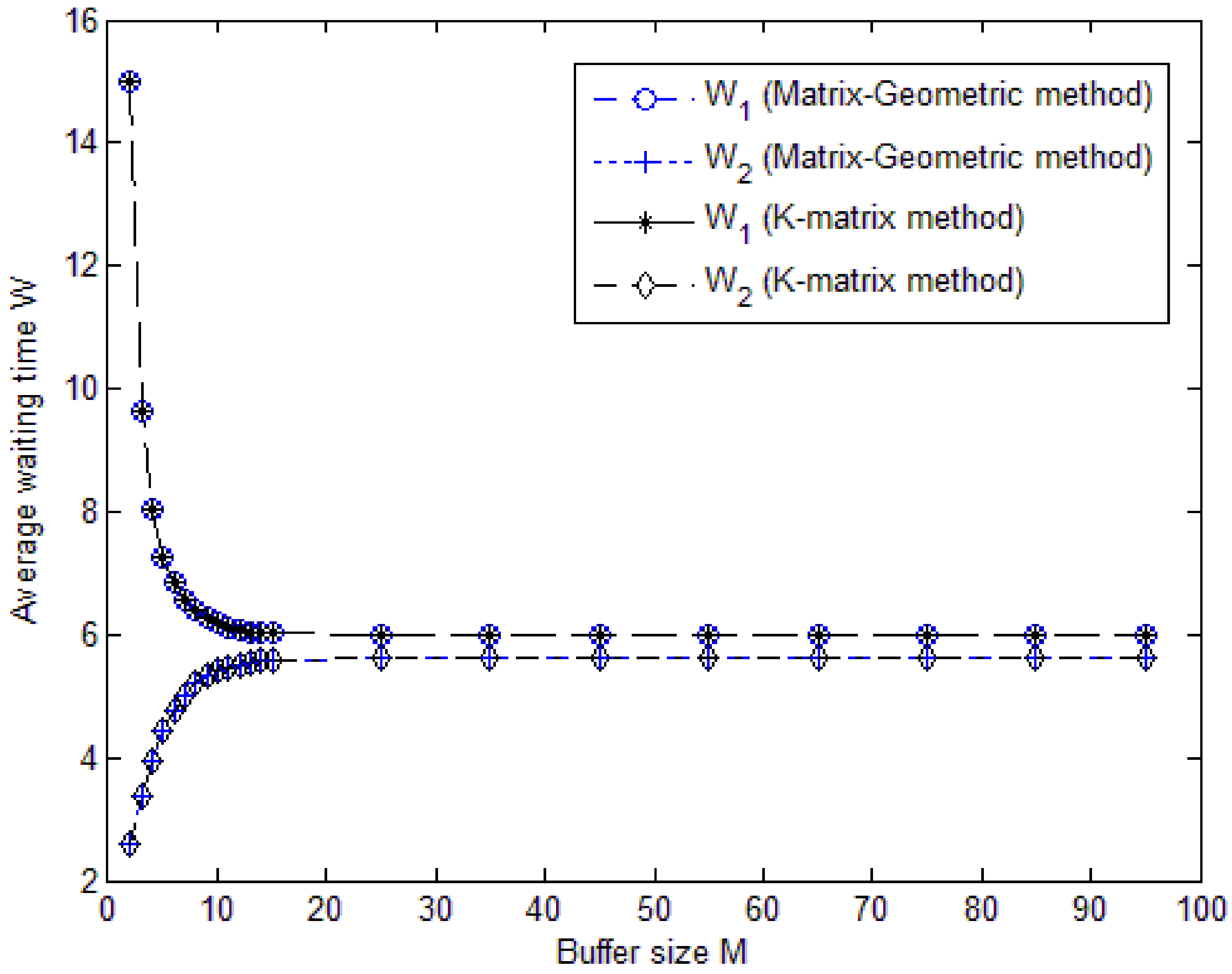
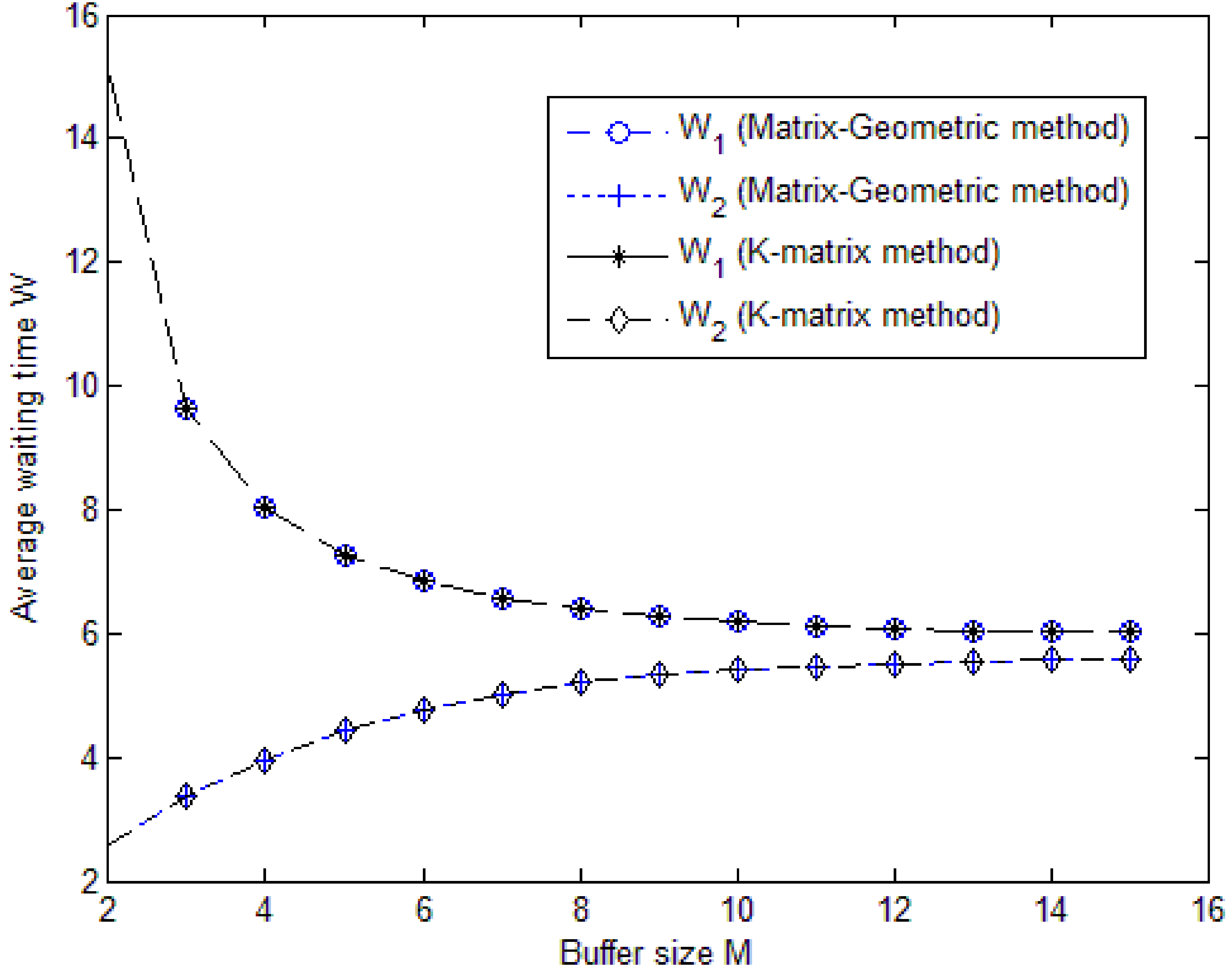

CPU time (Matrix-Geometric method)
CPU time (K-matrix method)
CPU time
Buffer size M
0
100
200
300
400
500
600
700
10
20
30
40
50
60
70
80
90
100



9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
Average queue length L
Buffer size M
L1 (Matrix-Geometric method)
L2 (Matrix-Geometric method)
L1 (K-matrix method)
L2 (K-matrix method)



W1 (Matrix-Geometric method)
W2 (Matrix-Geometric method)
W1 (K-matrix method)
W2 (K-matrix method)
Average waiting time W
Buffer size M
16
14
12
10
8
6
4
2
0
10
20
30
40
50
60
70
80
90
100



W1 (Matrix-Geometric method)
W2 (Matrix-Geometric method)
W1 (K-matrix method)
W2 (K-matrix method)
Average waiting time W
Buffer size M
16
14
12
10
8
6
4
2
2
4
6
8
10
12
14
16

QTNA 2013 TAICHUNG JULY 30~AUGUST 2

The 8th International Conference on Queueing Theory and Network Applications

July 30 August 2, Providence University, Taichung, Taiwan

BEST PAPER AWARD

has been awarded for the paper entitled

A Computing Approach to Two Competing Services with a Finite Buffer Effect

by

Hsing Luh, Zhe George Zhang, Chia-Hung Wang

Organizing Co- Chair, QTNA2013

Dr. Kuo-Hsiung Wang

Dr. Wen-Kuang Chou.

Dr. Hsiao-His Wang

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

102 年　10 月　20 日

報告人姓名	陸行	服務機構及職稱	政治大學應用數學系教授
時間 會議地點	2013/10/6--2013/10/12 Minneapolis, USA	本會核定補助文號	
會議名稱	（中文） （英文）The 2013 INFORMS Annual Conference		
發表論文題目	（中文） （英文）International Journal of Operations Research (IJOR)		

一、　參加會議經過

筆者原打算以研究論文提報與參加此次會議，但因受到 Informs 國際交流委員會主任 Judy Jin 教授的邀請於此會議中報告台灣的學術期刊發展的情形，因此由本人主持一個 session 邀請兩個台灣國際期刊的作者，這兩個期刊是 Journal of Industrial and Production Engineering (JIPE) 和 International Journal of Operations Research(IJOR) 報告研究和發展的情形。

我主持的這個場次在 10 月 7 日包含以下的題目和報告人：

- Title: Planning and Coordination of Scattered Hybrid Renewable Energy Systems. Presenting Author: Kuo-Hao Chang

- Title: On Deploying Vehicles for Public Electrical Scooter Sharing Systems. Presenting Author: I-Lin Wang

- Title: The Dynamic Multi-depot Vehicle Routing Problem with Pick-up and Deliveries. Presenting Author: Yiyo Kuo

- Title: International Journal of Operations Research (IJOR)
Presenting Author: Hsing Luh

- Title: On Attaining the National Universities Commission Academic Staff-mix by Rank via Recruitment Policy in n-Step
Presenting Author: Augustine A. Osagiede

因為 Judy Jin 教授的精心安排，在場人士有廣泛的討論和彼此介紹，IJOR 在 Informs 的會議中獲得與會學者的支持和認可，對於學術交流和台灣的知名度都有良好的影響，大家都覺得很有收獲。

10 月 8 日早上本人代表作業研究學會參加 Informs 的早餐會，藉由這會早餐會與 Informs 其他分會進行交流。在會議中不斷地推銷台灣作業研究學會發展的情形，同時邀請與會的貴賓到台灣進行學術交流。

10 月 8 日中午再次受到 Judy Jin 教授的邀請參加 Informs 國際交流午餐會，除筆者外，王逸琳教授和張國皓教授也受到邀請。我們和多國的代表交換國際交流活動的經驗，以及討論學會的發展和學生交換。也討論到產官學在各國的互動和文化差異。我們也特別邀請 Informs 的專案經理來台灣進行深化的交流，使得台灣作業研究可以與國際接軌，為台灣學術和產業帶來更多的國際機會。

這個會議是超大型的會議有超過 1000 篇的論文發表，專家學者來自世界各地的，如美國、法國、挪威、瑞典、以色列、意大利、韓國、日本、英國。內容包含作業研究的各各子領域，我選了幾個 Keynote speeches，如

- Pavel Kabát, Benefits of Systems Science for Policy Support

- Robert Haight, USDA Forest Service

- Anne Robinson, Advanced Analytics:Empowering Operations Research

- Lawrence M. Wein, Data-Driven Operations Research Analyses in the Public

Sector

- Edelman Reprise, Economically Efficient Standards to Protect the Netherlands Against Flooding
- Mark von Oven, The Physics of the Target Guest
- Dimitris Bertsimas, Health Care Analytics
- Van Hentenryck, Computational Disaster Management: The Role of OR/MS
- Guillermo Gallego, Pricing and Product Design in a Data-Driven Economy

筆者獲得許多寶貴的經驗，對未來的研究和研究議題提供深遠的影響。除了在明尼阿波利斯市參加 Informs 的會議，10 月 10 日早上搭機趕赴西華盛頓大學順道拜訪政大的姐妹校和本人的研究夥伴，討論兩校(系)的合作與學術交流的的工作與推展。

二、 與會心得

這個會議共有 276 個 sessions、超過 10 場 Keynote speeches，參與會議的人數超過 5000 人，是一個超大型的國際會議。筆者原打算以研究論文提報和參加此次會議，但因受到 Informs 國際交流委員會主任 Judy Jin 教授的邀請，於此會議中報告 International Journal of Operations Research 發展的情形。參與後發現許多值得學習的題目和研究方法。同時也可以將筆者過去研究出之評估效能的數學模型方法介紹給相關研究的學者專家。

三、 攜回資料名稱及內容

The 2013 INFORMS Annual Conference **會議手冊**

四、 附錄

會議手冊網址 http://meetings.informs.org/minneapolis2013/pdfs.html

Session Detail Information

Add this session to your itinerary

Cluster : International Activities Committee

Session Information : Tuesday Oct 08, 11:00 - 12:30

Title: International Journal of Operations Research (IJOR) and Journal of Industrial and Production Engineering (JIPE)

Chair: **Hsing Luh**,NCCU, Dept of Math Science, Nat'l Chengchi Uni, No. 64. Shih Nan Road, Wen-Shan District, Taipei 116, Taiwan - ROC, slu@nccu.edu.tw

Co-Chair: **Kuo-Huang Chang**,Assistant Professor, National Tsing Hua University, No. 101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan - ROC, birdhow@gmail.com

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Abstract Details

Title: Planning and Coordination of Scattered Hybrid Renewable Energy Systems

Presenting Author: **Kuo-Hao Chang**,chang@mx.nthu.edu.tw

Abstract: We propose a two-stage stochastic programming model to characterize the planning and coordination of scattered hybrid renewable energy systems when the power demand and renewable power are both uncertain. We further propose an efficient method to solve the model. Some realistic size instances are created to validate the viability of the proposed method in real settings.

Title: On Deploying Vehicles for Public Electrical Scooter Sharing Systems

Presenting Author: **I-Lin Wang**,ilinwang@mail.ncku.edu.tw

Abstract: In places of hot or rainy weather that is not biking friendly, electrical scooters may be better vehicles than bikes for a vehicle sharing system. This paper investigates how to deploy electrical scooters in each rental sites, given the estimated origin-destination demands and rates of battery consumption and charging. A mixed integer programming model will be proposed to calculate the optimal fleet deployment, as well as some interesting findings based on our preliminary computational experiments.

Title: The Dynamic Multi-depot Vehicle Routing Problem with Pick-up and Deliveries

Presenting Author: **Yiyo Kuo**,Ming Chi University of Technology, Industrial Engineering and Management, Tainan 709, Taiwan - ROC, yiyo@mail.mcut.edu.tw

Abstract: This paper considers the multi-depot vehicle routing problem which deals with two kinds of dynamic request. The first one is repair request which there is an urgent broken product need to be sent form the retail store to a depot for repair. All vehicles can provide the service immediately. The second one is sale request which there is a retail store need a product for sale immediately. The product can be sent form a depot to the store only when the vehicles have returned to depot for up load the product. A heuristic is proposed for solving the problem.

Title: International Journal of Operations Research (IJOR)

Presenting Author: **Hsing Luh**,NCCU, Dept of Math Science, Nat'l Chengchi Uni, No. 64. Shih Nan Road, Wen-Shan District, Taipei 116, Taiwan - ROC, slu@nccu.edu.tw

Abstract: : In 2003, the call for papers of first issue of the International Journal of Operations Research (IJOR) was brought out. IJOR reports on developments in Operations Research, Information Systems, and Management Sciences, including the latest research results and applications. Its aim is to meet the needs of accelerating technological change and changes in the global economy. Its abstracting/indexing includes Mathematical Reviews, EBSCOhost, Index of Information Systems Journals, CSA's Technology Research Database, CSA's Engineering Research Database, CSA's Industrial & Manufacturing Engineering Database, Zentralblatt MATH, INSPEC. Until October 2013, it has published about 30 issues. The authors come from more than 30 countries presenting research subjects among academia, government and industries.

Title: On Attaining the National Universities Commission Academic Staff-mix by Rank via Recruitment Policy in n-Step

Presenting Author: **Augustine A. Osagiede**,University of Benin, Benin City, Nigeria,

Co-Author: **Virtue U. Ekhosuehi**,University of Benin, Benin City, Nigeria, virtue.ekhosuehi@uniben.edu

Wilfred A. Iguodala,University of Benin, Benin City, Nigeria,

Abstract: We consider the unique specification of academic staff-mix by rank of the National Universities Commission (NUC) for Nigerian universities. We formulate a model consisting of systems of aggregate-fractional flow balance equations within a discrete-time Markov chain framework for each

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

102 年 07 月 04 日

報告人姓名	陸行	服務機構及職稱	政治大學應用數學系
時間 會議地點	102/06/24-102/06/26 Chicago, USA	本會核定補助文號	
會議名稱	（中文） （英文）INFORMS Healthcare 2013		
發表論文題目	（中文） （英文）**Whole Disease Modeling to Aid Survival Analysis -- An Example of Computing Approach on Chronic Hepatitis B Virus Infection**		

一、 參加會議經過

「INFORMS Healthcare 2013」是由美國作業研究與管理科學學會暨西北大學在芝加哥舉辦的會議。會議的主辦人是西北大學的 Sanjay Mehrotra 教授。會議在該市鬧區的 Marriott Hotel 舉行。自 2013 年 6 月 23 日至 6 月 26 日舉行，為期四天。含下列議題

- Healthcare, Analytics
- Healthcare, Case Studies
- Healthcare, Data Mining and Machine Learning
- Healthcare, Data Driven Modeling
- Healthcare, Stochastic Modeling
- Healthcare, Medical Decision Making
- Healthcare, Informatics
- Healthcare, Insurance
- Healthcare, Operations
- Healthcare, Quality

- Healthcare, Policy
- Healthcare, Process Engineering
- Product Design/ Design for Manufacture/ Assembly (DFM/DFA)
- Product Development
- Quality Control
- Healthcare, Simulation
- Healthcare, Optimization
- Healthcare, Systems Engineering
- Healthcare, Infectious Diseases
- Healthcare, Community and Public Health
- Healthcare, Global Health
- Health Care, Therapy and Treatment Delivery
- Health Care, Finance
- Health Care, Marketing

筆者是「Medical Decision Making II」的主持人。這個場次一共有四篇論文發表，包括: Enhanced Optimization Tools for Kidney Exchange Programs，A Hindsight Cut-off Boundary for Metabolic Syndrome Criteria，A Multi-State Disease Progression Model of Type 2 Diabetes Mellitus，和 Whole Disease Modeling to Aid Survival Analysis on Chronic Hepatitis B Virus Infection，筆者也是第四篇論文的報告人。其中第二篇、第三篇作者是來自台灣，他們分別是中原大學的陳慧芬教授和政大的陳政輝教授。

筆者向與會的學者特別介紹所謂「Whole disease system modeling」的觀念和一些研究方法。以數學模型和作業研究優化的手法描述病程所帶來的影響是新興的研究議題，在會場中引起許多針鋒相對的討論。除此之外，筆者也參加其他的場次，聽取其他專家學者的報告，於會場和多位學者談論相關的研究議題。但在其他會場中未再遇見其他的台灣學者。

大會特別安排小組討論，於午餐時間，由波士頓來的 Arnold Kamis 教授主持。會中有美國、日本、韓國和香港的學者分享研究經驗，研究方法和如何克服困難。是場別開生面，不同於一般大型學術研討論，非常有意義的活動。在近距離而且非正式的情形下，確實可以交換一些私人經驗，建立良好的互動。經過進一步的討論，筆者獲得許多寶貴的經驗，對未來的研究和研究議題提供深遠的影響。。

二、 會後心得與行程

因為「Whole disease system modeling」於決策模型上還是相當新而且有挑戰性的觀念和作為。因此於會後，筆者專程前往匹茲堡大學工業工

程研究所和公共衛生學院拜訪 Mark Roberts 教授和 Jagpreet Chhatwal 教授。主要的目的是請兩位學者在這方面的意見。因為他們有事無法參加芝加哥的研討會但都長期耕耘於這個領域，對於我的造訪，表示熱忱歡迎而且特別抽出兩天的時間與我密緊地討論。筆者過去研究出之評估效能的數學模型方法介紹給他們，他們提出非常嚴格但不失建設性的意見。希望能藉此運用數學模型解決他們在研究上遭遇的問題。

這個會議進行得非常順暢，認識一些新的研究議題，也知道美國社克和新加坡國立大學(DUKE & NUS)合作設立的 Health Service & Systems Research 研究所也在從事相關的研究課題。整體而言，是一次相當成功的會議經驗。

現在所有的會議資料都在網站上
http://meetings.informs.org/healthcare2013/program.html

各論文發表場次則於 Search the Program

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Session Detail Information

Add this session to your itinerary

Cluster : Contributed

Session Information : Tuesday Jun 25, 13:30 - 15:00

Title: Medical Decision Making II
Chair: **Hsing Luh**,Professor, National Chengchi University, Department of Mathematical Sciences, NO.64,Sec.2,ZhiNan Rd.,Wenshan District, Taipei, Taiwan - ROC, slu@nccu.edu.tw

Abstract Details

Title: Enhanced Optimization Tools for Kidney Exchange Programs

Presenting Author: **Ana Viana**,INESC TEC/ISEP.IPP, Campus da FEUP, Rua Dr Roberto Frias, Porto, Portugal, aviana@inescporto.pt
Co-Author: **Filipe Alvelos**,University of Minho, Campus de Gualtar, Braga, Portugal, falvelos@dps.uminho.pt
Miguel Constantino,University of Lisbon, Faculty of Science, Lisbon, Portugal, mfconstantino@fc.ul.pt
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João Pedro Pedroso,University of Porto/INESC TEC, Faculty of Science, Porto, Portugal, jpp@dcc.fc.up.pt
Abdur Rais,University of Minho, Campus de Gualtar, Braga, Portugal, abdur.rais@gmail.com
Nicolau Santos,INESC TEC, Campus da FEUP, Rua Dr Roberto Frias, Porto, Portugal, nicolau.f.santos@inescporto.pt
Paolo Tubertini,University of Bologna, Bologna, Bologna, Italy, paolo.tubertini@unibo.it

Abstract: This presentation updates current work and optimization tools being developed under a project funded by the Portuguese Foundation for Science and Technology. The project aims at tackling certain optimization problems that typically arise in kidney exchange programs. The tools developed in this project directly supports the Portuguese Institute for Blood and Transplantation Services.

Title: A Hindsight Cut-off Boundary for Metabolic Syndrome Criteria

Presenting Author: **Huifen Chen**,Professor, Chung-Yuan University, Industrial and Systems Engineering Dept., 200 Chung-Pei Road, Chung-Li, Taiwan - ROC, huifen@cycu.edu.tw
Co-Author: **Tien-Mu Hsiao**,Doctor, Taiwan Landseed Hospital, Department of Family Medicine, NO.77, Kwang-Tai Rd, Ping-jen, Taiwan - ROC, hsiaotm@landseed.com.tw
Hui -Hon Lin,Chung-Yuan University, Department of Applied Mathematics, 200 Chung-Pei Road, Chung-Li, Taiwan - ROC, distopia1984@gmail.com
Chien-Hua Wu,Professor, Chung-Yuan University, Department of Applied Mathematics, 200 Chung-Pei Road, Chung-Li, Taiwan - ROC, cwu@cycu.edu.tw

Abstract: Metabolic syndrome (MetS) is defined by a set of interrelated factors that increase the risk of stroke and diabetes mellitus (DM). Despite several different definitions of MetS that exist, definitions to better identify patients at risk are still needed. We construct an ellipsoid cut-off boundary for MetS criteria, whose size depends on hindsight data. Using data from Taiwan Landseed Hospital, we compare this hindsight boundary with the 2001 NCEP and 2009 consensus definition (IDF and AHA/NHLBI). Our results show that the hindsight boundary provides a plausible odds ratio between MetS and stroke/DM.

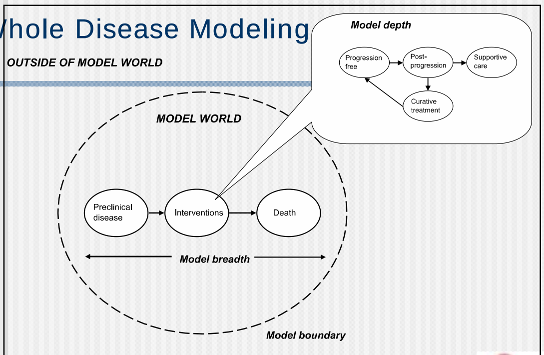
Whole Disease Modeling to Aid Survival Analysis on Chronic Hepatitis B Virus Infection

Hsing Paul Luh, Jenghuei Chen, Shin-Yu Chen
Dept. of Mathematical Sciences
Center for Computational Research and Applications
National Chengchi University
Taipei, Taiwan

Outline

- Whole Disease Modeling
- Why and how Operations Research can help?
- An Example of Chronic Hepatitis B Virus infection cases in Taiwan

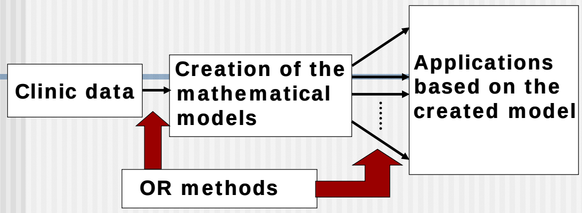
Whole Disease Modeling



(Tappenden et al. 2012)

Fig. 2 – Relationship between model boundary, breadth, and depth.

An example: Chronic diseases



- Clinic data are transformed into mathematical models base on statistical and optimization methods.
- The created models can be further used to study related problems formulated as statistical and optimization problems.

Taxonomy of model structure

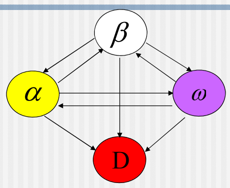
			A	B	C	D
			Cohort/Aggregate Level Counts		Individual Level	
			Expected value, Continuous state, Deterministic	Markovian, Discrete State, Stochastic	Markovian, Discrete State, Individuals	Non-Markovian, Discrete State, Individuals
1	No Interaction Allowed	Untimed	Decision Tree Rollback	Simulated Decision Tree (SDT)	Individual Sampling Model (ISM): Simulated Patient-Level Decision Tree (SPLDT)	
2		Timed	Markov Model (Evaluated Deterministically)	Simulated Markov Model (SMM)	Individual Sampling Model (ISM): Simulated Patient-Level Markov Model (SPLMM) (variations as in quadrant below for patient level models with interaction)	
3	Interaction Allowed	Discrete Time	System Dynamics (Finite Difference Equations, FDE)	Discrete Time Markov Chain Model (DTMC)	Discrete-Time Individual Event History Model (DT, IEH)	Discrete Individual Simulation (DT, DES)
4		Continuous Time	System Dynamics (Ordinary Differential Equations, ODE)	Continuous Time Markov Chain Model (CTMC)	Continuous Time Individual Event History Model (CT, IEH)	Discrete Event Simulation (CT, DES)

back

Why and how Operations Research can help?

- A frequently adopted model is the "multi-state" model due to its simplicity and sufficient accuracy.
- O.R. (statistics or optimization) can be applied to obtain the required information in the model.
- The model can be used to simulate the progression of the target disease and to study related problems under the O.R. framework.

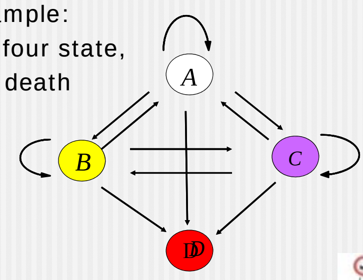
The Multi-state Models



- There are two components in this model: (1) states and (2) state transitions.

The Model of Markov Chain

- For example: We have four state, D means death



Two components in the Multi-state models-(1)

- The states α β ω D

They may denote the appearance of some symptoms or important laboratory marker measurements such as CD4 counts in AIDS. Each state indicates one healthy status of patients. Usually, these states will be specified by medical specialists based on clinic observations.

Two components in the Multi-state models-(2)

- State Transitions (e.g. α → β)

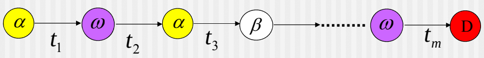
In the multi-state model, an arrow is used to indicate the change of healthy status in the specified direction.

Usually, this signals the significant progression of the chronic disease.

From mathematical viewpoints, the transitions between two different states are governed by certain rules. These rules can be established based on clinic data.

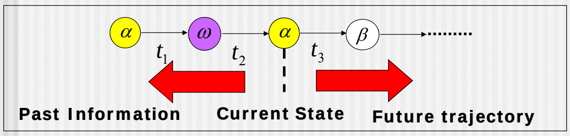
How this model works?

- A possible trajectory



A sequence of healthy statuses that a patient may experience chronically is denoted as a trajectory. This patient is initially with status α. After t_1 time units, his health status changes from ω to t_2 After time units, his status changes again from ω to α. This process terminates when the patient reaches a critical medical situation of death denoted as D.

Create Models (1) : A Semi-Markov example



$S = \{\alpha, \beta, \omega, D\}$

X_k : k^{th} state

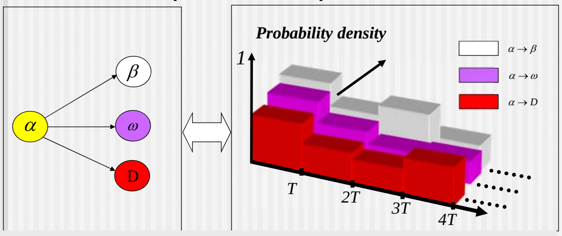
T_k : time at k^{th} transition

$\forall i, j \in S$ and $t \in [0, \infty)$, Kernel $K_{i,j}(t)$ satisfies

$$K_{i,j}(t) = P\{X_{k+1} = j, T_{k+1} - T_k \le t \mid X_0, \ldots X_k, T_0, \ldots T_k\}$$
$$= P\{X_{k+1} = j, T_{k+1} - T_k \le t \mid X_k = i\}$$

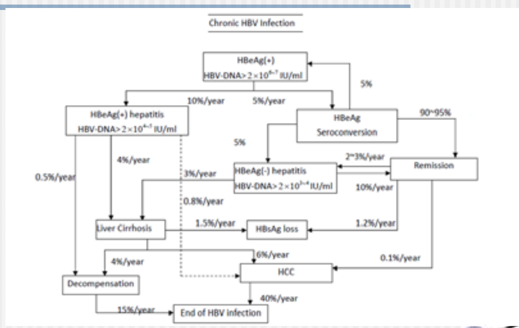
Create models (2) ----- A Semi-Markov example

Given the current state, the future trajectory is independent of the past information.



With a current state, we need to know the probability distribution of its next state and time to reach the next state.

HBV Disease Progression of Natural History



Remaining Life Year Table in Taiwan

年齡 Age t	生存數 l_t	死亡數 d_t	生存機率 ρ_t	死亡機率 σ_t	L_t	定常人口 T_t	$\mathring{e}_t$
0	100000	596	0.99404	0.00596	99513	7648688	76.69
1	99404	78	0.99922	0.00078	99365	7549176	75.94
2	99326	55	0.99945	0.00055	99299	7449810	75.00
3	99271	39	0.99961	0.00039	99252	7350512	74.04
4	99232	30	0.99970	0.00030	99217	7251260	73.07
5	99202	25	0.99974	0.00026	99190	7152043	72.10
6	99177	24	0.99976	0.00024	99165	7052853	71.11
7	99153	23	0.99977	0.00023	99142	6953688	70.13
8	99130	22	0.99978	0.00022	99119	6854546	69.15
9	99108	20	0.99980	0.00020	99098	6755427	68.16
10	99088	20	0.99980	0.00020	99078	6656329	67.18
11	99068	20	0.99980	0.00020	99058	6557250	66.29
12	99048	22	0.99978	0.00022	99037	6458192	65.20
13	99026	26	0.99974	0.00026	99013	6359155	64.22
14	99000	34	0.99966	0.00034	98984	6260142	63.23
15	98967	45	0.99954	0.00046	98944	6161158	62.25
16	98922	58	0.99941	0.00059	98893	6062214	61.28
17	98864	69	0.99931	0.00069	98829	5963321	60.32

Some Denotations

- *A*:The annual rate matrix of the disease, where A_{ij} means the probability from state *i* to state *j*.
- $L_{s,s+1}$:The probability that a person will survive the next one year when he or she is at the age of s.

The Revised Probability Matrix

- $P_{s,s+1}$ is a $n \times n$ transition probability matrix meaning a person at age s will be in some states or death at age $s+1$,with $P_{s,s+1}(i,j)$:

$$P_{s,s+1}(i,j) = A_{ij} \times L_{s,s} \text{ , } \forall\ 1 \le i,j \le n-1 \text{ , } s \in \{0,1,\dots,100\}$$

$$P_{s,s+1}(i,j) = A_{ij} \times L_{s,s} + 1 - L_{s,s} \text{ , } \forall\ 1 \le i \le n-1 \ \&\ j=n \text{ , } s \in \{0,1,\dots,100\}$$

$$P_{s,s+1}(i,j) = 0 \text{ , } i=n \ \&\ 1 \le j \le n-1 \text{ , } s \in \{0,1,\dots,100\}$$

$$P_{s,s+1}(i,j) = 1 \text{ , } i=j=n \text{ , } s \in \{0,1,\dots,100\}$$

The Proposed Method

- Let $P_{s,s+k} = \prod_{n=1}^{k} P_{s+(n-1),s+n}$, then $P_{s,s+k}(i,j)$ means that a person is at state i when he or she is at the age of s and he or she will be in state j when aged $s+k$ after k years.
- Then we consider the first hitting time,

$$P_{ij}^{(n)} = f_{ij}^{(n)} + \sum_{k=1}^{n-1} f_{ij}^{k} P_{jj}^{n-k}$$

The demonstration of the risk of a patient at age 25 with HBV infection

State j	Probability $\omega_{1,j}(15)\|_{25}$	Interpretation
Seroconversion Remission	27.56%	This patient has 27.56% probability of reaching seroconversion and remission within 15 years.
Decompensation	5.22%	This patient has 5.22% probability of reaching decompensation within 15 years.
Liver cirrhosis	19.18%	This patient has 19.18% probability of reaching liver cirrhosis within 15 years.
HBsAg loss	5.22%	This patient has 5.22% probability of reaching HBsAg loss within 15 years.
HCC	8.28%	This patient has 8.28% probability of reaching HCC within 15 years.
Death/Transplantation (End of HBV infection)	10.24%	This patient has 10.24% probability of death/transplantation within 15 years because of HBV infection or population mortality.

The demonstration of the risk of a HBV patient at age 40 with liver cirrhosis

State j	Probability $\omega_{8,j}(20)\|_{40}$	Interpretation
Decompensation	31.11%	This patient has 31.11% probability of reaching decompensation within 20 years.
HBsAg loss	11.67%	This patient has 11.67% probability of reaching HBsAg loss within 20 years.
HCC	46.66%	This patient has 46.66% probability of reaching HCC within 20 years.
Death/Transplantation (End of HBV infection)	74.53%	This patient has 74.53% probability of death/transplantation within 20 years because of HBV infection or population mortality.

A Semi-Markov example

- The creation of models leads to a kernel estimation problem. From the parametric estimation framework, it is a problem of computing maximal likelihood estimation.
- From the optimization framework, it becomes a non-convexity optimization problem.
- This gives a specific example of the role of O.R. methods in the model creation.

Gompertz Distribution

- Density function

$$f_i(t;\ a_i,\ b_i) = b_i \cdot e^{a_i t} \exp[\frac{b_i}{a_i}(1-e^{a_i t})]$$

- Cumulative distribution function

$$F_i(t;\ a_i,\ b_i) = 1-\exp[\frac{b_i}{a_i}(1-e^{a_i t})].$$

Gompertz Distribution

- The probability of an incidence occurrence before time t

$$P(T_{n+1}-T_n \le t | X_n = i,\ X_{n+1} \ne i) = F_i(t;\ a_i,\ b_i) = 1-\exp[\frac{b_i}{a_i}(1-e^{a_i t})].$$

- The probability of an incidence occurrence within one year

$$P(T_{n+1}-T_n \le 1 | X_n = i,\ X_{n+1} \ne i)) = 1-\exp[\frac{b_i}{a_i}(1-e^{a_i})] = p_i.$$

Gompertz Distribution

- b_i as a function of a_i

$$b_i = f(a_i) = \frac{a_i \ln(1-p_i)}{1-e^{a_i}}.$$

- The mean $u_t|_i$ of the distribution

$$u_t|_i = \frac{1}{a_i} e^{\frac{b_i}{a_i}} \left[\ln a_i - \ln b_i - \gamma - \sum_{k=1}^{\infty} \frac{\left(-\frac{b_i}{a_i}\right)^k}{k \cdot k!} \right]$$

Gompertz Distribution

- Replace b_i by $f(a_i)$

$$u_t\,|_i = \frac{1}{a_i} e^{\frac{\ln(1-p_i)}{1-e^{a_i}}} \left[\ln \frac{1-e^{a_i}}{\ln(1-p_i)} - \gamma - \sum_{k=1}^{\infty} \frac{\left(-\frac{\ln(1-p_i)}{1-e^{a_i}} \right)^k}{k \cdot k!} \right]$$

The average sojourn time in different liver status and the average time to reach different liver status

Symptoms	The average sojourn time	The average time
HBeAg(+) hepatitis HBD-DNA> $2\times10^{6\sim7}$ IU/mL	5.50 years	None
HBeAg(+) hepatitis HBD-DNA> $2\times10^{4\sim5}$ IU/mL	11.02 years	5.62 years
HBeAg seroconversion	1 year	5.42 years
HBeAg(-) hepatitis HBD-DNA> $2\times10^{3\sim4}$ IU/mL	7.23 years	18.46 years
Remission	13.42 years	6.96 years
Liver cirrhosis	7.65 years	17.72 years
HBsAg loss	31.74 years	20.37 years
Decompensation	6.67 years	22.94 years
HCC	6.01 years	22.97 years
Death	None	36.31 years

Conclusion:

- We developed the first Discrete Event Simulation model based on the natural course of Chronic hepatitis B virus.
- The model is effective by resembling individuals or cohorts of hypothetical patients and possible for tracking disease progression, complications, survival, and costs.

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行政院國家科學委員會補助國內專家學者出席國際學術會議報告

101 年 04 月 30 日

報告人姓名	陸行	服務機構及職稱	政治大學應用數學系教授
時間 會議地點	2012/4/21-2012/4/23 Chicago, USA	本會核定補助文號	
會議名稱	（中文） （英文）The 2012 POMS Annual Conference		
發表論文題目	（中文） （英文）A two-stage security-check system at border-crossing stations		

一、 參加會議經過

在參加洛利之「1st International IBM Cloud Academy Conference」後，緊接著參加此次會議。會議在芝加哥的 Marriott 的飯店舉行，為期四天。

這個會議有超過 1000 篇的論文發表，是大型的會議，專家學者來自世界各地的，如美國、法國、挪威、瑞典、以色列、意大利、韓國、日本、英國和。大會的子題共有 27 個，詳見附錄。

研究報告是「A two-stage security-check system at border-crossing stations」內容是關於分析安全服務系統，這一類的服務系統中存在兩個主要目標：最大化安全檢查的有效性，和最大限度地減少客戶的等待時間。研究發現，這兩個目標可以是一致的。或根據對容量狀態調整系統的衝突，主要是建立二階段式的選擇性安全檢查系統，研究中將此系統建成數學模

型，以一個兩階段的排隊過程分析其等候時間。每一位旅客都需經過第一階段的督察檢查，然後選出一個比例的客戶通過第二階段作進一步檢查。這個進一步檢查的比例，可以數學證明確定保有足夠的安檢水平，成為一個檢查約束。另外，也提供一階段與二階段之檢查比較分析，基於兩者之性能，以精確和近似方法計算隊列長度和等候時間以表示其服務能力。討論在一個"安全有利的"，"安全不利"或"安全不可行"的狀態，根據到達率和必要的安全水平調查在美國和加拿大邊界過境站之安全檢查的排隊系統。我們發現，兩個階段的安全檢查系統優於一階段安全檢查系統。雖然這些研究結果證實單一服務器模型，但是這些特性也保持在一個更一般性多服務器設置。

筆者也參加其他的議題報告內含如下列議題

- Observations from OASIS Violations Data for Border Inspection
- A Meta-Heuristic Optimization for Scheduling Heat-Treatment Furnace in Steel Casting Industry
- QRA and RBD techniques to evaluate the cost-effectiveness of transport security systems
- The Demand Weighted Vehicle Routing Problem
- A serial scheme for resource-constrained scheduling within Microsoft Project 2010
- Scheduling of Multi-skilled Staff Across Multiple Locations
- Bicriteria Scheduling with Batch Deliveries
- Approximation Schemes for Parallel Machine Scheduling with Availability
- Single machine batch scheduling with release times and delivery costs
- Solution Approaches for a Joint Production and Transportation Planning Problem
- Optimal delivery time quotation in supply chains to minimize tardiness and delivery costs
- Bi-criteria Scheduling Subject to Machine Availability
- Design of Characteristic Functions for Cooperative Games in Operations Planning
- Production Scheduling with Subcontracting: The Subcontractor’s Pricing Game

經過進一步的討論，筆者獲得許多寶貴的經驗，對未來的研究和研究議題提供深遠的影響。

二、 與會心得

筆者能參加此次會議，純屬因緣巧合。原因受到議題主持人的邀請，雖然此次會議並不是筆者過去長期參與的會議，但是參與後發現許多值得學習的題目和研究方法。同時也可以將筆者過去研究出之評估效能的數學模型方法介紹給從事智慧型製造研究的學者專家。也希望能在會議中能吸取其他的工業事例，藉此運用數學模型解決他們的問題。

三、 攜回資料名稱及內容

光碟會議集 (Proceedings of POMS 2012 Conference Program)。

四、 附錄

會議 Topics

Behavioral Operations
Capacity Management
Empirical Research in OM
Finance and OM Interface
Healthcare Operations Management
Humanitarian Operations and Disaster Management
Inventory Management
Manufacturing Operations
Operations Management in China and East Asia
OM in India / SE Asia
OM in Latin America and the Caribbean
Operations Management and Economic Models
OM – Marketing Interface
OM-Practice
OM in Travel, Tourism and Hospitality
Product Innovation and Technology Management
Product Management
Production Planning and Scheduling

Retail Operations Management
Scheduling and Logistics
Service Operations
Supply Management
Supply Chain Management
Supply Chain Risk Management
Sustainable Operations
Teaching in OM
Vendor and Supply Contracts

Gmail by Google

HSING LUH <orlab63@gmail.com>

Invited talk at the POMS 2012 – Chicago

Mustafa Cagri Gurbuz <mgurbuz@mit.edu> **Wed, Oct 19, 2011 at 5:27 AM**
To: slu@nccu.edu.tw
Cc: mgurbuz@zlc.edu.es

Dear Prof. Luh,

I am writing to invite you to contribute to a session that I am organizing for the upcoming POMS 2012 in Chicago, under the track ?Scheduling and Logistics?. I was approached by Prof. Chris Tang and Prof. Kumar Rajaram from UCLA to organize a session. Please find attached the conference flyer. POMS will take place in April 20-23, 2012.

I have chosen to include papers related to ?secure and efficient global supply chains?, specifically research on the risk based approach to improving security and the operational impact of current security initiatives on supply chains.

Based on the fact that you have done research in this particular field, I was wondering if you are able/willing to present a current research of yours on this topic in Chicago. I hope that you will. Even if not, it would help me greatly if you could recommend someone who could.

I look forward to hearing from you as soon as possible.

All the best,
Mustafa Cagri Gurbuz, PhD.
PhD Summer Academy Program Director
Professor at the Zaragoza Logistics Center

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<tr><td colspan="2">出國期間：104 年 8 月 18 日至 2014 年 8 月 21 日</td><td>報告繳交日期：　年　月　日</td></tr>
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　□於本機關業務會報提出報告
　□其他____________________
□9.其他處理意見及方式：</td></tr>
</table>

說明：

一、各機關可依需要自行增列審核項目內容，出國報告審核完畢本表請自行保存。

二、審核作業應儘速完成，以不影響出國人員上傳出國報告至「政府出版資料回應網公務出國報告專區」為原則。

行政院科技部補助國內專家學者出席學術會議報告

報告人姓名	陸　　行	服務機構 及職稱	政大應數系教授
時間 會議 地點	Aug. 18-21, 2014 Bellingham，USA	本會核定 補助文號	
會議 名稱	（中文）第九屆國際等候理論與網路應用會議 （英文）9Th International Conference on Queueing Theory and Network Applications		
發表 論文 題目	(中文) (英文)		

一、內容摘要

The 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) 於2014年8月18日至8月21日於美國西華盛頓大學舉行，會議為期4天。

本人是本次會議的論文審查委員。另外，因為會議的主辦人(Professor George Zhe Zhang)是本人專題研究計畫的研究夥伴，因此，參加本次會議的目的有二：

(1) 審查會議論文和安排相關審查與會場議題秩序的工作；

(2) 實地連繫Prfessor Zhang 強化研究成果，同時建立主辦學校與台灣政治大學的合作關係。

本次會議受到主辦學校高度重視，除了副校長致歡迎詞外，院長和系主任全程參與，希望能與臺灣、日本、韓國、中國和其他國家研究等候系統的學者專長們建立合作關係，本人因此特別向院長和副校長表示合作的意願, 以及可以合作的項目。在雙方積極連絡下，西華盛頓大學特別派英語學程的代表Miss Ting Hsien 於九月十一日來政大說明，招幕新生。

二、重要結論或研究成果（中英文論文、期刊、光碟、出版或獲校外研究經費補助）

這次的研討會相當成功，不但認識新的研究議題，更加深國際間的交流和合作。關於研究方面，也有進展，重要結論詳載如論文最後。

附件：

(1) 附研討會議程。

(2) Professor George Zhe Zhang的邀請函如後。

(3) 研究論文。

三、建議

四、相關聯結(活動網頁、與本學術活動有關聯結…)

The 9th International Conference on Queueing Theory and Network Applications (QTNA2014)

Western Washington University, Bellingham, USA

August 18-21, 2014

Edited by
Zhe George Zhang, Western Washington University, USA
Jianming Bai, Lanzhou University, China
Yutaka Takahashi, Kyoto University, Japan
Wuyi Yue, Konan University, Japan

Conference Sponsors
Center for Operations Research and Management Science (CORMS), Western Washington University, USA
College of Business and Economics, Western Washington University, USA
School of Management, Lanzhou University, China

Table of Content

Preface

The 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) is held at Western Washington University in Bellingham, Washington, USA, on August 18-21, 2014. The conference is a continuation of a series of successful conferences: QTNA 2006 (Seoul, Korea), QTNA 2007 (Kobe, Japan), QTNA 2008 (Taipei, Taiwan), QTNA 2009 (Singapore), QTNA 2010 (Beijing, China), QTNA 2011 (Seoul, Korea), QTNA 2012 (Kyoto, Japan), and QTNA 2013 (Taichung, Taiwan). The aim of this series is to bring together international researchers and practitioners to share critical issues in queueing theory and network applications. It is our goal to work together to discover pioneering solutions to these issues. While all previous conferences in this series have been hosted in Asian cities, QTNA 2014 (Bellingham) is the first to be held in America.

All accepted papers will be included in the proceedings in USB. Selected papers from those presented at the conference will be considered for *Journal of Industrial and Management Optimization* (JIMO), *Quality Technology and Quantitative Management* (QTQM) and *International Journal of Operations Research* (IJOR).

We hope that this conference offers an excellent forum to exchange the latest research accomplishments among academia and industries. Furthermore, it is hoped that this conference will cultivate mutual friendship among professionals and researchers from different countries.

We would like to thank the speakers and attendees for making this conference a great success. The conference would not be successful without your support and participation. We would also like to thank the members of the Organizing Committee and the Technical Program Committee for their great support.

George Zhang, Craig Tyran
Co-Chairs
Organizing Committee

Wuyi Yue, Yutaka Takahashi, Hsing Paul Luh, Jau-Chuan Ke
Co-Chairs
Technical Program Committee

Message from Organizing Committee Chairs

On behalf of the organizing committee, we cordially welcome you to the 9th International Conference on Queueing Theory and Network Applications (QTNA 2014) held at Western Washington University in beautiful Bellingham.

QTNA has been firmly supported by leading international researchers in Queueing Theory and Network Applications. This year's QTNA has the first to come from Asia to America. It offers an excellent open forum to exchange the latest research accomplishments among academia and industries, and also to cultivate a mutual friendship among professionals and researchers from the world.

We would like to take this opportunity to thank the following sponsors:
·Center for Operations Research and Management Science (CORMS), Western Washington University, USA
·College of Business and Economics, Western Washington University, USA
·School of Management, Lanzhou University, China

We would like to thank members of Technical Program Committee for their time and dedication to develop this conference program. Many thanks go to all active members of QTNA2014.

Finally, we wish this year's QTNA conference great success and every participant a very enjoyable stay in Bellingham and the State of Washington.

George Zhang (Co-Chair), Western Washington University
Craig Tyran (Co-Chair), Western Washington University

Message from Technical Program Committee Chairs

We welcome everyone to the 9th International Conference on Queueing Theory and Network Applications (QTNA2014). It is very enthusing that many researchers from Asia, Europe, and North America have participated in QTNA 2014. So far about 30 contributions submitted from the USA, Canada, Taiwan, Japan, Korea, China and Europe have been selected to be presented at the QTNA2014 conference. This conference disseminates the latest results in several research fields such as performance modeling and analysis of telecommunication networks, retrial and vacation queueing models, optimization of queueing system, matrix analytic methods, probability generating function method, and other areas such as reliability engineering and supply chain management.

Building upon the success of the previous years, we hope to provide a significant opportunity for researchers of all backgrounds to share their achievements and discoveries, collaborate on studies, and create new friendships to drive the future development of our shared fields.

We would like to acknowledge all the members of the Program Committee of QTNA2014 for their extremely valuable support. We also thank the authors who attend for their excellent technical contributions and new theoretical results.

We express gratitude to the Organizing Committee for their work in organizing this event, Co-Chairs Professor George Zhang and Professor Craig Tyran, and leading members of the organizing committee Professor Jianming Bai, and Ms Racheal Scholler for their hard work throughout the process of planning and putting together the meeting. We hope that this year's conference will be full of new findings and interesting experiences for all involved.

Finally, we hope all the participants enjoy this fascinating and fruitful conference. We wish all the participants enjoy their stay in Bellingham and Washington State.

Wuyi Yue (Co-Chair), Konan University, Japan
Yutaka Takahashi (Co-Chair), Kyoto University, Japan
Hsing Paul Luh (Co-Chair), National Chengchi University, Taiwan
Jau-Chuan Ke (Co-Chair), National Taichung University of Science and Technology, Taiwan

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Events

August 18 (Monday)
16:00-18:00 Registration

August 19 (Tuesday)
Registration in Morning Hours
08:30-09:00 Light Breakfast
09:00-09:40 Opening Ceremony and Photo
09:40-10:30 Plenary Speaking
10:30-10:50 Coffee Break
10:50-12:20 Session 1
12:20-13:30 Lunch
13:30-15:30 Session 2
15:30-16:00 Coffee Break
16:00-18:00 Session 3
18:00-20:00 Welcome Dinner

August 20 (Wednesday)
Registration in Morning Hours
08:30-09:00 Light Breakfast
09:00-10:30 Session 4
10:30-11:00 Coffee Break
11:00-12:30 Session 5
12:30-13:30 Lunch
13:30-15:30 Session 6
15:30-16:00 Coffee Break
16:00-17:30 Session 7
18:00-20:30 Banquet and Closing Ceremony

August 21 (Thursday)
09:00-16:00 Meetings of Committees and Discussion about Next QTNA

Conference Venue
Viking Union, Western Washington University

Welcome Dinner
Anthony's Hearthfire Grill

Banquet and Closing Ceremony
Viking Union, Western Washington University

Program Overview

August 19 (Tuesday)	
08:30-09:00	**Light Breakfast**
09:00-09:40	**Opening Ceremony** (Room: VU 462) Dr. Bruce Shepard President of Western Washington University Dr. Craig Dunn Dean of College of Business and Economics **Photo**
09:40-10:30	**Plenary Speaking** (Room: VU 462) Phase-Type Representation, Coxianization, and Majorization Dr. Qi-Ming He, University of Waterloo, Canada
10:30-10:50	**Coffee Break**
10:50-12:20	**Session 1** (Room: VU 567) Breakdown Models
12:20-13:30	**Lunch**
13:30-15:30	**Session 2** (Room: VU 567) Network Models
15:30-16:00	**Coffee Break**
16:00-18:00	**Session 3** (Room: VU 567) Vacation Models
18:00-20:00	**Welcome Dinner**

August 20 (Wednesday)	
08:30-09:00	**Light Breakfast**
09:00-10:30	**Session 4** (Room: VU 567) Optimization
10:30-11:00	**Coffee Break**
11:00-12:30	**Session 5** (Room: VU 567) Reliability Models
12:30-13:30	**Lunch**
13:30-15:30	**Session 6** (Room: VU 567) Queueing Models
15:30-16:00	**Coffee Break**
16:00-17:30	**Session 7** (Room: VU 567) Queueing Applications
18:00-20:30	**Banquet and Closing Ceremony**

August 21 (Thursday)	
09:00-16:00	**Meetings of Committees and Discussion about Next QTNA** (Room: TBA)

August 19 (Tuesday) Morning Sessions

09:00-09:40
Opening Ceremony (Room: VU 462)
Dr. Bruce Shepard, President of Western Washington University, USA
Dr. Craig Dunn, Dean of College of Business and Economics, Western Washington University, USA

Photo

09:40-10:30
Plenary Speaking (Room: VU 462)
Phase-Type Representation, Coxianization, and Majorization
Dr. Qi-Ming He, University of Waterloo, Canada

10:30-10:50
Coffee Break

10:50-12:20
Session 1 Breakdown Models (Room: VU 567)
Session Chair: Yutaka Takahashi

1. Optimal Control of the Machine Repair Problem with Removable Repairman Subject to Working Breakdowns
   Wen-Kuang Chou (Huanghuai University)
   Haitao Wu (Huanghuai University)
   Kuo-Hsiung Wang (Providence University)
   Tseng-Chang Yen (National Chung-Hsiung University)

2. Extended Optimal Replacement Policy for a Two-Unit System under Cumulative Damage Model
   Shey-Huei Sheu (Providence University)
   Tzu-Hsin Liu (Providence University)
   Zhe George Zhang (Western Washington University)

3. Maximum Entropy Analysis to the *N* Policy M/G/1 Queue with Working Breakdowns
   Jia-Yu Chen (National Chung-Hsiung University)
   Kuo-Hsiung Wang (Providence University)
   Shin-Pyng Sheu (National Chung-Hsiung University)
   Wen-Kuang Chou (Providence University)

August 19 (Tuesday) Afternoon Sessions

13:30-15:30
Session 2 Network Models (Room: VU 567)
Session Chair: Hsing Paul Luh

1. Performance Analysis of MAC Protocol of EDCA on Common Channel and Reservation on Service Channels for IEEE 802.11p/1609.4 WAVE
   Bong Dae Choi (Sungkyunkwan University)
   Yun Han Bae (Sangmyung University)

2. Call Blending Retrial Queue with Gated Type Incoming Call Service
   Zsolt Saffer (Budapest University of Technology and Economics)
   Wuyi Yue (Konan University)

3. Performance Analysis of Energy-Saving Server Scheduling Mechanism for Large-scale Data Centers
   Masataka Kato (Kyoto University)
   Hiroyuki Masuyama (Kyoto University)
   Shoji Kasahara (Nara Institute of Science and Technology)
   Yutaka Takahashi (Kyoto University)

4. Performance Analysis of the Gate-Polling Spectrum Access Strategy in Cognitive Radio Networks
   Shunfu Jin (Yanshan University)
   Wuyi Yue (Konan University)
   Zsolt Saffer (Budapest University of Technology and Economics)

15:30-16:00
Coffee Break

16:00-18:00
Session 3 Vacation Models (Room: VU 567)
Session Chair: Jau-Chuan Ke

1. Fluid Model Modulated by an M/M/1 Working Vacation Queue with Negative Customer
   Xiuli Xu (Yanshan University)
   Xianying Wang (Yanshan University)

2. Analysis of Decision-Making Behavior in Geo/G/1 Queues with Vacations
   Jihong Li (Shanxi University)
   Qingqing Ma (Shanxi University)

3. Equilibrium in Vacation Queueing System with Complementary Service
   Yan Ma (Central South University)
   Ben Fu (Simon Fraser University)
   Zaiming Liu (Central South University)
   Zhe George Zhang (Western Washington University, Simon Fraser University)

4. Analysis of an M/M/1 Queue with Vacations and Impatient Time which Depends on the Server's States
   Dequan Yue (Yanshan University)
   Wuyi Yue (Konan University)
   Guoxi Zhao (Yanshan University)

August 20 (Wednesday) Morning Sessions

09:00-10:30
Session 4 Optimization (Room: VU 567)
Session Chair: Zhe George Zhang

1. Supply Chain Cooperative Advertising Based on Advertising Efforts and Price Discount
   Lihong He (Lanzhou University)
   Jianzu Wu (Lanzhou University)
   Zhe George Zhang (Western Washington University, Simon Fraser University)
   Peter Haug (Western Washington University)

2. Resource Renting Problem in Project Scheduling with Self-Owned Resources, Multi-mode, and Penalty for Tardiness
   Guorong Chai (Lanzhou University)
   Yana Su (Lanzhou University, Lanzhou Polytechnic College)
   Shengliang Zong (Lanzhou University)
   Chun Yuan (Lanzhou University)

3. Optimization of Production with Green-Awareness Demands
   Zhaofu Hong (Lanzhou University)

10:30-11:00
Coffee Break

11:00-12:30
Session 5 Reliability Models (Room: VU 567)
Session Chair: Dequan Yue

1. Availability of the Series System with Unreliable Server and Imperfect Coverage
   Ching-Chang Kuo (National Taichung University of Science and Technology)
   Jau-Chuan Ke (National Taichung University of Science and Technology)
   Fu-Min Chang (Chaoyang University of Technology)

2. Availability of Machine Repairing System with Unreliable Server and Switching Failure
   Ching-Chang Kuo (National Taichung University of Science and Technology)
   Jau-Chuan Ke (National Taichung University of Science and Technology)
   Jyh-Bin Ke (National Chung-Hsing University)

3. Analysis of Type III System Model with Failed Service in Star Networks
   Sun Lijun (Qingdao University of Science and Technology)
   Qiao Yongjuan (Qingdao University of Science and Technology)
   Zhao Yue (Qingdao University of Science and Technology)

August 20 (Wednesday) Afternoon Sessions

13:30-15:30
Session 6 Queueing Models (Room: VU 567)
Session Chair: Bong Dae Choi

1. A Composite Priority Queue with Binomial Gated Polling Groups and Priority Groups
   Tetsuji Hirayama (University of Tsukuba)

2. Fluid Vacation Model with Markov Modulated Load and Gated Discipline
   Zsolt Saffer (Budapest University of Technology and Economics)
   Miklós Telek (Budapest University of Technology and Economics)

3. Analysis of the MMPP/G/1/K Queue with a Modified State-Dependent Service Rate
   Doo Il Choi (Halla University)
   Bokeun Kim (Korea Advanced Institute of Science and Technology)
   Dae Eun Lim (Baekseok University)

4. Stochastic Analysis of an Impatient Retrial Queue due to Preemptive Priority
   Shan Gao (Beijing Jiaotong University, Fuyang Normal College)
   Jinting Wang (Beijing Jiaotong University)
   Tien Van Do (Budapest University of Technology and Economics)

15:30-16:00
Coffee Break

16:00-17:30
Session 7 Queueing Applications (Room: VU 567)
Session Chair: Wuyi Yue

1. An Analysis on the CSAR (Combat Search and Rescue) Operation using Queue with Impatient Customers
   Bong-Kyoo Yoon (Korea National Defense University)
   Sung-Woo Kim (Korea National Defense University)
   Sungjune Park (University of North Carolina at Charlotte)

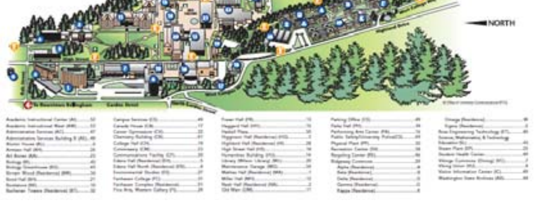
2. Tail Asymptotics of Heavy-Tailed Random Sums and its Applications to Distributed Server Systems
   Byeongchan Lee (Korea Advanced Institute of Science and Technology)
   Jonghun Yoon (Korea Advanced Institute of Science and Technology)
   Yang Woo Shin (Changwon National University)
   Ganguk Hwang (Korea Advanced Institute of Science and Technology)

3. Game Analysis in a Dual Channels System with Different Power Structures and Service Provision
   Guoxing Zhang (Lanzhou University)
   Shuai Fang (Lanzhou University)

August 21 (Thursday)

09:00-16:00
Meetings of Committees and Discussion about Next QTNA (Room: TBA)

BUILDING KEY



The 9th International Conference on

Queueing Theory and Network Applications

(QTNA 2014)

Western Washington University, Bellingham, WA, USA

August 18-21, 2014

Abstracts

Optimal Control of the Machine Repair Problem with Removable Repairman Subject to Working Breakdowns

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Abstract

This paper deals with a single removable repairman in the machine repair problem with warm standbys and working breakdowns. We assume that the repairman can be subject to working breakdowns only when there is at least one failed machine in the system. Applying the matrix-analytic method, we develop the steady-state probabilities of the number of failed machines in the system as well as several system performance measures. We construct a cost model to compute the optimal threshold *N*, and the joint optimal values for the fast and slow service rates simultaneously by two-stage optimization method whose effectiveness is proved by numerical results. Moreover, we also analyze the sensitivity with numerical illustration based upon different system parameter values.

Extended Optimal Replacement Policy for a Two-Unit System under Cumulative Damage Model

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Zhe George Zhang
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Abstract

In this article, we consider a system consisting of two major units (A and B), which is subject to two types of shocks that occur according to a non-homogeneous Poisson process. The probabilities of these two shock types are age-dependent. Each type I shock causes a minor failure of unit A, which also results in an amount of damage to unit B. The damages to unit B are accumulated to trigger a preventive replacement or a corrective replacement action. In addition, a minor failure for unit B with cumulative damage of z will occur with probability $\pi(z)$ at a unit A failure instant. A type II shock is a major one and the system is replaced at its occurrence. We consider a more general replacement policy where the system is replaced at age T, or at the time which the total damage to unit B exceeds a pre-specified level Z (but less than the failure level K) or at any type II shock or when the total damage to unit B exceeding a failure level K, whichever occurs first. The expected cost per unit time is formulated by introducing relative costs.

Maximum Entropy Analysis to the *N* Policy M/G/1 Queue with Working Breakdowns

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Abstract

This paper deals with the *N* policy M/G/1 queue with working breakdowns. In this queueing system, the steady-state probabilities cannot be derived explicitly. We employ maximum entropy approach with several constraints to develop the approximate formulae for the steady-state probability distributions of queue length and the expected waiting time in the queue. We perform a comparative analysis between the approximate results and established exact results for three different service time distributions, such as exponential, 2-stage Erlang, and deterministic. We demonstrate that the maximum entropy approach is quite accurate for practical purpose and is useful for complex queueing systems solving.

Performance Analysis of MAC Protocol of EDCA on Common Channel and Reservation on Service Channels for IEEE 802.11p/1609.4 WAVE

Bong Dae Choi
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Sungkyunkwan University
Seoul, Korea

Yun Han Bae
Department of Mathematics Education
Sangmyung University
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Abstract

The IEEE 1609.4 for Wireless Access in Vehicular Environment (WAVE) network is designed to support both safety applications (e.g., emergency service) and non-safety applications (e.g., data service) for Intelligent Transportation System (ITS). The Wave operates on multi-channels consisting of one control channel (CCH) and 6 service channels (SCHs). In this paper, we propose and analyze a MAC protocol consisting of Enhanced Distributed Channel Access (EDCA) on the CCH and reservation on SCHs in IEEE 802.11p/1609.4 WAVE. Specifically, emergency packets and status packets for safety service, and request for service (RFS) packets to reserve a SCH for non-safety service are transmitted on the common channel by contention-based EDCA scheme. Non-safety applications such as information and commercial data file are transmitted on SCHs by contention-free scheme after reserving with RFS packet. We assume that an out-dated safety packet is replaced by the new one and a RFS packet is generated after previous service file is completed successfully. On board unit (OBU) in a vehicle is assumed to have dual radios in order to utilize the full capacity of channels. We assume that only the road-side unit (RSU) sends acknowledgment (ACK) message to the broadcasted packet, to improve the successful delivery probability of safety packets. We present mathematical models of our proposed MAC protocol. From the mathematical model, various performance measures such as successful delivery probability, delay of packet and throughput are obtained. Numerical results show that 98 percent successful delivery probability and less than 100 ms delay of safety packet can be achieved.

Call Blending Retrial Queue with Gated Type Incoming Call Service

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Abstract

In this paper we consider call blending retrial queue with gated type incoming call service. Call blending is a way of mixing incoming and outgoing call activities in call centers, which is applied mainly in order to increase the operator utilization and thus also the overall productivity. The incoming calls waiting in the orbit perform retrial with constant rate. We apply a gated-type balancing mechanism in order to achieve a kind of fairness between the incoming and outgoing calls. The methodology used in this paper differs from the usual ones applied in retrial queue context. This analysis consists of two steps. In the first one steady-state relationships are established among quantities at characteristic embedded epochs. Then they are used for the derivation of the results at arbitrary epoch in the second step. The main results are the probability-generating function and the mean of the number of incoming calls at arbitrary epoch. We also discuss the steps of the numerical solution.

Performance Analysis of Energy-Saving Server Scheduling Mechanism for Large-Scale Data Centers

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Abstract

Large-scale data centers for cloud computing services consist of a number of commodity servers, resulting in a huge amount of power consumption. In order to save this consumption, BEEMR (Berkeley Energy Efficient MapReduce), a MapReduce workload manager, is developed. In a BEEMR-based data center, servers are classified into the interactive and batch zones. Arriving jobs with a small size are immediately processes in the former zone, while large-sized jobs are queued and served simultaneously at every fixed service period in the latter zone. In this paper, we evaluate the effect of BEEMR-type job scheduling on the power consumption. We consider two queueing models for the interactive and batch zones. The interactive zone is modeled as a single-server queueing system with processor-sharing (PS) service. In terms of the batch zone, we consider a queueing system with gated service in which arriving jobs are queued and served at every fixed service period. For these models, the time-average power consumption and the mean response time are derived as the performance measures. Numerical examples show that the power consumption is significantly affected by the number of servers in the batch zone, while the power consumption is insensitive to the length of the batch-service period.

Performance Analysis of the Gate-Polling Spectrum Access Strategy in Cognitive Radio Networks

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Abstract

In this paper, we present a novel centralized spectrum access strategy with a gate-polling mechanism by considering the fairness of spectrum usage. Accordingly, we build a gated vacation queueing model with non-zero switchover procedure and interrupted service. By applying the method of a regeneration cycle, the performance of the proposed spectrum allocation strategy is evaluated analytically, the formulas for the system measures in terms of the delay jitter of the SU packets and the spectrum switching ratio are derived. We also present a method to optimize the arrival rate of the licensed users with a cost function. Numerical results with analysis are provided in order to investigate the system performance on different parameters in cognitive radio networks such as delay jitter of the SU packets, spectrum ratio and optimal cost.

Fluid Model Modulated by an M/M/1 Working Vacation Queue with Negative Customer

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Abstract

This paper investigates a fluid model driven by an M/M/1 queue with working vacations and RCE (Removal of customer in the end) policy of negative customer. In the external environment, the negative customer is not served by the server and only removes the positive customer in the end one-to-one. We establish a fluid flow model based on this stochastic process, and obtain the mean buffer content and the probability of empty buffer for this fluid queue using the LT (Laplace transform) method. Moreover, several special cases of the model here are obtained. Finally, some numerical examples are presented to demonstrate the effects of parameters on the performance indices of the fluid model.

Analysis of Decision-Making Behavior in Geo/G/1 Queues with Vacations

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Abstract

In this paper, the decision-making behavior is introduced into Geo/G/1 queueing models. Starting from the customer to maximize his benefit, the customer optimal behavior in the single-server discrete-time Geo/G/1 queues with generally distributed service and vacation times has been studied. In the unobservable queue, the overall profit function about the individual customer and the whole customers are constructed by a method of mean value analysis, then the customer equilibrium balking strategies and socially optimal balking strategies are analyzed. Further, the almost observable case is considered and equilibrium strategies are determined within the parameters of different ranges. At last, the results are improved by empirical analysis and numerical simulations.

Equilibrium in Vacation Queueing System with Complementary Service

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Abstract

This paper studies a vacation queue where customers need complementary services. The main service provider or the queue server may become absence when the system is empty or adopts multiple vacation policy, which is more common in practice. The secondary service provider offers instantaneous service (no queue). The two services are complementary and a customer has no benefit from obtaining just one of them. We investigate the equilibrium solutions in time-based fee model under competition and monopoly cases, respectively. A flat fee model is also analyzed.

Analysis of an M/M/1 Queue with Vacations and Impatient Time which Depends on the Server's States

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Abstract

In this paper, we consider an M/M/1 queueing system with vacations and impatient customers. Whenever a customer arrives at the system, it activates a random "impatience timer." If the customer's service has not been completed before the customer's impatient timer expires, the customer abandons the queue, and never to return. It is assumed that customers have different impatience timers in server's busy period and server's vacation period. By using the probability generating functions method, we obtain explicit expressions for various performance measures such as the mean system sizes when the server is either on vacation or busy, the proportion of customers served, and the average rate of abandonments due to impatience.

Supply Chain Cooperative Advertising Based on Advertising Efforts and Price Discount

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Abstract

When market demand is sensitive to sales price and the advertising efforts, both manufacturer and retailer in a supply chain system must make decisions on their advertising effort levels and price discount. In this paper, we develop two models to study how to make such decisions. The first one is a non-cooperative Stackelberg advertising model, in which a manufacturer is a Stackelberg leader and the ratailer is a follower and the second one is a Partnership co-operative advertising (PCA) model. The optimal advertising and pricing strategies, such as the levels of national advertising effort and local advertising effort, the share rate of advertising, and the price discount, are theoretically obtained in the two models. The results reveal that the levels of advertising effort by both a manufacturer and retailer in the PCA strategy are greater than those in the Stackelberg equilibrium; the manufacturer provides a higher price discount in the PCA strategy than in Stackelberg equilibrium; thus, the profit of a supply chain using the PCA strategy is greater than that in the Stackelberg equilibrium. Besides, we also find that there is a negative nonlinear correlation between the price discount offered by the manufacturer to customers and the manufacturer's sharing rate for the retailer's local advertising cost. And there is a positive linear correlation between the retailer's advertising cost and the manufacture's one. Specifically, the former is twice as much as the latter. Finally, we examine the Pareto improvement to coordinate the supply chain. It has been found that the Pareto efficient cooperation can be achieved in distributing the supply chain extra profit between the manufacturer and the retailer in the PCA strategy.

Resource Renting Problem in Project Scheduling with Self-Owned Resources, Mmulti-Mode, and Penalty for Tardiness

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Abstract

In this paper, we present a resource renting problem with self-owned resources and penalty for tardiness (RRP-SP) based on the resource renting problem (RRP). In many real-life projects, the contractors only rent bottleneck resources other than their self-owned resources, so we introduce self-owned resources into the RRP. And the clients often set up a tardicost per tardiness from the due date of the project to encourage the contractor to fulfill the project on time, so we permit tardiness with penalty in the model. For more practical significance we divide the object cost into two parts: working cost and renting cost. Then, we give a genetic algorithm for the RRP-SP and test our algorithm by some numerical instances. We also analysis how the project instance itself and rent level affect renting strategy.

Optimization of Production with Green-Awareness Demands

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Abstract

This paper studies the production decision problem of a manufacturer considering green-awareness demands and carbon emission regulations. Carbon emissions generated in production are limited by a mandatory emission cap imposed by governments, under which both regular and green technologies are equipped by the manufacturer to comply emission regulations. Customers in retail markets are heterogeneous and sensitive on the price and the carbon footprint of products. The manufacturer pursues maximal profit by optimizing his decisions on the carbon footprint, the wholesale price, the usage of the technologies and the retailer selection. The problem is formulated as a two-stage Stackelberg game model, where the manufacturer acts as the leader and determines the carbon footprint and the wholesale price while the retailers act as the followers and determine their retail price and the willingness to cooperation. The decision problem is proven to be NP-hard and a hybrid algorithm combining dynamic programming algorithm, analytical method and genetic algorithm is developed to efficiently solve the model.

Availability of the Series System with Unreliable Server and Imperfect Coverage

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Abstract

In this paper, we discuss the steady-state availability of three different series system configurations with unreliable server and imperfect coverage. The primary and standby components are included in each of three different series system configurations, and the repair time of standby components are exponentially distributed with respective parameter and λ , α . When the server goes to repair, it is subjected to active breakdown, and its breakdown time is assumed to have exponential distribution with parameter γ . When the primary components fail, the standby components replace the primary components right away. The switch from standby to active is perfect. The coverage factors for a primary component failure and for a warm standby component failure are assumed to be the same as *c*. The repair time of the failed components and the repair time of the breakdown server are generally distributed. Here we use supplementary variable method and integro-differential equations to obtain the steady-state availability $A(\infty)$ of these three different series system configurations. In the end, we compare the cost/benefit between the three configurations with given to the distribution parameters, and to the cost of the primary and standby components.

Availability of Machine Repairing System with Unreliable Server and Switching Failure

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Abstract

This paper studies the machines' repairing steady-state availability of two different series system configurations with an unreliable server and switching failure. Each of two different series system configurations includes the main and standby components, and the repair time of standby components are exponentially distributed with respective parameter and λ, α. The server subjects to active breakdown when he is repairing. The server's breakdown time is also assumed to have exponential distribution with parameter γ. When the main components fail, the standby components replace the main components successfully with rate 1-*q*. The repair time of the failed components and the repair time of the breakdown server are generally distributed. Further, we use supplementary variable method and integro-differential equations to obtain the steady-state availability $A(\infty)$ of these two different series system configurations. Finally, we compare the cost/benefit between the two configurations with given to the distribution parameters, and to the cost of the primary and standby components.

Analysis of Type III System Model with Failed Service in Star Networks

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Abstract

Contention-Collision Cancellation (C-CC) access control mode is an important access control mode in star network, and it was divided into six system models, whose mathematical modeling have been almost finished for star network with one server. However, due to the difficulty and complexity of the type III system model, its analysis was based on a simplified model, in which all services were considered as successful. In this paper, the complete type III system model under general circumstances, i.e. service failure situation included, is discussed, and the customer state transfer probability, average queue length, and the average service time are given. At last, we evaluate the performance of this system through the numerical calculation. The conclusion not only consummates the mathematical modeling for single-star network, but also provides the overall reliable theoretical foundation to the application of star network.

A Composite Priority Queue with Binomial Gated Polling Groups and Priority Groups

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Abstract

We consider a multiclass queueing system with two categories of customer groups: ordinary and priority. The system has a global priority mechanism where customers in the priority groups can always begin service before customers in the ordinary groups begin. In real communication networks with various classes of traffic, composite scheduling mechanisms are often used that combine priority queueing for important classes and weighted round robin queueing for normal classes. Then we also consider the following composite mechanism in addition to the global priority. Local priority is introduced into the priority groups, and a local polling mechanism is introduced into the ordinary groups where each group is served by a binomial gated discipline, which is a variation of weighted round robin mechanism. We analyze the average sojourn times in the system by the functional computation method (FCM), which we have been developing in order to provide a framework for analysis of various multiclass M/G/1 type queueing systems.

Fluid Vacation Model with Markov Modulated Load and Gated Discipline

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Abstract

In this paper we analyze a fluid vacation model with gated discipline. The fluid source is modulated by a background continuous-time Markov chain. The fluid is removed during the service period by constant rate. We adapt the descendant set approach used in polling models to the continuous fluid model. This enables to establish the steady-state relationship on Laplace transform level among the joint distributions of the fluid level and the state of the modulating Markov chain at end of vacation and at start of vacation. The main results of the paper are the steady-state vector LT and mean of the fluid level at arbitrary epoch in terms of the previously determined quantities at the vacation end and vacation start epochs. We present numerical examples to illustrate the numerical solution.

Analysis of the MMPP/G/1/K Queue with a Modified State-Dependent Service Rate

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Abstract

We analyze an MMPP/G/1/*K* queue with a modified state-dependent service rate. The service time of customers upon service initiation is changed if the number of customers in the system reaches a threshold. Then, the changed service time is continued until the system becomes empty completely, and this process is repeated. We analyze this system using an embedded Markov chain and a supplementary variable method, and present the queue length distributions at a customer's departure epochs and then at an arbitrary time.

Stochastic Analysis of an Impatient Retrial Queue due to Preemptive Priority

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Abstract

This paper deals with a preemptive priority M/G/1 retrial queue with impatient customers. If a new arrival finds the server idle, he begins his service immediately, otherwise, with probability α he will preempt the customer being served to commence his service or with probability $1-\alpha$ join the waiting queue. We assume that the preempted customer may leave the service area with probability p to join a retrial queue and repeats the attempts to get service in random intervals or with probability $1-p$ leaves the system forever (called impatient customer). For classical retrial policy and general retrial policy, by using embedded Markov chain technique and the supplementary variable method, we find the necessary and sufficient condition for the system to be stable and discuss the joint distribution of the server state, the numbers of customers in service area and retrial group in the steady state.

An Analysis on the CSAR (Combat Search and Rescue) Operation using Queue with Impatient Customers

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Abstract

Since pilots are highly valuable asset, it is important to manage CSAR (Combat Search and Rescue) operations in an efficient way. In CSAR operation, key decision variables are the number of rescue teams and the probability that the rescue is successful. Meanwhile, since pilots could leave the place where they sent the distress call or be captured by enemy force, it is imperative to include so called impatient customer phenomena to the model for analyzing CSAR operation. This paper suggests a model to derive key performance measures for CSAR such as the success probability of the rescue operation using queue with impatient customers. In addition, this paper shows that the key performance measures for CSAR could be derived in an easier way by the concept of phase-type distribution.

Tail Asymptotics of Heavy-Tailed Random Sums and its Applications to Distributed Server Systems

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Abstract

The appearance of heavy-tailedness in users' traffic significantly degrades the performance of communication systems, and a distributed server system is considered as a good solution to this problem because of its distributed service characteristic by multiple servers. So we tackle the question in this paper that a distributed server system can alleviate heavy-tailedness, so that users experience good QoS as if there were no heavy-tailedness. To this end, we first mathematically model a distributed server system and obtain a heavy-tailed random sum with the help of the theory of perturbed random walk. We then analyze the tail asymptotic of the heavy-tailed random walk to find a condition with which the distributed server system can alleviate heavy-tailedness.

Game Analysis in a Dual Channels System with Different Power Structures and Service Provision

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Abstract

This paper studies a dual channel supply chain in which a manufacturer sells products to a retailer as well as to customers who are sensitive to both channel price and the retail service. Three game models (Manufacturer Stackelberg, Retailer Stackelberg and Vertical Nash) are built according to members' different bargaining power in a dual channels system. We show that consumers can receive lower channel price and higher retail service level when channel members possess equal bargaining power (e.g. Vertical Nash), however, when the retailer occupies the market leadership (e.g. Retailer Stackelberg), consumers always receive the least welfare because of the higher channel price and lower retailer service. Interestingly, the retailer can take advantage of market leadership to make more profits, while the manufacturer is more willing to give up its power and act as a Stackelberg follower. Furthermore, Manufacturer Stackelberg and Vertical Nash is a strictly dominated strategy for the retailer and the manufacturer respectively.

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July 14, 2014

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Dear Prof. Luh,

I am pleased to invite you cordially of visiting Western Washington University from August 17 to August 23. During your visit, besides your attending QTNA 2014 conference, I expect you to meet some leaders at departmental, college, and university levels to discuss further collaboration between your university and Western Washington University. In addition, we may also discuss the on-going joint research projects while you are at our university.

Please do not hesitate to contact us if you have any queries regarding our invitation. My e-mail address is George.Zhang@wwu.edu.

We are looking forward to meeting you at Western Washington University

Yours Sincerely

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Computing the waiting time in a security check system

Hsing Luh

Abstract. This project studies the performance analysis and trade-off between security and cargo service goals of a security-check system during the global supply chain. There are relatively fewer studies on security-check waiting lines using analytical models. We address the important tradeoff issue between the security screening effectiveness and the supply chain efficiency, i.e., the two main goals of a security-check system while considering the global supply chain management. A multiple servers security system is considered in this report. Stationary probabilities are fundamental in response to various measures of performance in queueing networks. Solving stationary probabilities in Quasi-Birth-and-Death (QBD) type Markov Chain normally are dependent on the structure of the queueing network. In this report, a new computing scheme is developed for attaining stationary probabilities in queueing networks of the multiple servers security systems. Our approach is to develop a stylized queueing model with the novel features pertaining to the real system. The goal of this report is to provide a modelling framework to understand the economic tradeoffs embedded in container-inspection decisions and to use this framework to analyze policy initiatives.

1 Introduction

The motivation of this study arises from a U.S. law enacted in August 2007, "Implementing Recommendations of the 9/11 Commission Act of 2007" [4], popularly called the 9/11 Commission Act. The law requires that, before any cargo bound for the United States is loaded onto a ship at an international port, it must be scanned using Non-Intrusive Imaging (NII) and radiation detection technology to detect radiological contraband. The deadline for compliance with this law is July 1, 2012, unless the Secretary of Homeland Security grants extensions, which can be offered in two-year increments [4].

A U.S. law mandating non-intrusive imaging and radiation detection for 100% of U.S.-bound containers at international ports has provoked widespread concern that the resulting congestion would hinder trade significantly. The consensus among security experts is that the most probable way that Americans would be targeted by a nuclear weapon would be for al-Qaeda or a future adversary to smuggle it into the United States. The millions of shipping containers that are used to transport goods in ocean-going vessels provide terrorists with one promising way to hide a nuclear device destined for U.S. shores. By using a container, terrorists can potentially achieve mass disruption of global supply chains: widespread public anxiety that other containers may contain nuclear devices would result in stepped-up inspections that would cause congestion throughout the global intermodal transportation system.

To counter the threat of nuclear terrorism, the United States has initiated various security measures, both at domestic and foreign ports. These measures can require the cooperation of foreign nations, trading companies, terminal operators, customs brokers, trucking companies, ocean carriers, and other participants in the maritime supply chain. In this report, we focus on security initiatives implemented at international ports, namely, the Container Security Initiative (CSI) and the Secure Freight Initiative (SFI). These constitute only 2 out of nearly 25 to 30 U.S. and international initiatives and legislations directed at enhancing maritime security.

CSI is a security program administered by the U.S. Bureau of Customs and Border Protection (CBP), an agency that falls within the Department of Homeland Security. The program, announced in January 2002, uses an "automated targeting system" (ATS) that employs rules-based software to identify containers bound for the United States that are at risk of being tampered with by terrorists. A key input to this system is the container's shipping manifest, which contains information about the container's sender, recipient, and contents. CBP's "24-hour rule" mandates that an ocean carrier transporting a container to the United States forward manifest information to CSI officials at least 24 hours prior to the container's lading onto a vessel that will call on a U.S. port. The most common concern is that the congestion that would result from this security requirement will substantially increase the cost of doing business and hurt commerce.

Stank and Crum [23] suggested that border crossings create delays in transportation and add uncertainty to transit times as customs clearance, traffic congestion, and other operating procedures are often highly variable with respect to time. The interval that a vehicle spends at a border impacts a wide range of carrier and shipper tactical and operational plans, including driver staffing, warehouse usage, vehicle routing and scheduling, and total cost. Taylor et al. [24, 25] estimated that, in 2003, the overall annual cost to carriers and shipper of crossing between Canada and the U.S.A. was about 6.3 billion, with the costs of transit time and uncertainty being about 4.0 billion of that total.

The U.S. Office of Freight Management and Operations [26] concluded that the number of inspection and processing booths open at each point-of-entry at any given time had a significant influence on the variability of travel time and delay. Goodchild et al. [27] reported that there was a direct correlation between delays and the number of customs/immigration booths open—the greater the number of booths open, the shorter the delay. Taylor et al. [25] stated that the most common cause of current delays and uncertainty related to the number of available customer primary inspection booths and the staffing of those booths, and the staffing of customs secondary inspection yards. They ranked staffing at border crossings as a most severe cause of border delays. Although many models for staff planning have been proposed (e.g., Edwards [28], Ernst et al. [29], and references therein), few of these models have been applied to border staffing and, more specifically, to the question of how many booths or lanes to have open at a crossing or how many truck inspectors to have on duty.

A key first step in planning responses to border delays is estimating how long a driver and vehicle will require to cross (or often, wait) at a border crossing. When studying queueing systems, it is important to predict their performance. Common performance measures include the average time that containers spend in the inspection system, the average number of containers in the system, and the maximal service rate at which the custom can inspect containers.

2 Research background

This project is prepared as a basic model of conducting queueing analysis for waiting time in security applications such as search and screening checkpoints.

Security access control and security screening (”search”) applications will routinely cause a waiting line as the people, baggage, packages or vehicles begin to enter for ”processing.” The processing time is the period from the moment a person leaves the head of the queue and enters the security checkpoint process, until that person has completed the security procedure and been released to proceed freely within the secured area. Processing time depends primarily upon the tasks that are performed, for example check photo I.D., items through x-ray, person through magnetometer, etc. A simple and common security process would be the swiping of an access control card at a card reader that then releases a mechanical or optical turnstile. A more complex security process would be baggage x-ray screening and weapons or explosives scan, and other measures such as a vehicle search.

Each task and/or instrument utilized in the security process consumes time. The processing time for each individual is translated into the maximum number that can be ”processed” per minute or per hour. This is commonly referred to as the ”throughput”. While actual security processing time can vary widely depending upon the tasks to be performed and the actual instruments in use, some examples may be helpful. A typical screening configuration consisting of 2 x-ray machines with a walk-through magnetometer (”metal or weapons detector”) can process about 3 to 4 persons per minute realistically. A vehicle search lane with multiple security personnel can properly process a vehicle in approximately 45 to 60 seconds. Generally, increasing throughput by adding additional ”lanes” is the method used to reduce wait time.

Most security managers and others that have addressed this issue raise its importance as seriously as the travellers do. In practice, some operations will ”monitor” the queue in order to make rapid adjustments such as opening additional lanes when the queue becomes excessive. For example, people have become accustomed to long waits at airport security screening while the security check may have been conducted by using corner surveillance monitor to check the traveller in line. But no person desires to stand in line for more than 30 minutes although it is likely to be less than many people might expect in today’s airport environment. In general, the delay occurring in the airport is restrained by the boarding time by which a aircraft is set to take off. It is necessary for the security client to first determine a TARGET average waiting period as the maximum time in queue, in order for security consultants to determine the necessary configuration. The object of this proposal is to built up a queueing model for waiting analysis at security checkpoints.

A security-check system such as border-crossing station can be modeled as a two-stage queueing system. A certain proportion (q) of customers (either cars or persons) are selected for further inspection and rest of customers will leave without going through further inspection after asking some questions and a brief visual inspection. The security-check level depends on two parameters $-$ q, the proportion of further inspection customers, and S the average time of the further inspection (mean service time of the second stage). As the waiting space is limited in the second stage and we must check all customers in this stage, the probability that the number of customers is above a certain limit (waiting space limit) must be small enough (such as less than 0.01). Thus the tail probability smaller than an upper bound is used as a service capacity requirement for a given security level (q_0, S_0). On the other hands, we must ensure that average customer waiting time is kept no more than a limit, say 30 minutes or minimized subject to the security level constraint. The tradeoff between ensuring sufficient security level and achieving good customer service must be made in such a service system. Waiting time in security applications or any other similar application in control could simply provide just one lane and one server or multiple lanes with several servers.

3 System Description and Model Formulation

Consider a two-stage queueing model. This model is for a selective inspection system that often is in operation for an international border-crossing station or a security-check point at airport. In such a system, there are two stages for inspection: the waiting space at the first stage is fairly and is assumed to be infinite; but at the second stage is the waiting space is quite limited due to the service capacity B which is expandable with a significant cost per spot. In the first stage service, customers after initial screen are either transferred immediately to the second stage further inspection with probability q or continues to the routine check and leaves the system. The first year provides a system description and model formulation with analytic solution. The second year will focus on determining the optimal staffing and inspection strategy for a given security-check level.

We consider the queueing system for the security-check waiting lines, where customers arrive according to a Poisson process with mean arrival rate λ. There are c_1 servers in this system, and each one provides a preliminary first phase of the first-stage inspection (Phase 1) to all arriving customers. The average service time of first-phase inspection is exponentially distributed with rate μ_1 of each server. As soon as the first phase is completed, the customer may be provided with a second-phase service at the first-stage inspection with probability $1-q$ $(0 \leq q \leq 1)$, where the average service rate of each server is μ_2, or may enter the second-stage inspection with probability q. Assuming that the average service rate of the second-stage inspection is ν of each server. Those service times are mutually independent and follow exponential distributions.

For constructing a queueing model, consider a two-stage $M/Cox(2)/c_1 \to /M/c_2/B$ system. First stage has c_1 servers and a buffer of infinite capacity and second stage has c_2 servers and a buffer of finite capacity of $B - c_2$. First, we define the system state as (n, i, j, m), where n denotes the number of customers at the first stage, m denotes the number of customers at the second stage, i and j denote the total number of customers in phase 1 and in phase 2 at the first stage, respectively. Then we have the state space

$$\mathbf{S} = \{(n,i,j,m)|\ i+j=n, \text{if } n<c_1;\ i+j=c_1, \text{if } n \geq c_1, i,\ j,\ n \in \{0\} \cup \mathbb{N},\ m \in \{0,1,2,\ldots,B\}\}.$$

Denote $\overline{n}$ as the system state vector for $n = 1, 2, \ldots$, where state

$$\overline{1} = \{(1,0,1,0),(1,1,0,0),(1,0,1,1),(1,1,0,1),\ldots,(1,0,1,B),(1,1,0,B)\}$$

$$\overline{2} = \{(2,0,2,0),(2,1,1,0),(2,2,0,0),(2,0,2,1),(2,1,1,1),(2,2,0,1),\ldots,(2,0,2,B),(2,1,1,B),(2,2,0,B)\}$$

$\overline{1}$ is of dimension $2(B+1)$. Given $n < c_1$, any combination of n servers gives the same pattern of service speed since the servers are homogeneous, which is independent of m. For example, the service rate at state $(1,1,0,B)$ is the same as at $(1,0,1,B)$, while that at $(1,1,0,2)$ is the same as that at $(1,0,1,3)$. thus, state $\overline{n}_1$ is of dimension $(n+1)(B+1)$, when $0 < n < c_1$, and $\overline{n}$ is of $(c_1+1)(B+1)$ when $n \geq c_1$. A picture of possible transitions is drawn in Figure 1.

The infinitesimal generater $\mathbf{Q}$ is of the block-tridiagonal form and written as follows

$$\mathbf{Q} = \begin{bmatrix} \mathbf{B}_0 & \mathbf{C}_0 & & & & & & \\ \mathbf{A}_1 & \mathbf{B}_1 & \mathbf{C}_1 & & & & & \\ & & \ddots & \ddots & \ddots & & & \\ & & & \mathbf{A}_{c_1-1} & \mathbf{B}_{c_1-1} & \mathbf{C}_{c_1-1} & & \\ & & & & \mathbf{A} & \mathbf{B} & \mathbf{C} & \\ & & & & & \ddots & \ddots & \ddots \end{bmatrix}$$

where the submatrices $\mathbf{A}_n$, $\mathbf{B}_n$ and $\mathbf{C}_n$ are dimensional of $((n+1)(B+1) \times (n)(B+1))$, $((n+1)(B+1) \times (n+1)(B+1))$, and $((n+1)(B+1) \times (n+2)(B+1))$ for $0 < n \leq c_1$ respectively, but $\mathbf{A} = \mathbf{A}_{c_1}$, $\mathbf{B} = \mathbf{B}_{c_1}$ and $\mathbf{C} = \mathbf{C}_{c_1}$ for $n > c_1$.

Define

$$\mathbf{A}_n = \begin{bmatrix} \bar{\boldsymbol{\alpha}} & \boldsymbol{\alpha} & & & & \\ & \bar{\boldsymbol{\alpha}} & \boldsymbol{\alpha} & & & \\ & & \ddots & \ddots & & \\ & & & & \ddots & \boldsymbol{\alpha} \\ & & & & & \bar{\boldsymbol{\alpha}} \end{bmatrix}$$

where $\boldsymbol{\alpha}$ and $\bar{\boldsymbol{\alpha}}$ are the size of $(n+1) \times n$, i.e.,

$$\bar{\boldsymbol{\alpha}} = \begin{bmatrix} a_n & & & & \\ & a_{n-1} & & & \\ & & \ddots & & \\ & & & a_2 & \\ & & & & a_1 \\ 0 & & & & 0 \end{bmatrix}$$

where $a_k = k\mu_2$ if $k < c_1$; $a_k = c_1\mu_2$ otherwise.

$$\boldsymbol{\alpha} = \begin{bmatrix} 0 & 0 & & & \\ qb_1 & & & & \\ & qb_2 & & & \\ & & & \ddots & \\ & & & & qb_n \end{bmatrix}$$

where $b_k = k\mu_1$ if $k < c_1$; $b_k = c_1\mu_1$ otherwise.

Define

$$\mathbf{B}_n = \begin{bmatrix} \bar{\boldsymbol{\beta}} & & & & & \\ \tilde{\boldsymbol{\beta}}_1 & \bar{\boldsymbol{\beta}} & & & & \\ & \ddots & \ddots & & & \\ & & \tilde{\boldsymbol{\beta}}_k & \bar{\boldsymbol{\beta}} & & \\ & & & \ddots & \ddots & \\ & & & & \tilde{\boldsymbol{\beta}}_B & \bar{\boldsymbol{\beta}} \end{bmatrix}$$

$\tilde{\boldsymbol{\beta}}_k$ and $\bar{\boldsymbol{\beta}}$ are the size of $(n+1) \times (n+1)$.

$$\bar{\boldsymbol{\beta}} = \begin{bmatrix} \delta_n & & & & \\ (1-q)b_1 & \delta_{n-1} & & & \\ & & \ddots & & \\ & & & (1-q)b_n & \delta_0 \end{bmatrix}$$

$\tilde{\boldsymbol{\beta}}_k = k\nu\mathbf{I}_{n+1}$ if $k < c_2$; $\tilde{\boldsymbol{\beta}}_k = c_2\nu\mathbf{I}_{n+1}$ otherwise.

Define

$$\mathbf{C}_n = \begin{bmatrix} \bar{\mathbf{c}} & & & \\ & \bar{\mathbf{c}} & & \\ & & \ddots & \\ & & & \bar{\mathbf{c}} \end{bmatrix}$$

where $\bar{\mathbf{c}} = \lambda[I_n, \mathbf{0}]$ is the size of $(n+1) \times (n+2)$. The solution of this model is not easy to obtain because of its highly dependent state relation and complicated stationary probability structure resulting ill-conditioned matrices. Due to the nature of the Coxian service, any sub-outflows of c_1 can be considered. With probability $1-q$, the customer leaves the system after two phases of the service time (stage 1). This output flow becomes the input flow of the second stage inspection (service). With probability q, the customer continues to complete the second phase of the service time. However, the service at stage 2 is independently carried out for its security check by each continuing customer which makes the computational procedure intricate and intractable.

To simplify the analysis, we first investigate a stylized one stage queueing model with c_1 servers but of which an additional phase of service rate ν is made similarly as a security check in phase 2. It is certainly an approximation of the proposed model (a multi-server system for both stages).

Once we have our $\mathbf{Q}$ matrix, the next step is to obtain some steady state results. The steady-state probabilities for this queue satisfy $\overline{\pi}\mathbf{Q} = \mathbf{0}$ and $\overline{\pi}\mathbf{1} = 1$, where $\overline{\pi} \geq \overline{0}$ is partitioned into blocks corresponding to the states for 0 customer, 1 customer, 2 customers, ..., etc. That is, $\overline{\pi} = (\overline{P}_0, \overline{P}_1, \overline{P}_2, \ldots)$. Using the block probabilities and the elements of the $\mathbf{Q}$ matrix, we need to find the $\overline{P}_n$'s that satisfy:

$$\overline{P}_0 \mathbf{B}_0 + \overline{P}_1 \mathbf{A}_1 = \mathbf{0}, \tag{3.1}$$

$$\overline{P}_n \mathbf{C}_n + \overline{P}_{n+1} \mathbf{B}_{n+1} + \overline{P}_{n+2} \mathbf{A}_{n+2} = \mathbf{0}, \quad \text{for } n = 0, 1, \ldots, c-1, \tag{3.2}$$

$$\overline{P}_n \mathbf{C} + \overline{P}_{n+1} \mathbf{B} + \overline{P}_{n+2} \mathbf{A} = \mathbf{0}, \ n = c, c+1, \ldots. \tag{3.3}$$

From (3.3), the matrix geometric procedure gives the vector solution

$$\overline{P}_n = \overline{P}_c \mathbf{R}^{n-c}, \ n = c, c+1, \ldots, \tag{3.4}$$

where $\mathbf{R}$ is the matrix solution of the equation

$$\mathbf{C} + \mathbf{R}\mathbf{B} + \mathbf{R}^2 \mathbf{A} = \mathbf{0}.$$

Nuets [9] showed that the iteration

$$\mathbf{R}_i = -(\mathbf{C} + \mathbf{R}_{i-1}^2 \mathbf{A}) \mathbf{B}^{-1}, \ i = 1, 2, \ldots,$$

converges to the solution $\mathbf{R}$ starting with $\mathbf{R}_0 = \mathbf{0}$. Using the recurrence relation (3.4) in equations (3.1), (3.2) and the normalization equation $\overline{\pi}\mathbf{1} = 1$, we can determine the steady state probability vector $\overline{\pi}$.

For example, we solve a special case of $c_1 = 2$, i.e., $M/Cox(2)/2$ queueing model for security-check waiting lines. Suppose that customers arrive the system according to a Poisson process with mean arrival rate λ. There are two servers (named server I and server II) in this system, and each one provides a preliminary first phase of the first-stage inspection (Status 1) to all arriving customers. The average service time of first-phase inspection is exponentially distributed with rate μ_1. As soon as the first phase is completed, the customer may be provided with a second-phase service of the first-stage inspection (Status 2) with probability $1-q$ $(0 \leq q \leq 1)$ or may enter the second stage (Status 3) with probability q. Assuming that the average service rate of the second-phase service is μ_2, and the average service rate of the second-stage inspection is ν. Those service times are mutually independent and follow exponential distributions.

First, we define the system state as (n, i, j), where n represents the number of customers in the system, i represents the status of service in the server I, j represents the status of service in the server II. Then we have the state space

$$\mathbf{S} = \{(n, i, j) |\ n \in \{0\} \cup \mathbb{N}, \ i \in \{0, 1, 2, 3\}, \ j \in \{0, 1, 2, 3\}\}.$$

Denote $\overline{n}$ as the system state vector, where

$$\overline{0} = \{(0,0,0)\},$$

$$\overline{1} = \{(1,1,0),(1,2,0),(1,3,0),(1,0,1),(1,0,2),(1,0,3)\},$$

$$\overline{n} = \{(n,1,1),(n,2,1),(n,3,1),(n,1,2),(n,2,2),(n,3,2),(n,1,3),(n,2,3),(n,3,3)\},$$

for $n = 2, 3, \ldots$. The multi-dimensional states $\overline{n}$ correspond to the number of customers in the system, the status of server I and the status of server II.

The infinitesimal generator matrix has the following structure:

$$\mathbf{Q} = \begin{array}{c|cccccccc} & \overline{0} & \overline{1} & \overline{2} & \overline{3} & \overline{4} & \overline{5} & \cdots & \cdots \\ \hline \overline{0} & \mathbf{B}_{00} & \mathbf{C}_{01} & 0 & 0 & \cdots & \cdots & \cdots & \cdots \\ \overline{1} & \mathbf{A}_{10} & \mathbf{B}_{11} & \mathbf{C}_{12} & 0 & 0 & \cdots & \cdots & \cdots \\ \overline{2} & 0 & \mathbf{A}_{21} & \mathbf{B} & \mathbf{C} & 0 & \cdots & \cdots & \cdots \\ \overline{3} & 0 & 0 & \mathbf{A} & \mathbf{B} & \mathbf{C} & 0 & \cdots & \cdots \\ \overline{4} & 0 & 0 & 0 & \mathbf{A} & \mathbf{B} & \mathbf{C} & 0 & \cdots \\ \vdots & & & & \ddots & \ddots & \ddots & \ddots & \end{array}$$

where those sub-matrices are

$$\mathbf{B}_{00} = [-\lambda],$$

$$\mathbf{C}_{01} = \begin{bmatrix} \frac{\lambda}{2} & 0 & 0 & \frac{\lambda}{2} & 0 & 0 \end{bmatrix},$$

$$\mathbf{A}_{10} = \begin{bmatrix} 0 \\ \mu_2 \\ \nu \\ 0 \\ \mu_2 \\ \nu \end{bmatrix},$$

$$\mathbf{B}_{11} = \begin{bmatrix} -(\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 & 0 & 0 & 0 \\ 0 & -(\mu_2+\lambda) & 0 & 0 & 0 & 0 \\ 0 & 0 & -(\nu+\lambda) & 0 & 0 & 0 \\ 0 & 0 & 0 & -(\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 \\ 0 & 0 & 0 & 0 & -(\mu_2+\lambda) & 0 \\ 0 & 0 & 0 & 0 & 0 & -(\nu+\lambda) \end{bmatrix},$$

$$\mathbf{C}_{12} = \begin{bmatrix} \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 \\ \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 \end{bmatrix},$$

$$\mathbf{A}_{21} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu_2 & 0 & 0 \\ 0 & 0 & 0 & \nu & 0 & 0 \\ \mu_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mu_2 & 0 & 0 & \mu_2 & 0 \\ 0 & 0 & \mu_2 & 0 & \nu & 0 \\ \nu & 0 & 0 & 0 & 0 & 0 \\ 0 & \nu & 0 & 0 & 0 & \mu_2 \\ 0 & 0 & \nu & 0 & 0 & \nu \end{bmatrix},$$

$$
\mathbf{A} = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\nu & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\mu_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \mu_2 & 0 & \mu_2 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \mu_2 & \nu & 0 & 0 & 0 & 0 & 0 \\
\nu & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \nu & 0 & 0 & 0 & 0 & \mu_2 & 0 & 0 \\
0 & 0 & \nu & 0 & 0 & 0 & \nu & 0 & 0
\end{bmatrix},
$$

$$
\mathbf{B} = \begin{bmatrix}
-(2\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 & (1-p)\mu_1 & 0 & 0 & p\mu_1 & 0 & 0 \\
0 & -(\mu_1+\mu_2+\lambda) & 0 & 0 & (1-p)\mu_1 & 0 & 0 & p\mu_1 & 0 \\
0 & 0 & -(\nu+\mu_1+\lambda) & 0 & 0 & (1-p)\mu_1 & 0 & 0 & p\mu_1 \\
0 & 0 & 0 & -(\mu_1+\mu_2+\lambda) & (1-p)\mu_1 & p\mu_1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -(2\mu_2+\lambda) & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -(\nu+\mu_2+\lambda) & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -(\nu+\mu_1+\lambda) & (1-p)\mu_1 & p\mu_1 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -(\nu+\mu_2+\lambda) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -(2\nu+\lambda)
\end{bmatrix},
$$

$$
\mathbf{C} = \begin{bmatrix}
\lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & \lambda & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \lambda
\end{bmatrix}.
$$

4 Anticipated resultants in the first year

4.1 The Matrix Geometric Solution

Once we have our $\mathbf{Q}$ matrix, the next step is to obtain some steady state results. The steady-state probabilities for this queue satisfy $\overline{\pi}\mathbf{Q} = \overline{0}$ and $\overline{\pi}\overline{1} = 1$, where $\overline{\pi} \geq \overline{0}$ is partitioned into blocks corresponding to the states for 0 customer, 1 customer, 2 customers, etc., in the system. That is, $\overline{\pi} = (\overline{P}_0, \overline{P}_1, \overline{P}_2, \ldots)$. Using the block probabilities and the elements of the $\mathbf{Q}$ matrix, we need to find the $\overline{P}_n$'s that satisfy:

$$\overline{P}_0\mathbf{B}_0 + \overline{P}_1\mathbf{A}_{10} = \overline{0} \tag{4.1}$$

$$\overline{P}_0\mathbf{C}_0 + \overline{P}_1\mathbf{B}_{11} + \overline{P}_2\mathbf{A}_2 = \overline{0} \tag{4.2}$$

$$\overline{P}_1\mathbf{C}_1 + \overline{P}_2\mathbf{B} + \overline{P}_3\mathbf{A} = \overline{0} \tag{4.3}$$

$$\overline{P}_{n+2}\mathbf{C} + \overline{P}_{n+3}\mathbf{B} + \overline{P}_{n+4}\mathbf{A} = \overline{0},\ n = 0, 1, 2, \ldots \tag{4.4}$$

From (4.4), the matrix geometric procedure gives the vector solution

$$\overline{P}_n = \overline{P}_2\mathbf{R}^{n-2},\ n = 3, 4, \ldots, \tag{4.5}$$

where $\mathbf{R}$ is the matrix solution of the equation

$$\mathbf{C} + \mathbf{R}\mathbf{B} + \mathbf{R}^2\mathbf{A} = \overline{0}.$$

Nuets [9] showed that the iteration

$$\mathbf{R}_i = -(\mathbf{C} + \mathbf{R}_{i-1}^2\mathbf{A})\mathbf{B}^{-1},\ i = 1, 2, \ldots$$

converges to the solution $\mathbf{R}$ starting with $\mathbf{R}_0 = \overline{0}$. Using the recurrence relation (4.5) in equations (4.1), (4.2), (4.3) and the normalization equation $\overline{\pi}\overline{1} = 1$, we can determine the steady state probability vector $\overline{\pi}$.

We will use the first moment of the queue length (or waiting time) of M/G/2 queue to study the performance of stage 1 queue as follows. Since the departure of stage 1 is the arrival to stage 2 queue, we adopt the renewal process approximation (see Whitt 1983) to obtain the LST of the interarrival time for the second stage queue. Our approximation is based on the following assumption: When the server is busy, the departure process is determined by assuming that the service is continuous and no idle period occurs. When the server is idle, the departure process is determined by assuming that the every service is separated by an idle period. Assume that the stage 1 service time follows a Coxian-2 distribution with μ_1 and μ_2 as the parameters of the exponentially distributed phase 1 and phase 2 durations. Let $X(s) = \mu_1/(\mu_1 + s)$ and $Y(s) = [\mu_1/(\mu_1 + s)][\mu_2/(\mu_2 + s)]$. Let $L(2)$ be a random number of customers in the queue where there are 2 servers in the model. By the proposed matrix computation in the project and [**?**], we are able to give an analysis of the stationary probability of $\overline{P}_n$, $n = 0, 1, 2, \cdots$.. It is the work of the proposal to investigate the following two theorems.

Theorem 4.1 *Suppose $W(2)$ is a random variable of waiting time in the queue when there are two servers. There exists a stationary distribution of $Pr\{W(2) < t\}$*

Based on $W(2)$, we may derive the following theorems.

Theorem 4.2 *Given an $\epsilon > 0$, there exists a number N such that $Pr\{L(2) > N\} < \epsilon$*

According to Theorem 4.2, one may choose an optimal N by which when the number customers is no larger than this threshold number, the waiting time of each customer is able to control under 30 minutes with a guaranteed probability. However, it is only for the model $M/Cox(2)/2$. Our goal of this research, by extending the results of Theorems 4.1 4.2, is to obtain the similar the waiting time distribution and optimal control for performance of $M/Cox(2)/c_1 \rightarrow /M/c_2/B$. In other words, the proposed research will focus on analyzing service systems in a stochastic environment with highly complicated matrix. It is obvious that matrix geometric solution plays an essential role to design better systems or systems control policies, e.g. choosing an optimal N. Since N could be used as a signal to guarantee the waiting time for most customers, it is sufficient to apply for $M/Cox(2)/c_1 \rightarrow /M/c_2/B$. Moreover, what if the congestion occurs and the number of waiting customers is more than N, is it the moment to add an additional server? To answer this question, it can be accomplished by using queueing models 3 as outlined in this proposal, treating c_1 and c_2 as the control variables. Thus, to continue with Theorems 4.1 4.2 by considering multiple servers in both stages, we need derive the stationary probability by using the matrix geometric solution for 3, which will be carried out to the second year research and investigation of this project.

5 Anticipated resultants in the second year

5.1 Determining the Staffing Level of the Second Stage

Suppose the proportion for the second stage check q_0 and the required mean service time at the second stage is S_0, which are considered as the security level. Given (q_0, S_0) a security level (q_0, S_0), the minimum arrival rate to the second stage is λq_0 and the minimum mean service time is $S_0 = 1/\nu$. Assume that there are c_2 servers in the second stage. We have an $GI/M/c_2$ model with $A(s)$ as the LST of the arrival process. The stationary distribution of the queue length, denoted by m_j, can be obtained as

$$m_j = K r_0^j \quad \text{for } j \geq c_2$$

where r_0 is the root of $A[c_2\nu(1-z)] = z$. The constant K and the m_j $(j = 0, 1, ..., B - c_2)$ must be determined from the normalization condition $\sum_{j=0}^{\infty} q_j = 1$ and the the stationary probability balanced equations, using the transition probability formulas given in 3. A recursive relation for m_j, when $j < c_2$ can be developed as standard results for $GI/M/c$ queue. Suppose that the waiting space for the second stage inspection is limited by size $B - c_2$. Then the tail probability of queue length exceeding N_0 is defined as $\alpha_0 = \sum_{j=N_0+1}^{B-c_2} m_j$. For a given λ, q_0, S_0, there is a minimum requirement $x(\alpha)$ for the system that guarantees the minimum waiting, that is $\lambda q_0 S_0 / c_2 < x(\alpha)$ or $c_2 > \lambda q_0 S_0 / x$, which gives the range of c_2 for a guaranteed waiting time. We need to find an appropriate initial c_2 such that a feasible range of $q \geq q_0$ and $S \geq S0$ with $\alpha < \alpha_0$ exists. This initial feasible staffing level denoted by c_2^0 can be obtained by numerical search over (q, S) subject to the constraint $\alpha < \alpha_0$. Obviously, the larger the c_2^0, the larger the feasible region of (q, S). Note that as c_2 increases, the feasible region of $\alpha < \alpha_0$ will expand. For a given S, we can determine the maximum feasible $q_m ax$. Thus the feasible q should be in $(q_0, q_{\max})$.

Optimization Problem: The main issue in a two-stage security-check system is to determine the staffing level for a required security check level and the optimal policy parameter to minimize the average customer waiting time. Let $E(W_i)$ be the expected waiting time in stage i queue, where $i = 1, 2$. For a set of feasible $c_2 > c_0^2$ and $S > S_0$, our problem of finding the optimal (c_1, c_2) can be written as

$$\min_{c_1, c_2} E(W) = (1-q)E(W_1) + q[E(W_1) + E(W_2)] = E(W_1) + qE(W_2).$$

Subject to $q_0 < q < q_{\max}$. It is very interesting to see that $E(W_1)$ is determined by μ_1, μ_2, and q, the parameters of the Coxian distribution of service time at Stage 1.

Proposition 1: $E(W_1)$ can be written as

$$E(W_1) = \frac{\frac{\lambda}{\mu_1^2} + (1-q)(\frac{\lambda}{\mu_2^2} + \frac{\lambda}{\mu_1 \mu_2})}{1 - \frac{\lambda}{\mu_1} - (1-q)\frac{\lambda}{\mu_2}}.$$

Numerically, we can demonstrate that $E(W)$ is a unimodal function of q with a single minimum. Based on the properties of the system performance measures, we develop a procedure of determining the optimal staffing level (c_1, c_2) and the inspection policy (q). There are two possible cases for the expected waiting time minimization: (Case 1) for a security check feasible case; and (Case 2) for a security check infeasible case.

A Search Procedure for Finding the Optimal Feasible q^*:

Step 1 : For a given traffic demand and a security check requirement (q_0, S_0), find an initial staffing level c_1, c_2 for the security inspection based on the tail probability constraint of $\alpha < \alpha_0$.

Step 2 : Compute $E(W)$ for $q > q_0$. If for $q_2 > q_1$, $E(W(q_2)) < E(W(q_1))$, based on the unimodual property of $E(W)$, it is Case 1. Thus, q is security-check feasible and can be used as the proportion of customers selected for the second stage inspection with the expected waiting time $E(W(q^*))$. Stop, (c_1, c_2, q) is the policy with optimum. Otherwise, it is Case 2, go to the next step.

Step 3 : If $q^* < q_0$, any increase in q will increase $E(W(q))$. This is a case where an increased staffing level with a feasible q^* for the second stage inspection should be considered. For an increased pair $(\acute{c}_1, \acute{c}_2)$ $> (c_1^0, c_2^0)$ such that q^*, q_0, $E(W(q))$ curve will shift so that the optimal q^* may become feasible. To indicate the dependence on (c_1, c_2), we denote the expected waiting time by $E(W(q)|(c_1, c_2))$.

Theorem 5.1 *Suppose the waiting cost rate is h_1 and the staffing cost rate is h_2, a policy (c_1^0, c_2^0, q_0) is said to be dominated, if there exits a policy $(\acute{c}_1, \acute{c}_2, q_0^*)$ so that $h_1\{E(W(q_0)|(c_1^0, c_2^0)) - E(W(q^*)|(\acute{c}_1, \acute{c}_2))\} > h_2\{(\acute{c}_1 + \acute{c}_2) - (c_1^0 + c_2^0)\}$.*

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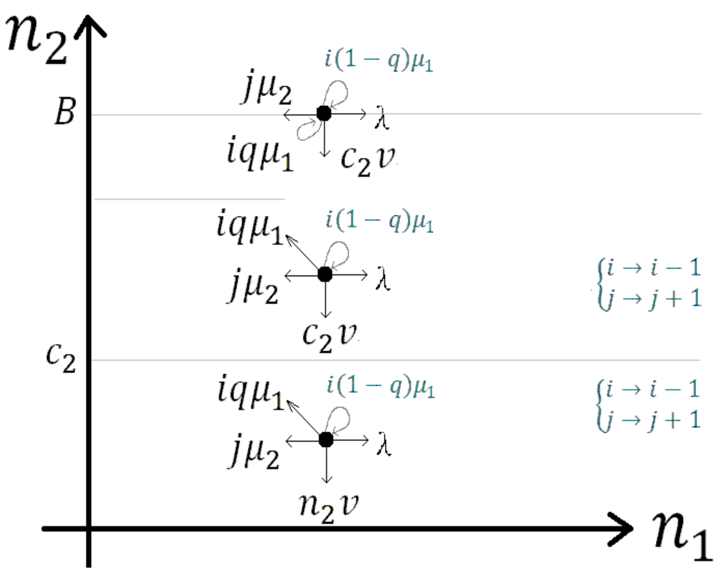

Figure 1: A possible state transitions

行政院國家科學委員會補助國內專家學者出席國際學術會議報告

102 年　10 月　20 日

報告人姓名	陸行	服務機構及職稱	政治大學應用數學系教授
時間 會議地點	2013/10/6--2013/10/12 Minneapolis, USA	本會核定補助文號	
會議名稱	(中文) (英文) The 2013 INFORMS Annual Conference		
發表論文題目	(中文) (英文) International Journal of Operations Research (IJOR)		

一、　參加會議經過

筆者原打算以研究論文提報與參加此次會議,但因受到 Informs 國際交流委員會主任 Judy Jin 教授的邀請於此會議中報告台灣的學術期刊發展的情形，因此由本人主持一個 session 邀請兩個台灣國際期刊的作者,這兩個期刊是 Journal of Industrial and Production Engineering (JIPE) 和 International Journal of Operations Research(IJOR) 報告研究和發展的情形。

我主持的這個場次在 10 月 7 日包含以下的題目和報告人：

- Title: Planning and Coordination of Scattered Hybrid Renewable Energy Systems. Presenting Author: Kuo-Hao Chang

- Title: On Deploying Vehicles for Public Electrical Scooter Sharing Systems. Presenting Author: I-Lin Wang

- Title: The Dynamic Multi-depot Vehicle Routing Problem with Pick-up and Deliveries. Presenting Author: Yiyo Kuo

- Title: International Journal of Operations Research (IJOR) Presenting Author: Hsing Luh

- Title: On Attaining the National Universities Commission Academic Staff-mix by Rank via Recruitment Policy in n-Step Presenting Author: Augustine A. Osagiede

因為 Judy Jin 教授的精心安排，在場人士有廣泛的討論和彼此介紹，IJOR 在 Informs 的會議中獲得與會學者的支持和認可，對於學術交流和台灣的知名度都有良好的影響，大家都覺得很有收獲。

10 月 8 日早上本人代表作業研究學會參加 Informs 的早餐會，藉由這會早餐會與 Informs 其他分會進行交流。在會議中不斷地推銷台灣作業研究學會發展的情形，同時邀請與會的貴賓到台灣進行學術交流。

10 月 8 日中午再次受到 Judy Jin 教授的邀請參加 Informs 國際交流午餐會，除筆者外，王逸琳教授和張國皓教授也受到邀請。我們和多國的代表交換國際交流活動的經驗，以及討論學會的發展和學生交換。也討論到產官學在各國的互動和文化差異。我們也特別邀請 Informs 的專案經理來台灣進行深化的交流，使得台灣作業研究可以與國際接軌，為台灣學術和產業帶來更多的國際機會。

這個會議是超大型的會議有超過 1000 篇的論文發表，專家學者來自世界各地的，如美國、法國、挪威、瑞典、以色列、意大利、韓國、日本、英國。內容包含作業研究的各各子領域，我選了幾個 Keynote speeches，如

- Pavel Kabát, Benefits of Systems Science for Policy Support

- Robert Haight, USDA Forest Service

- Anne Robinson, Advanced Analytics:Empowering Operations Research

- Lawrence M. Wein, Data-Driven Operations Research Analyses in the Public

Sector

- Edelman Reprise, Economically Efficient Standards to Protect the Netherlands Against Flooding
- Mark von Oven, The Physics of the Target Guest
- Dimitris Bertsimas, Health Care Analytics
- Van Hentenryck, Computational Disaster Management: The Role of OR/MS
- Guillermo Gallego, Pricing and Product Design in a Data-Driven Economy

筆者獲得許多寶貴的經驗，對未來的研究和研究議題提供深遠的影響。除了在明尼阿波利斯市參加 Informs 的會議，10 月 10 日早上搭機趕赴西華盛頓大學順道拜訪政大的姐妹校和本人的研究夥伴，討論兩校(系)的合作與學術交流的的工作與推展。

二、 與會心得

這個會議共有 276 個 sessions、超過 10 場 Keynote speeches，參與會議的人數超過 5000 人，是一個超大型的國際會議。筆者原打算以研究論文提報和參加此次會議，但因受到 Informs 國際交流委員會主任 Judy Jin 教授的邀請，於此會議中報告 International Journal of Operations Research 發展的情形。參與後發現許多值得學習的題目和研究方法。同時也可以將筆者過去研究出之評估效能的數學模型方法介紹給相關研究的學者專家。

三、 攜回資料名稱及內容

The 2013 INFORMS Annual Conference 會議手冊

四、 附錄

會議手冊網址 http://meetings.informs.org/minneapolis2013/pdfs.html

Session Detail Information

Add this session to your itinerary

Cluster : International Activities Committee

Session Information : Tuesday Oct 08, 11:00 - 12:30

Title: International Journal of Operations Research (IJOR) and Journal of Industrial and Production Engineering (JIPE)

Chair: **Hsing Luh**,NCCU, Dept of Math Science, Nat'l Chengchi Uni, No. 64. Shih Nan Road, Wen-Shan District, Taipei 116, Taiwan - ROC, slu@nccu.edu.tw

Co-Chair: **Kuo-Huang Chang**,Assistant Professor, National Tsing Hua University, No. 101, Section 2, Kuang-Fu Road, Hsinchu, Taiwan - ROC, birdhow@gmail.com

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Abstract Details

Title: Planning and Coordination of Scattered Hybrid Renewable Energy Systems

Presenting Author: **Kuo-Hao Chang**,chang@mx.nthu.edu.tw

Abstract: We propose a two-stage stochastic programming model to characterize the planning and coordination of scattered hybrid renewable energy systems when the power demand and renewable power are both uncertain. We further propose an efficient method to solve the model. Some realistic size instances are created to validate the viability of the proposed method in real settings.

Title: On Deploying Vehicles for Public Electrical Scooter Sharing Systems

Presenting Author: **I-Lin Wang**,ilinwang@mail.ncku.edu.tw

Abstract: In places of hot or rainy weather that is not biking friendly, electrical scooters may be better vehicles than bikes for a vehicle sharing system. This paper investigates how to deploy electrical scooters in each rental sites, given the estimated origin-destination demands and rates of battery consumption and charging. A mixed integer programming model will be proposed to calculate the optimal fleet deployment, as well as some interesting findings based on our preliminary computational experiments.

Title: The Dynamic Multi-depot Vehicle Routing Problem with Pick-up and Deliveries

Presenting Author: **Yiyo Kuo**,Ming Chi University of Technology, Industrial Engineering and Management, Tainan 709, Taiwan - ROC, yiyo@mail.mcut.edu.tw

Abstract: This paper considers the multi-depot vehicle routing problem which deals with two kinds of dynamic request. The first one is repair request which there is an urgent broken product need to be sent form the retail store to a depot for repair. All vehicles can provide the service immediately. The second one is sale request which there is a retail store need a product for sale immediately. The product can be sent form a depot to the store only when the vehicles have returned to depot for up load the product. A heuristic is proposed for solving the problem.

Title: International Journal of Operations Research (IJOR)

Presenting Author: **Hsing Luh**,NCCU, Dept of Math Science, Nat'l Chengchi Uni, No. 64. Shih Nan Road, Wen-Shan District, Taipei 116, Taiwan - ROC, slu@nccu.edu.tw

Abstract: : In 2003, the call for papers of first issue of the International Journal of Operations Research (IJOR) was brought out. IJOR reports on developments in Operations Research, Information Systems, and Management Sciences, including the latest research results and applications. Its aim is to meet the needs of accelerating technological change and changes in the global economy. Its abstracting/indexing includes Mathematical Reviews, EBSCOhost, Index of Information Systems Journals, CSA's Technology Research Database, CSA's Engineering Research Database, CSA's Industrial & Manufacturing Engineering Database, Zentralblatt MATH, INSPEC. Until October 2013, it has published about 30 issues. The authors come from more than 30 countries presenting research subjects among academia, government and industries.

Title: On Attaining the National Universities Commission Academic Staff-mix by Rank via Recruitment Policy in n-Step

Presenting Author: **Augustine A. Osagiede**,University of Benin, Benin City, Nigeria,

Co-Author: **Virtue U. Ekhosuehi**,University of Benin, Benin City, Nigeria, virtue.ekhosuehi@uniben.edu

Wilfred A. Iguodala,University of Benin, Benin City, Nigeria,

Abstract: We consider the unique specification of academic staff-mix by rank of the National Universities Commission (NUC) for Nigerian universities. We formulate a model consisting of systems of aggregate-fractional flow balance equations within a discrete-time Markov chain framework for each department in a faculty. Then, we iteratively solve the systems of equations using the Gaussian

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August 27, 2013

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Dear Professor Luh

I would like to invite you to come and visit me in the Beedie School of Business at Simon Fraser University from October 10 to October 13, 2013. During the visit, I would like to discuss with you on our current joint research projects, and explore more future research opportunities.

If you have any questions, please contact me at (778) 782-5559 or by e-mail via my website at http://www.sfubusiness.ca/homes/gzhang/gzhang.htm

Best regards,

Yours truly,

Zhe George Zhang

Professor in Management Science,
Beedie School of Business
Simon Fraser University

SIMON FRASER UNIVERSITY THINKING OF THE WORLD

科技部補助計畫衍生研發成果推廣資料表

日期:2014/12/30

科技部補助計畫	計畫名稱: 邊境安全檢查之等候模型與計算	
	計畫主持人: 陸行	
	計畫編號: 101-2221-E-004-002-MY2	學門領域: 作業研究

無研發成果推廣資料

101 年度專題研究計畫研究成果彙整表

計畫主持人：陸行			計畫編號：101-2221-E-004-002-MY2				
計畫名稱：邊境安全檢查之等候模型與計算							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	2	0	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	4	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	1	0	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	3	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	一篇研討會論文獲得等候理論與網路應用國際研討會最佳論文獎。

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

科技部補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

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專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

目前一篇論文在準備投稿作業中；一篇論文在審稿中。

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

開發之等候模型具有應用價值，目前正與相關單位接洽中。