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# *Prologue*

As the sixth in a series of *International Workshops on Retrial Queues*, the present one is a satellite event of the Second Madrid Conference on Queueing Theory (July 3-7, 2006). Our objective in this workshop is to provide a meeting point where scientific and technicians in the field can find a discussion forum to promote research and encourage interaction and exchange of ideas. Topics for the workshop include, but are not limited to Analytical Innovations, Approximations and Computational Methods, Control and Statistical Inference and Applications in the specific field of retrial queues.

The 6th WRQ has gathered together 23 participants from 9 countries all over the world. We would like to express our deep and sincere gratitude to these participants for their contributions and taking the trouble of coming over here from different parts of the globe. Thanks are also due to the institutions which supported the workshop (Ministerio de Educación y Ciencia and Complutense University of Madrid).

*Jesús R. Artalejo & Antonio Gómez-Corral*

# *Programme Committee*

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A. Gómez-Corral (Complutense University of Madrid, Spain)

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A. Economou (University of Athens, Greece)
A. Krishnamoorthy (Cochin University of Science and Technology, India)
R.D. Nobel (Vrije University of Amsterdam, The Netherlands)

# *General Information*

*Date*

July 8 (Saturday) – July 10 (Monday), 2006

*Venue*

The meeting will take place at *"La Cristalera"*, a conference and residence hall at 2 Km from Miraflores de la Sierra, a small village located 50 Km north of Madrid. You may visit *"La Cristalera"* website (in Spanish) at http://www.lacristalera.com.

All participants and their accompanying persons are invited to travel from Madrid to the conference venue by bus in the morning of July 8.

*Organized by*

Complutense University of Madrid

*Sponsored by*

Ministerio de Educación y Ciencia & Complutense University of Madrid

*Website*

http://www.mat.ucm.es/~mcqt/confe06/workshop.html

*Social Program*

During the workshop, participants and companions are invited for breakfast, lunch and dinner at the restaurant of *"La Cristalera"*. There will be a buffet dinner on July 8 (Saturday), 19:30-21:00.

A visit to the main historical places of Segovia is planned on July 10. The arrival to Madrid is scheduled around 19:00 hours.

*Publication*

A selection of high quality contributions presented at the 6th WRQ will be published in the special issue *"Advances in Retrial Queues"* of the *European Journal of Operational Research*.

# *Program Schedule*

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**July 8**

**Departure from Madrid:** 10:00 hours
**Arrival at "La Cristalera":** 11:00 hours
**Technical Sessions:** 15:00 hours to 18:30 hours

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13:00 – 14:15 Lunch Time

14:45 – 15:00 Opening Ceremony

**Session Sat-1** – Chair: A. Gómez-Corral

15:00 – 15:30 Title: Convergence of the stationary distributions of $M/M/s/K$ retrial queue as $K$ tends to infinity
Author: *Y.W. Shin* (Changwon National University, Korea)

15:30 – 16:00 Title: On the distribution of the number of retrials
Author: *M.J. López-Herrero* (Complutense University of Madrid, Spain)

16:00 – 16:30 Title: Retrial queueing models in discrete time
Author: *R.D. Nobel* (Vrije University of Amsterdam, The Netherlands)

16:30 – 17:00 Coffee Break

**Session Sat-2** – Chair: B. Kim

17:00 – 17:30 Title: An simple numerical approximation of joint probabilities of calls in service and calls in retrial group in a picocell
Authors: *B.D. Choi* (Korea University, Korea) and *A.Z. Melikov*

17:30 – 18:00 Title: A discrete-time $Geo/G/1$ retrial queue with independent breakdowns
Authors: *I. Atencia* and *P. Moreno* (Pablo de Olavide University, Spain)

18:00 – 18:30 Title: The $BMAP/PH/N$ retrial queueing system with breakdowns
Authors: *C.S. Kim*, *V.I. Klimenok* and *D.S. Orlovsky* (Belarusian State University, Belarus)

19:30 – 21:00 Party – Buffet Dinner

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**July 9**

**Morning Technical Sessions:** 10:00 hours to 13:30 hours
**Afternoon Technical Sessions:** 16:00 hours to 19:00 hours

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9:00 – 9:45 Breakfast Time

**Session Sun-1** – Chair: L. Lakatos

10:00 – 10:30 Title: Multi-server retrial queueing system operating in Markovian random environment
Authors: *C.S. Kim*, *V.I. Klimenok*, *V.V. Mushko* and *A.N. Dudin* (Belarusian State University, Belarus)

10:30 – 11:00 Title: The $Geo/Geo/c$ retrial queue: An algorithmic analysis
Author: *A. Gómez-Corral* (Complutense University of Madrid, Spain)

11:00 – 11:30 Title: Transient analysis of an $M/G/1$ retrial queue subject to disasters and server failures
Authors: *J. Wang* (Beijing Jiaotong University, China) and *J. Li*

11:30 – 12:00 Coffee Break

**Session Sun-2** – Chair: J.A.C. Resing

12:00 – 12:30 Title: Mobile customer model with retrials
Author: *F. Machihara* (Tokyo Denki University, Japan)

12:30 – 13:00 Title: A discrete cyclic-waiting system with collisions
Author: *L. Lakatos* (Eotvos Lorand University, Hungary)

13:00 – 13:30 Title: A discrete-time $Geo/G/1$ retrial queue with the server subject to starting failures
Authors: *I. Atencia* (University of Málaga, Spain) and *P. Moreno*

14:00 – 15:15 Lunch Time

**Session Sun-3** – Chair: M.J. López-Herrero

16:00 – 16:30 Title: Retrial queues with self-generation of priorities
Authors: *A. Krishnamoorthy* (Cochin University of Science and Technology, India), *V.C. Narayanan* and *B. Krishna Kumar*

16:30 – 17:00 Title: Estimators of the retrial rate in $M/G/1$ retrial queues
Author: *A. Rodrigo* (Complutense University of Madrid, Spain)

17:00 – 17:30 Coffee Break

**Session Sun-4** – Chair: J.R. Artalejo

17:30 – 18:00 Title: $Geo/PH/1$ queueing system with repeated attempts
Authors: *I. Atencia* (University of Málaga, Spain), *P.P. Bocharov* and *P. Moreno*

18:00 – 18:30 Title: On multiserver feedback retrial queue with finite buffer
Authors: *B. Krishna Kumar* (Anna University, India), *R. Rukmani* and *V. Thangaraj*

18:30 – 19:00 Title: Algorithmic analysis for the busy period of the $M/M/c$ retrial queue
Author: *A. Economou* (University of Athens, Greece)

19:30 – 20:45 Dinner Time

# *Abstracts*

In this section, abstracts are listed in alphabetical order of the first author.

## $Geo/PH/1$ queueing system with repeated attempts

*I. Atencia* – University of Málaga, Spain
*P.P. Bocharov* – Peoples' Friendship University of Russia, Russia
*P. Moreno* – Pablo de Olavide University, Spain

**Abstract.**– This paper is concerned with the study of a discrete-time single-server retrial queue with geometrical interarrival times and a phase-type service process. We analyze the underlying Markov chain. An iterative algorithm to calculate the stationary distribution of Markov chain is given. By using the Fast Fourier Transform we obtain numerical examples that give the probability distribution of the number of customers in the orbit related to the specific phase in which the service process is.

## A discrete-time $Geo/G/1$ retrial queue with the server subject to starting failures

*I. Atencia* – University of Málaga, Spain
*P. Moreno* – Pablo de Olavide University, Spain

**Abstract.**– This paper studies a discrete-time $Geo/G/1$ retrial queue where the server is subject to starting failures. We analyse the Markov chain underlying the regarded queueing system and present some performance measures of the system in steady-state. Then, we give two stochastic decomposition laws and find a measure of the proximity between the system size distributions of our model and the corresponding model without retrials. We also develop a procedure for calculating the distributions of the orbit and system size as well as the marginal distributions of the orbit size when the server is idle, busy or down. Besides, we prove that the $M/G/1$ retrial queue

with starting failures can be approximated by its discrete-time counterpart. Finally, some numerical examples show the influence of the parameters on several performance characteristics.

### A discrete-time $Geo/G/1$ retrial queue with independent breakdowns

*I. Atencia* – University of Málaga, Spain
*P. Moreno* – Pablo de Olavide University, Spain

**Abstract.**– Under the EAS policy, we study a discrete-time retrial queue in which external customers arrive in conformity with a Bernoulli process. The server fails independently of its state, i.e., it can break down during the idle an busy periods (passive and active breakdowns). The server lifetimes are geometrically distributed and depend on the server state. When the service station breaks down, it is immediately sent to fix with two different repair models, according to whether the failures occur in an idle or working period of the server. The customers whose services are interrupted by an active breakdown either join the orbit with a certain probability or leave the system forever with the complementary probability. Once the server is completely repaired, it waits the arrival of external or repeated customers in order to provide them their services.

### An simple numerical approximation of joint probabilities of calls in service and calls in retrial group in a picocell

*B.D. Choi* – Korea University, Korea
*A.Z. Melikov* – National Academy of Science, Azerbaijan

**Abstract.**– In this paper, we consider a single cell in a wireless network with new calls and handoff calls where a fixed number of guard channels is reserved for handoff calls and blocked new calls will enter to the retrial group with a positive probability and they retry again after exponential retrial time.

Let us describe the system in details. An isolated cell in a wireless networks contains $N + R$ channels. New calls (or originating calls) are generated by Poisson process with rate $\lambda_n$ and handoff calls are generated by Poisson process with rate $\lambda_h$. If upon arrival of handoff call there are free channels in the cell, the handoff call occupies one channel and is connected to continue; otherwise the call is forced to terminate the connection and blocked handoff call will be lost i.e, will not redial. Arriving new call (fresh or blocked) is not admitted if upon its arriving moment the number of occupied

channels is greater than or equal to $N$. The blocked fresh new call will enter to the retrial group with probability $\gamma$ and will leave the system forever with probability $1-\gamma$. The blocked calls after an unsuccessful retrial return to retrial group again with probability $\delta$ and leave the system with probability $1-\delta$. The retrial time for each blocked call is exponentially distributed with rate $\theta$ and channel holding time of both calls are exponential with rate $\mu$.

Let $X_1(t)$ be the number of calls in services and $X_2(t)$ be the number of blocked new calls in the retrial group at time $t$. Then $(X_1(t), X_2(t))$ is 2-dimensional continuous time Markov chain. We are interested in the limiting distribution of CTMC $(X_1(t), X_2(t))$ as far as the author's knowledge is concerned, exact analytic solution of the stationary distribution of the given CTMC with $\delta > 0$ is not known yet. We will provide a simple numerical approximation of joint probabilities by state space merging principle.

## Algorithmic analysis for the busy period of the $M/M/c$ retrial queue

*A. Economou* – University of Athens, Greece

**Abstract.**– The main multiserver retrial queue of $M/M/c$ type with exponential repeated attempts is known to be analytically intractable due to the spatial homogeneity of the underlying Markov chain, caused by the retrial feature. For this reason several models have been proposed for approximating its stationary distribution, that lead to satisfactory numerical implementations. In this talk we present algorithmic procedures for calculating the busy period distribution of the main approximation models of Wilkinson (1956), Falin (1983) and Neuts and Rao (1990). We also present stable recursive schemes for the computation of the busy period moments. The corresponding distributions for the total number of customers served during a busy period can also be studied using this methodology. Several numerical scenarios that illustrate the use of the methods will be also presented.

## The $Geo/Geo/c$ retrial queue: An algorithmic analysis

*A. Gómez-Corral* – Complutense University of Madrid, Spain

**Abstract.**– In this talk, we consider a discrete-time queue of $Geo/Geo/c$ type with geometric repeated attempts. It is known that its continuous counterpart, namely the $M/M/c$ queue with exponential retrials, is analytically intractable due to the spatial heterogeneity of the underlying Markov chain, which is caused by the retrial feature. In discrete-time, the occur-

rence of multiple events at each slot increases the complexity of the model and raises further computational difficulties. We first notice that the underlying Markov chain describing the system state can be thought of as a level-dependent Markov chain of $GI/M/1$-type. We propose several algorithmic procedures for the efficient computation of the main performance measures of the system. Specifically, we investigate the stationary distribution of the system state, the busy period and the waiting time. Several numerical examples illustrate our analysis.

**Multi-server retrial queueing system operating in Markovian random environment**

*C.S. Kim* – Sangji University, Korea
*V.I. Klimenok* – Belarusian State University, Belarus
*V.V. Mushko* – Belarusian State University, Belarus
*A.N. Dudin* – Belarusian State University, Belarus

**Abstract.**– Multi-server retrial queueing system with the Batch Markovian Arrival Process (BMAP) and phase type (PH) service time distribution is considered. The processes of customers arrival, service and retrial depend on the state of an external finite state Markovian process called as random environment. Sufficient condition for ergodicity of the multi-dimensional continuous time Markov chain describing the state of the system is derived. Stationary distribution of this Markov chain is computed. Main performance measures of the system are calculated. Numerical results are presented. Opportunity of simple approximations for the main performance measures of the system is discussed.

**The $BMAP/PH/N$ retrial queueing system with breakdowns**

*C.S. Kim* – Sangji University, Korea
*V.I. Klimenok* – Belarusian State University, Belarus
*D.S. Orlovsky* – Belarusian State University, Belarus

**Abstract.**– A multi-server retrial queue with the Bath Markovian Arrival Process (BMAP) is considered. The servers are identical and independent of each other. The service time distribution of a customer by a server is of the phase (PH) type. If a group of primary calls meets idle servers the primary calls occupy the corresponding number of servers. If the number if idle servers is insufficient the rest calls go to the orbit of unlimited size and repeat their attempts to get service after exponential amount of time independently of each other. Busy servers are subject to breakdowns and

repairs. The common flow of breakdowns is the MAP. An event of this flow with equal probability causes a failure of any busy server. When a server fails the repair period starts immediately. This period has PH type distribution and does not depend on the repair time of other broken-down servers and the service time of customers occupying the working servers. A customer whose service was interrupted goes to the orbit with some probability and leaves the system with the supplementary probability. We derive the ergodicity condition and calculate the stationary distribution and the main performance characteristics of the system. Illustrative numerical examples are presented.

**On multiserver feedback retrial queue with finite buffer**

*B. Krishna Kumar* – Anna University, India
*R. Rukmani* – Madras University, India
*V. Thangaraj* – Madras University, India

**Abstract.**– This paper deals with a multiserver feedback retrial queueing system with finite waiting position and constant retrial rate. This system is analyzed as a quasi-birth-and-death (QBD) process and the necessary and sufficient condition for stability of the system is investigated. Some important system performance measures are obtained using matrix geometric method. The effect of various parameters on the system performance measures are illustrated numerically. Finally, the algorithmic development of the full busy period for the model under consideration is discussed.

**Retrial queues with self-generation of priorities**

*A. Krishnamoorthy* – Cochin University of Science and Technology, India
*V.C. Narayanan* – Government Engineering College, Sreekrishnapuram, India,
*B. Krishna Kumar* – Anna University, India

**Abstract.**– We consider a retrial queue where arrival forms an MAP. Customers encountering a busy server will have to go to the orbit and try their luck in accessing it. This follows a linear retrial rate. While in the orbit customers may generate priority and will proceed to the service station immediately. If the server is busy with a priority generated customer such a customer leaves the system for ever. Else the server takes this customer, pre-empting the service of the ordinary unit in service. Service times follow PH distribution. The long run system state distribution is numerically computed. Several performance measures are also obtained. Further the results

are illustrated numerically.

### A discrete cyclic-waiting system with collisions

*L. Lakatos* – Eotvos Lorand University, Hungary

**Abstract.**– We consider a discrete time queueing system functioning in the following way: if the entering entity cannot be taken for service, it is cycling with a constant cycle time $T$ equal to $n$ time units. The following requests for service may be put only at moments differing from the moment of arrival by the multiples of cycle time $T$, i.e. reaching again the starting position.

By Kovalenko's proposal we examine such system with customers of two types, the customers of first type may only join the free system and there can stay only one of them, there is no restriction on the customers of second type. The interarrival and service times have geometrical distributions. The states of system are defined as the number of present customers at moments just before starting their services. For a time unit there is possible the simultaneous entry of customers of both types, i.e. collisions may appear. We examine three possibilities: 1. in case of collision both customers are refused and lost, 2. both customers are accepted and first we deal with the customer of first type, 3. the customer of first type is accepted, the customer of second type is refused. We find the condition of equilibrium and the ergodic distribution.

### On the distribution of the number of retrials

*M.J. López-Herrero* – Complutense University of Madrid, Spain

**Abstract.**– We deal with the number of repeated attempts produced by a customer until he reaches a free server. The main objective is the numerical computation of the stationary distribution of the number of retrials made by a customer during his waiting time. We consider two basic models: the $M/G/1$ retrial queue and the $M/M/c$ retrial queue.

### Mobile customer model with retrials

*F. Machihara* – Tokyo Denki University, Japan

**Abstract.**– A cellular system consisted of small zones is studied. Since their zones are small, the change of the number of mobile customers in a

cell gives influence on the performance. The hand-off failure probability and blocking probability may be important as the performance measures. In this paper, we consider the retrial behavior of customers who meet the hand-off failure and blocking. We classify customers into three types: the retrial resignation type, the ordinary retrial type and the persistent retrial type. We evaluate the effect of the existence of the mobile customers with retrials.

**Retrial queueing models in discrete time**

*R.D. Nobel* – Vrije University of Amsterdam, The Netherlands

**Abstract.**– An overview will be presented of recent results on one-server retrial queues in discrete time. In these queueing models the time-axis is divided in slots and time is only counted in slots. Characteristic of all the models discussed is that, when upon arrival a customer finds the server busy this customer is not put in a queue, but is 'sent into orbit', i.e. a virtual waiting space from which the customer will approach the server some random time later. New arrivals are called primary arrivals and arrivals from the orbit secondary arrivals. In all models the number of primary arrivals in a slot follows a general probability distribution and the different numbers of primary arrivals in consecutive time slots are mutually independent. Each customer requires from the server a generally distributed number of slots for his service. All service times are mutually independent. Customers arriving in a slot can start a service only at the beginning of the next slot. This is called *Delayed Access*. When upon arrival in a slot customers find the server idle, then one of the incoming customers (randomly chosen) in that slot starts its service at the beginning of the next slot, whereas the other incoming customers in that slot, if any, are sent into orbit. During each slot the customers in the orbit try to reenter the system individually, independently of each other, with a given retrial probability. Arrivals have precedence over departures. For this reason the models discussed are termed *Late Arrival Systems*.

We will discuss three different models, all extensions or variants of the basic model described succinctly above. The first extension is that the arrivals can be of two types with a different priority. So-called type-1 customers have a non-preemptive priority over the type-2 customers. Only the type-2 customers are sent into orbit when they find the server busy upon arrival, whereas the type-1 customers are lost in that case. Type-1 and type-2 customers have different service times and follow a different arrival pattern.

The second variant of the basic model is a model with feedback: upon a service completion the customer is sent back to the orbit with a given feedback probability to compete for another service.

The third variant concerns a model in a random environment. The environment is always in one of two states, say green or orange, and the arrival pattern of the customers is different for these states. The environment switches, non-intermittently and independently from any other event, from green to orange and vice versa. The number of slots between two consecutive transitions of the environment follows a geometric distribution with a transition-dependent parameter. So the (random) duration in the green state is different from the duration in the orange state.

For all these models the generating function of the equilibrium distribution of the number of customers in orbit is calculated. From the generating function several performance measures are deduced, like the average orbit size. Also the mean busy period, defined as the time lapse from the start of a service after the server has been idle with no customers in orbit, until the first time slot that the server becomes idle while the orbit is empty again, is discussed. Extensive numerical results will be presented.

### Estimators of the retrial rate in $M/G/1$ retrial queues

*A. Rodrigo* – Complutense University of Madrid, Spain

**Abstract.**– In this article we analyze the $M/G/1$ retrial queue from a statistical viewpoint. Assuming that retrials are exponentially distributed we focus on the estimation of the retrial parameter for constant and non constant retrial policies, including the nonergodic case. We consider different estimators and compare their asymptotic variances. We test numerically the accuracy of the proposed estimators.

### Convergence of the stationary distributions of $M/M/s/K$ retrial queue as $K$ tends to infinity

*Y.W. Shin* – Changwon National University, Korea

**Abstract.**– We consider an $M/M/s/K$ retrial queue with $s$ identical servers and $K-s$ waiting positions and the retrial rates that depend on the number of customers in orbit. We investigate the convergence of the stationary distributions $x(K)$ of $M/M/s/K$ retrial queue to the stationary distribution $x$ of $M/M/s$ queue as $K$ tends to infinity. It is showed $x(K)$ converges geometrically to $x$ and the convergence rate is characterized by the traffic intensity. The result is proved by comparing with the stationary distributions of some censored Markov chains and $M/M/s/K$ retrial queue with constant retrial rate.

**Transient analysis of an $M/G/1$ retrial queue subject to disasters and server failures**

*J. Wang* – Beijing Jiaotong University, China
*J. Li* – Beijing Jiaotong University, China

**Abstract.**– An $M/G/1$ retrial queueing system with disasters and unreliable server is investigated in this paper. Primary customers arrive in the system according to a Poisson process, and they will receive service immediately if the server is available upon arrival. Otherwise, they will enter a retrial orbit and try their luck after a random time interval. We assume the catastrophes arrive following Poisson stream, and if a catastrophe occurs, all customers in the system are deleted immediately and it also causes the server's breakdown. Besides, the server has an exponential lifetime in addition to the catastrophe process. When the server breaks down, it is sent to repair immediately. It is assumed that the service time and two kinds of repair time of the server are all arbitrarily distributed. By applying the supplementary variables method, we obtain the transient and steady-state solutions for both queueing measures and reliability quantities of interest.

# *List of Participants*

Julia Amador
Complutense University of Madrid
School of Statistics
28040 Madrid, Spain
E-mail: jamador@estad.ucm.es

Jesús Artalejo
Complutense University of Madrid
Department of Statistics and Operations Research
Faculty of Mathematics
28040 Madrid, Spain
E-mail: jesus_artalejo@mat.ucm.es

Iván Atencia
University of Málaga
Department of Applied Mathematics
E.T.S.I. de Telecomunicación – Campus de Teatinos
29013 Málaga, Spain
E-mail: iatencia@ctima.uma.es

Bong Dae Choi
Korea University
Department of Mathematics and TMRC
Anam-dong, Seongbuk-gu
136-713 Seoul, Korea
E-mail: queue@korea.ac.kr

Alexander N. Dudin
Belarusian State University
4, Independence Avenue
Minsk-30, 220030, Belarus
E-mail: dudin@bsu.by

Antonis Economou
University of Athens
Department of Mathematics
Section of Statistics and Operations Research
15784 Athens, Greece
E-mail: aeconom@math.uoa.gr

Antonio Gómez-Corral
Complutense University of Madrid
Department of Statistics and Operations Research
Faculty of Mathematics
28040 Madrid, Spain
E-mail: antonio_gomez@mat.ucm.es

Spyridoula Kanta
University of Athens
Department of Mathematics
Section of Statistics and Operations Research
15784 Athens, Greece
E-mail: spkanta@math.uoa.gr

Stella Kapodistria
University of Athens
Department of Mathematics
Section of Statistics and Operations Research
15784 Athens, Greece
E-mail: stellakap@math.uoa.gr

Bara Kim
Korea University
Department of Mathematics and TMRC
1, Anam-dong, Sungbuk-ku
136-701 Seoul, Korea
E-mail: bara@korea.ac.kr

B. Krishna Kumar
Anna University
Department of Mathematics
College of Engineering
600 025 Chennai, India
E-mail: drbkkumar@hotmail.com

A. Krishnamoorthy
Cochin University of Science and Technology

Department of Mathematics
682022 Kochi, India
E-mails: ak@cusat.ac.in; akcusat@yahoo.com

Laszlo Lakatos
Eotvos Lorand University
ELTE Department of Computer Algebra
P.O.B. 32
H-1518 Budapest, Hungary
E-mail: lakatos@compalg.inf.elte.hu

María Jesús López-Herrero
Complutense University of Madrid
School of Statistics
28040 Madrid, Spain
E-mail: lherrero@estad.ucm.es

Fumiaki Machihara
Tokyo Denki University
Hatoyama, Hikigun
350-0394 Saitama, Japan
E-mail: fumi@j.dendai.ac.jp

María Pilar Moreno
Pablo de Olavide University
Department of Economics, Quantitative Methods
and Economic History
Faculty of Business Studies
41013 Seville, Spain
E-mail: mpmornav@upo.es

Shoichi Nishimura
Tokyo University of Science
1-3 Kagurazaka, Shinjuku-ku
162-8601 Tokyo, Japan
E-mail: nishimur@rs.kagu.tus.ac.jp

Rein D. Nobel
Vrije University of Amsterdam
Department of Econometrics
De Boelelaan 1105
1081 HV Amsterdam, The Netherlands
E-mail: rnobel@feweb.vu.nl

Dmitry S. Orlovsky
Belarusian State University
4, Independence Avenue
Minsk-30 220030, Belarus
E-mail: odms@tut.by

Jacques A.C. Resing
Eindhoven University of Technology
Department of Mathematics and Computer Science
P.O. Box 513
5600 MB Eindhoven, The Netherlands
E-mail: j.a.c.resing@tue.nl

Antonio Rodrigo
Complutense University of Madrid
Department of Economics
Faculty of Economics
28223 Madrid, Spain
E-mail: arodrigo@ccee.ucm.es

Yang Woo Shin
Changwon National University
Department of Statistics
9 Sarim-dong, Changwon
641-773 Gyeongnam, Korea
E-mail: ywshin@changwon.ac.kr

Jinting Wang
Beijing Jiaotong University
Department of Mathematics
100044 Beijing, China
E-mails: wjting@yahoo.com; jtwang@center.njtu.edu.cn