

*3rd meeting of the EURO Working Group on  
Stochastic Modelling*

*StochMod10*

*June 7-9, 2010*

*Amalia Hotel*

*Nafplio, Greece*

*Book of Abstracts*

*Organized by  
Department of Mathematics  
University of Athens*



## Prologue

We welcome you to Nafplio for StochMod10.

This meeting is the third in a series aiming to promote research and encourage interaction in the working group of stochastic modelling. The first meeting of the EURO Working Group on Stochastic Modelling was held from 19th April until 21st April 2006 at the Department of Mathematics at the Vrije Universiteit in Amsterdam, The Netherlands. The second meeting was held from 23rd June until 25th June 2008 at Koc University in Istanbul, Turkey.

Stochastic modelling is an active research field with much interaction between theory and practice. Up to now there was no platform for European researchers working within this broad field. This explains the idea for a European Working Group on Stochastic modelling. In June 2004 this was first proposed to EURO, the Association of European Operational Research Societies. The Working Group is concerned with all aspects, both theoretical and practical, of mathematical modelling using stochastic models. The areas of interest include, but are not restricted to performance analysis of telecommunication systems, the modelling of logistics and service systems, the theory of queueing and inventory models, revenue management, stochastic models in finance and more.

The meeting brings together 41 participants from 14 countries. We would like to express our appreciation to all participants for contributing and presenting their work. We also thank the University of Athens for economic and administrative support.

Nafplio, June 7, 2010

*Apostolos Burnetas & Antonis Economou*

## Scientific Program Committee

Z. Aksin (Koc University, Turkey)

A. Burnetas (University of Athens, Greece), chair

A. Economou (University of Athens, Greece)

F. Karaesmen Koc University, Turkey)

G. Koole (VU University Amsterdam, The Netherlands)

L. Ormeci (Koc University, Turkey)

P. Chevalier (Universite catholique de Louvain, Belgium)

## General Information

### *Dates*

June 7 (Monday) – June 9 (Wednesday), 2010

### *Conference Venue*

*Hotel Amalia*, Nafplio, Greece.

### *Website*

<http://www.math.uoa.gr/stochmod10/>



# *Program Schedule*

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**Monday June 7, 2010**

**Session M1: Plenary Talk**

**Session M2: Call Centers**

**Session M3: Inventory and Capacity Management**

**Session M4: Queueing – Optimization**

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09:00 – 09:15 Welcome

**Session M1: Plenary Talk**

09:15 – 10:15 Title: Polling

Author: Onno Boxma

10:15 – 10:45 Coffee break

**Session M2: Call Centers** (Chair Ger Koole)

10:45 – 11:05 Title: Call Centers with Delay Information: Models and Insights

Authors: Oualid Jouini, Zeynep Aksin, Yves Dallery

11:05 – 11:25 Title: Staffing a Contract Center with Uncertain Non-Stationary Arrival Rates, Agents Flexibility and Global Service Level Constraint

Authors: Shuangqing Liao, Christian Van Delft, Ger Koole, Oualid Jouini

11:25 – 11:45 Title: Approximate Dynamic Programming techniques for the control of time-varying queueing systems applied to call centers with abandonments and retrials

Authors: Sandjai Bhulai, Dennis Roubos

11:45 – 12:05 Title: Modeling Customer Reactions to Sales Attempts: If Cross-Selling Backfires

Authors: Evrim Gunes, Zeynep Aksin, Lerzan Örmeci, Hazal Ozden

12:05 – 12:25 Title: Practice and theory of skill-based routing in call centers

Author: Ger Koole

12:35 – 13:50 Lunch

**Session M3: Inventory and Capacity Management** (Chair Fikri Karaesmen)

13:50 – 14:10 Title: Inventory Rationing Policy for Spare Parts  
Authors: Baris Balcioglu, Pedram Sahba, Dragan Banjevic

14:10 – 14:30 Title : Optimal Decision Rules for Product Recalls  
Authors : Ali Devin Sezer, Cagr Haksoz

14:30 – 14:50 Title: Equilibria characterization in a two-player auction with maximum and minimum capacity constraints  
Authors : Panagiotis Andrianesis, George Liberopoulos

14:50 – 15:10 Title: A multi-objective stochastic programming model for designing robust supply chain networks  
Author : Amir Azaron

15:10 – 15:30 Title: Dynamic Pricing of Inventories with Non-Uniform Quality Levels  
Authors : Fikri Karaesmen, Seray Aydin, Yalcin Akcay

15:30 – 16:00 Coffee Break

**Session M4: Queueing – Optimization** (Chair Mark Lewis)

16:00 – 16:20 Title: Optimal Strategies in the observable constant retrial queue  
Authors : Spyridoula Kanta, Antonis Economou

16:20 – 16:40 Title : Customer Equilibria in an Observable  $M/M/1$  Queue with Dynamic Service Control  
Authors : Ioannis Dimitrakopoulos, Apostolos Burnetas

16:40 – 17:00 Title: Equilibrium balking behavior in an unreliable queue with complete removals at failure epochs  
Authors : Olga Boudali, Antonis Economou

17:00 – 17:20 Full-Service Policy Optimality with Heterogeneous Servers  
Authors : William Millhiser, Charu Sinha, Matthew Sobel

17:20 – 17:40 Flexible Server Allocation and Customer Routing Policies for Two Parallel Queues when Service Rates are not Additive  
Authors : Mark Lewis, Hyun-soo Ahn



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**Tuesday June 8, 2010**

**Session T1: Queueing – Performance Evaluation**

**Session T2: Markov Decision Processes and Applications**

**Session T3: Stochastic Models and Statistics**

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**Session T1: Queueing – Performance Evaluation** (Chair Michael Zazanis)

08:30 – 08:50 Title: Queueing Systems with Appointment-Driven Arrivals, Non-Punctual Customers, and No-Shows

Authors : Oualid Jouini, Saif Benjaafar

08:50 – 09:10 Title: Approximation of transient performance measures of service systems with retrials

Authors : Raik Stolletz

09:10 – 09:30 Title: On priority queues with gradual preemption

Authors : Tom Maertens, Joris Walraevens, Marc Moeneclaey, Herwig Bruneel

09:30 – 09:50 Title: Analytical study of a queueing system with non-geometric tail behavior

Authors : Mark Van Lokeren, Bart Steyaert and Herwig Bruneel

09:50 – 10:10 Title: Residual service times in the M/G/1 queue conditioned on the queue length: revisiting an old problem

Author : Michael Zazanis

10:20 – 10:45 Coffee break

**Session T2: Markov Decision Processes and Applications** (Chair Lerzan Örmeci)

10:45 – 11:05 Title: Optimal stopping of Markov chain, Gittins Index and Related Optimization Problems

Author : Isaac Sonin

11:05 – 11:25 Title: 2. Stochastic Inventory Models with an Option in Delivery Time Upgrade

Authors : Houmin Yan, Xiaoying Liang

11:25 – 11:45 Title: Structured Optimal Policies in Robust Dynamic Programming

Authors : Zeynep Turgay, Fikri Karaesmen, Lerzan Örmeci

11:45 – 12:05 Title: A Modeling Framework for Control of Preventive Services

Authors : Lerzan Örmeci, Derya Kunduzcu, Evrim Didem Gunes

**Session T3: Stochastic Models and Statistics** (Chair Katsunori Ano)

12:30 – 12:50 Title: Application of the new OPLS-DA statistical modeling technique to manage large number of variables in a burn injury case control study

Authors : Homayoun Sadeghi-Bazargani, Shrikant Bangdiwala, Reza Mohammadi, Kazem Mohammad

12:50 – 13:10 Title: Adaptive Sampling Under Incomplete Information and a Sample-Path Cost Constraint

Authors : Odisseas Kanavetas, Apostolos Burnetas

13:10 – 13:30 Title: Diffusion processes over products of simplices

Authors : Panayotis Mertikopoulos and Aris Moustakas

13:30 – 13:50 Title: Bayesian real swing option on the geometric random walk

Author : Katsunori Ano

14:00 – 15:00 Lunch

16:00 Excursion to Epidaurus

21:00 Conference Dinner

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**Wednesday June 9, 2010**

**Session W1: Applied Probability**

**Session W2: Inventory Management**

**Session W3: Plenary Talk**

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**Session W1: Applied Probability** (Chair Stella Kapodistria)

08:30 – 08:50 Title: Results on convolutions of compound geometric distributions

Author : Georgios Psarrakos

08:50 – 09:10 Title: Flow Time Analysis of a Continuous Sampling Plan Policy

Authors : George Mytalas, Michael Zazanis

09:10 – 09:30 Title:  $GI/M/1$  Markov chains with a level-phase independent stationary distribution

Authors : Safieh Mahmoodi, Guy Latouche

09:30 – 09:50 Title: Continuous-time Markov Chains with Binomial Transitions: Modeling, Analysis and Applications to Queueing Systems with Synchronized Events

Authors : Stella Kapodistria and Antonis Economou

10:00 – 10:20 Coffee break

**Session W2: Inventory Management** (Chair Dimitrios Pandelis)

10:20 – 10:40 Title: An  $(s - 1, s)$  Inventory System with General Product Lifetimes and Customer Impatience

Authors : Stratos Ioannidis, Oualid Jouini, Angelos Economopoulos, Vassilis Kouikoglou

10:40 – 11:00 Title: Optimal  $(r, nQ, T)$  Inventory Control under Stationary Demand

Authors : Athanasios Lagodimos, Ioannis Christou, Konstantina Skouri

11:00 – 11:20 Title: Periodic review  $(R, T)$  inventory control policy for stochastic demand and yield

Authors : Konstantina Skouri, Athanasios Lagodimos and Ioannis Konstantaras

11:20 – 11:40 Title: A Stochastic Delivery-Pickup Problem

Authors : Dimitrios Pandelis, Constantinos Karamatsoukis, Epaminondas Kyriakidis

**Session W3 : Plenary Tank**

12:00 – 13:00 Title: Markov Decision Processes with Applications

Author : Ulrich Rieder



# Abstracts\*

## *Polling*

Onno Boxma

### **Abstract**

We consider a multi-class single-server polling model with switchover times. Throughout the vast polling literature, it is almost always assumed that customers arrive at the queues according to independent Poisson processes, having independent service requirements. The resulting input processes in the queues thus constitute independent compound Poisson processes (CPP). We relax this assumption in several ways. First, we let the input process  $W$  change at polling and switching instants; in classical polling models, the arrival rates and service requirement distributions are typically fixed once and for all. Second, we consider Levy-driven, possibly correlated input, i.e., we assume that the input process is an  $N$ -dimensional Levy subordinator (increasing process), where  $N \geq 1$  corresponds to the number of queues. The generalization from CPPs to Levy input implies that we can no longer speak of customers. Instead, the focus will now be on another key performance measure of polling systems, viz., the (joint) workload process.

By considering the input as an  $N$ -dimensional Levy process  $W$  instead of  $N$  one-dimensional processes  $W_i$ , we accomplish an easy incorporation of correlation between input to different queues. This stems from the fact that every Levy process is uniquely characterized by its characteristic exponent, which in the multidimensional case also contains the correlation structure between the coordinates.

Resing (QUESTA 13, 1993) has shown that for a large class of classical polling models, including those with exhaustive or gated visit discipline at all queues, the evolution of the queue-length process at successive polling instants at a fixed queue can be described as a multi-type branching process (MTBP) with immigration. Models that satisfy this MTBP structure allow for an exact analysis, whereas models that violate the MTBP-structure are often much more intricate. Analogously, we identify a class of visit disciplines (again including exhaustive and gated) that allows to describe the multidimensional workload in the system at successive polling instants at a fixed queue as a multi-type continuous state space (discrete time) branching process. This branching process is referred to in the sequel as MTJBP due to Jirina (Czechosl. Math. J. 8, 1958), who introduced the notion of continuous state space branching processes and gave special attention to discrete time processes (called Jirina processes in the literature).

We are thus able to obtain the LST of the joint steady-state workload at polling instants. Following a martingale approach we finally use that LST to obtain the LST of the joint workload at arbitrary instants.

Note: This is joint work with Jevgenijs Ivanovs, Kamil Kosinski and Michel Mandjes

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\* Abstracts are listed according to the program.

# *Call Centers with Delay Information: Models and Insights*

Oualid Jouini, Zeynep Aksin and Yves Dallery

## **Abstract**

We analyze a call center with impatient customers. We study how informing customers about their anticipated delays affects performance. Customers react by balking upon hearing the delay announcement, and may subsequently renege, particularly if the realized waiting time exceeds the delay that has originally been announced to them. The balking and renegeing from such a system are a function of the delay announcement. Modeling the call center as an  $M/M/s + M$  queue with endogenized customer reactions to announcements, we analytically characterize performance measures for this model. The analysis allows us to explore the role announcing different percentiles of the waiting time distribution, i.e., announcement coverage, plays on subsequent performance in terms of balking and renegeing. Through a numerical study we explore when informing customers about delays is beneficial, and what the optimal coverage should be in these announcements. It is shown how managers of a call center with delay announcements can control the tradeoff between balking and renegeing, through their choice of announcements to be made.

*Keywords:* queues; call centers; impatient customers; state-dependent analysis; announcing delays.

# *Staffing a Contract Center with Uncertain Non-Stationary Arrival Rates, Agents Flexibility and Global Service Level Constraint*

Shuangqing Liao, Christian Van Delft, Ger Koole and Oualid Jouini.

## **Abstract**

This paper considers a multi-periodic multi-shift contract center staffing problem with two types of jobs: calls and emails. The arrival rate of calls is random and non-stationary. The workforce presents some flexibility: the agents can be affected to one job type in real-time. For calls, the contract center is subject to a global service level constraint for the whole day and a minimum service level constraint per period in a day. Emails are answered with a 1-day delay. All the emails to handle in a day are then available at the beginning of the day.

The staffing problem is modeled as a newsboy-type model under an expected cost criterion. The problem is to minimize the cost of shifts, under constraints on the global service level and the minimum service level per period for calls. Penalty costs are added if the emails cannot be answered during regular work hours or if some service level constraints for calls are not met. We underline that the service level constraints for calls are modeled in any accurate way instead of using an approximation.

We then consider three different approaches in order to solve the optimization problem. First, we explicitly formulate the expected cost newsboy-type formulation as a stochastic program. Second, the formulation is extended to the conditional value-at-risk (CVaR) setting. Third, we develop the robust optimization approach. While the formers require a discrete set of scenarios, the robust optimization approach has the computational advantage that it only requires to solve some “worse case” scenario. It is computationally much faster.

The proposed approaches are evaluated with real data obtained from the call center of a Dutch hospital. Computational results show that the robust approach is highly tractable. We show in addition that the stochastic approaches are much better than the deterministic approach (which ignores the randomness in arrival rates) as the penalty costs increase. Blending calls and emails help reduce the total cost and the variance of the cost.

*Keywords:* contact centers staffing; uncertain arrival parameters; stochastic programming; robust programming; global service.

## *Approximate Dynamic Programming techniques for the control of time-varying queueing systems applied to call centers with abandonments and retrials*

Sandjai Bhulai and Dennis Roubos

### **Abstract**

In this presentation we develop techniques for applying Approximate Dynamic Programming (ADP) to the control of time-varying queueing systems. First, we show that the classical state space representation in queueing systems leads to approximations that can be significantly improved upon by increasing the dimensionality of the state space by state disaggregation. Second, we deal with time-varying parameters by adding them to the state space with an ADP parameterization. We demonstrate these techniques for the optimal admission control in a retrial queue with abandonments and time-varying parameters. The numerical experiments show that our techniques have near to optimal performance.

*Keywords:* call centers; approximate dynamic programming; time-varying systems; markov decision theory.

## *Modeling Customer Reactions to Sales Attempts: If Cross-Selling Backfires*

Evrin Didem Gunes, Zeynep Aksin, Lerzan Ormeci and Hazal Ozden

### **Abstract**

Cross-selling attempts, based on estimated purchase probabilities, are not guaranteed to succeed and such failed attempts may annoy customers. There is a general belief that cross-selling may backfire if not implemented cautiously, however there is not a good understanding of the nature and impact of this negative reaction or appropriate policies to counter-balance it. This paper focuses on this issue and develops a modeling framework that makes use of a Markov decision model to account for negative customer reactions to failed sales attempts, and the effect of past contacts in managing cross-selling initiatives. Three models are analyzed, where purchase probabilities are affected from customer maturity or the number of failed attempts since the last purchase, or both. The analysis shows that customer reactions to cross-sell attempts make the purchase probabilities endogenous to the firms cross-selling decisions; hence the optimal cross-selling policy becomes a function of customer state. The results highlight the role the cost of excessive cross-selling (direct as well as in the form of customer reactions) plays in optimal policies. Cross-sell data from a retail bank illustrates in what context the modeling framework can be applied and underlines the importance of customizing cross-sell policies to individual customers.

*Keywords:* Markov decision model; call center; cross-sellingabstract.

# *Practice and theory of skill-based routing in call centers*

Ger Koole

## **Abstract**

We discuss call routing in call centers, with a special emphasis on routing based on waiting time thresholds. We discuss both practical issues (based on work of Pim Thomassen) and theoretical work (joint work with Ren Bekker, Bo Nielsen, and Thomas Nielsen).

*Keywords:* call centers; queueing.

# *Inventory Rationing Policy for Spare Parts*

Pedram Sahba, Baris Balcioglu and Dragan Banjevic

## **Abstract**

We consider a system with different fleets of machines and assume that each machine can fail due to a single type of repairable critical component. Failed components are repaired in a centralized repair shop. There is also a centralized spare part inventory of these components operated according to an inventory rationing (IR) policy. Under the IR policy, there exists a rationing level for each fleet. Higher the rationing level, lower-priority is the fleet. When a machine fails, if the inventory level is above the rationing level of its fleet, a spare part is immediately installed decreasing the inventory level by 1 and the machine continues running without interruption. Otherwise, no spare part is installed and the machine is down until the inventory level climbs up to the rationing level and the repair shop can dispatch a repaired component. This implies that when a failed component is repaired, it is not dispatched to fleets with down machines unless the inventory level is at their rationing levels. Thus, when the inventory level is not at a rationing level, the repaired component is placed in inventory to increase the inventory level by 1.

Although the IR policy is analyzed exactly in production/inventory systems where customer arrival rates are constant, in our problem its exact analysis is not possible for more than 3 threshold levels. This is due to the effect of spare parts on state dependent failure rates from each fleet. Therefore, we analyze this problem approximately when more rationing levels are needed. To do this, we use a sequence of queueing systems. Each queue is indexed with a rationing level/fleet  $r$  and is employed to obtain the distribution of down machines in fleet  $r$ . Each one of these queues is a single server queue serving a finite number of customers (corresponding to the machines in fleet  $r$ ). Additionally, the server is subject to interruptions (corresponding to the time the repair shop is busy repairing components for higher-priority fleets). The server can be interrupted (corresponding to a failure in a higher-priority fleet) while it is idle (corresponding to times when there are no down machines in fleet  $r$ ) or busy (corresponding to times when there are no orders from higher-priority fleets but from fleet  $r$ ). Our method is approximate since we approximate the distribution of the length of the interruption by simple Phase-Type distributions. We test the accuracy of our approximation in finding the optimal rationing levels as well as the system cost under the IR policy. We also compare the performance of the IR policy with two alternative systems. In both alternatives, there is a centralized inventory that is depleted on a first-come-first-served (FCFS) basis. Both systems also have local inventories for each fleet. When centralized inventory is depleted and local inventories also fall below their base-stock levels, in one system the repair shop dispatches the repaired components on an FCFS basis, the other one considers static priorities among the fleets.

*Keywords:* spare parts; inventory rationing; priority queues; multiple finite population queueing systems; queues with unreliable servers.



# *Optimal Decision Rules for Product Recalls*

Ali Devin Sezer and Cagr Haksoz

## **Abstract**

We consider a company that has just manufactured and sold a number of copies of a product. It is known that with a small probability the company committed a manufacturing fault that requires a recall. The company is able to observe the expiration times of the sold items whose distribution depends on whether the fault is present or absent. At the expiration of each item, an inspection takes place that may reveal the fault, if it exists. Based on this information, the company can recall the product anytime it pleases. On recall, each customer is paid back the price of the product. If the company is not able to recall before an inspection reveals the fault, it pays a fine per item sold which is assumed to be much larger than the price of the product. We compute the optimal recall time that minimizes the expected cost of recall.

*Keywords:* product recall; optimal stopping; quality risk; statistics of stochastic processes; point processes.

# *Equilibria characterization in a two-player auction with maximum and minimum capacity constraints*

Panagiotis Andrianesis and George Liberopoulos

## **Abstract**

Fabra et al. (2006) analyze a basic duopoly model with asymmetric maximum capacity constraints and costs, under uniform and discriminatory auction formats. Their aim is to address the design of electricity auctions and capture some of the key features of decentralized electricity markets. To this end, they examine the cases of deterministic and stochastic demand and characterize the equilibrium outcomes for both cases. We extend the model of Fabra et al. (2006) by including in it asymmetric minimum capacity constraints in addition to the maximum capacity constraints. Our aim is to address an additional important feature of electricity generation units, namely, that of the technical minimum constraint, which has not been treated thus far in the relevant literature. Firstly, we characterize the equilibrium outcomes under deterministic demand. Then, we derive explicit formulae for mixed strategy equilibria under stochastic demand. Finally, we present an example to illustrate the results, and we discuss the most interesting findings.

*Keywords:* auction; capacity constraints; equilibrium.

## **References**

- [1] Fabra, N., von der Fehr, N.-H., Harbord, D. 2006. Designing electricity auctions. RAND Journal of Economics 37 (1) 23-46.

# *A multi-objective stochastic programming model for designing robust supply chain networks*

Amir Azaron

## **Abstract**

A multi-objective stochastic programming model is developed to design robust supply chain configuration networks. Demands, supplies, processing, transportation and inventory-holding costs are all considered as the uncertain parameters, which will be revealed after building the sites at the strategic level. The decisions about the optimal flows are made at the tactical level depending upon the actual values of uncertain parameters. It is also assumed that the suppliers are unreliable. This is a multi-period model, which considers processing, transportation and especially inventory-holding costs at different time intervals. The main advantage of a multi period model over a single-period one is that it may achieve more profit by keeping inventory in some periods, at tactical level, in order to meet demands in later periods. To develop a robust model, two additional objective functions are added into the traditional multi-period supply chain design problem in that the only objective is the maximization of the net present value (NPV). So, the proposed model accounts for the maximization of the NPV, and the minimization of the risk, reflected by the variance of the total cost and the downside risk or the risk of loss. Then, goal attainment technique is used to obtain the Pareto-optimal solutions that can be used for decision-making. The equivalent deterministic form of the proposed stochastic model is a large-scale mixed-integer nonlinear programming problem and so a meta-heuristic approach is also developed to solve it.

*Keywords:* multiple objective decision making; supply chain management

# *Dynamic Pricing of Inventories with Non-Uniform Quality Levels*

Seray Aydin, Yalcin Akcay and Fikri Karaesmen

## **Abstract**

In contrast to most inventory management literature, this research considers inventories of items whose quality levels are heterogenous. The pricing and inventory management of such items is challenging due to this differentiation which influences customer preferences. All else being equal, customers have preferences for higher quality items, while lower quality items tend to stay unsold longer. With this in mind, we explore an inventory pricing problem where the same price is charged for all items at a certain time but customers choose the best available items first. The seller does not directly invest in quality assessment but is able to obtain information about the quality distribution of its inventory based on realized sales. In order to understand the main drivers in this complicated setting, we consider a dynamic pricing problem for seasonal items that are sold over a finite horizon. We investigate the case where the season can be divided into two periods for price adjustment purposes and assess the benefits of dynamic pricing.

*Keywords:* inventory management; dynamic pricing; stochastic dynamic programming.

# *Optimal Strategies in the observable constant retrial queue*

Spyridoula Kanta and Antonis Economou

## **Abstract**

We consider the single server constant retrial queue with a Poisson arrival process and exponential service and retrial times. This system has not waiting space, so the customers that find the server busy are forced to abandon the system, but they can leave their contact details. Hence, after a service completion, the server seeks for a customer among those that have unsuccessfully applied for service, at a constant retrial rate.

We assume that the arriving customers that find the server busy decide whether to leave their contact details or to balk based on a natural reward-cost structure, which incorporates their desire for service as well as their unwillingness to wait. We examine the customers' behavior and we identify the Nash equilibrium joining strategies. We also study the corresponding social and profit maximization problems. We consider the observable case where the customers get informed about the number of customers waiting for service.

*Keywords:* queueing; balking; pricing; Nash equilibrium; optimal strategies.

# *Customer Equilibria in an Observable M/M/1 Queue with Dynamic Service Control*

Ioannis Dimitrakopoulos and Apostolos Burnetas

## **Abstract**

We consider the problem of customer equilibrium behavior of a single server Markovian queue with dynamic control of the service rate. Customers arrive according to a Poisson procedure. The system administrator employs a  $T$ -threshold dynamic service policy, where the service rate is equal to  $\mu_l$  when the number of customers in the system is below  $T$  and equal to  $\mu_h > \mu_l$  otherwise.

We assume that customers are identical and they make join or balk decisions in order to maximize their expected utility, which consists of a fixed reward for service completion and the expected waiting cost. We also assume that customers are aware of the service policy and the queue length prior to entering the system.

We consider characterization of symmetric Nash equilibrium strategies for the customers. For the special case where  $T = 1$  we show that a symmetric Nash equilibrium is a mixed threshold policy. We also demonstrate an algorithm to derive symmetric Nash equilibrium strategies for the case of general  $T$ .

*Keywords:* queues with Strategic Customers; dynamic Service Control.

# *Equilibrium balking behavior in an unreliable queue with complete removals at failure epochs*

Olga Boudali and Antonis Economou

## **Abstract**

We consider a single-server Markovian queue with server failures, complete removals of customers and repair times. Failures of the server occur according to a Poisson Process. Whenever a failure occurs, all the customers are forced to abandon the system. The system is rendered inoperative and an exponential repair time process is set on. We consider two different models according to whether the system admits customers during the repair time or not. We assume that arriving customers decide whether to join the system or balk based on a natural reward-cost structure which incorporates their desire for service, their unwillingness both to wait and to be removed due to a failure as well as failure compensation.

We examine customer behavior under various levels of information regarding the system state. More specifically, a customer, before making his decision, may be fully informed about the exact state of the system (state of server and number of present customers), partially informed or not informed at all. We derive equilibrium strategies for the customers under the various levels of information. We also illustrate several qualitative aspects of the model and the behavior of the customers by presenting some numerical scenarios.

*Keywords:* queueing; failures/catastrophes; repair times; continuous time Markov chain; balking; equilibrium strategies; individual optimization; stationary distribution.

# *Full-Service Policy Optimality with Heterogeneous Servers*

William Millhiser, Charu Sinha and Matthew Sobel

## **Abstract**

We consider a problem faced by urban emergency response providers such as police, emergency medical, and fire/rescue services. In such systems, emergency response vehicles (i.e., the “servers”) are heterogeneous due to different capabilities and locations. Upon an emergency call (i.e., a “customer arrival”), if multiple vehicles are idle, one must decide which vehicle to dispatch. However, when no response units are available, emergency calls queue and the decision becomes to which caller to assign the next available vehicle. While the latter decision is related to the generalized c-mu rule, we relax the heavy traffic assumptions and propose a model that optimizes the former. Specifically, we formulate an MDP model and present sufficient conditions under which the “full-service” policy achieves the optimal assignment of servers to customers, such that total expected discounted cost and the long-run average cost are minimized over finite and infinite horizons. While the model incorporates the cost of matching each customer class with every server, we conclude with a numerical counter-example to the optimality of the full-service policy when service rates depend both on the identity of the server and the type of customer being served.

*Keywords:* queueing systems; emergency response; Markov decision processes.

# *Flexible Server Allocation and Customer Routing Policies for Two Parallel Queues when Service Rates are not Additive*

Mark Lewis and Hyun-soo Ahn

## **Abstract**

In this paper we consider the simultaneous control of routing and capacity allocation of two servers with two parallel stations. Customers arrive to each station in accordance with independent Poisson processes. Station dependent holding costs are accrued per customer per unit time. When a customer arrives it may join the queue at the station where it arrived or be routed at cost  $r$  to the other station. All service requirements are assumed to be exponential with rate 1. When the servers work at separate stations the service rates are  $\mu$ , while when the work at same station it is  $\mu_c$ . The sub-additive ( $2\mu > \mu_c$ ) and super-additive ( $\mu_c > 2\mu$ ) cases are considered.

*Keywords:* queueing control; Markov decision process - applications.

# *Queueing Systems with Appointment-Driven Arrivals, Non-Punctual Customers, and No-Shows*

Oualid Jouini and Saif Benjaafar

## **Abstract**

We consider queueing systems where a finite number of customers arrive over time to a service system, consisting of either a single or multiple servers. The arrival of customers is driven by appointments, with a scheduled appointment time associated with each customer. However, customers are not necessarily punctual and may arrive either earlier or later than their scheduled appointment times. Customers may also not show up altogether. The arrival times of customers (relative to their scheduled appointments) and their service times are both stochastic. Customers are not homogeneous in their punctuality, show-up probabilities, and time between previous and subsequent appointments, which may vary from customer to customer. We develop an exact analytical approach to obtain various performance measures of interest and illustrate the usefulness of the approach by describing numerical results that examine the impact of not accounting for non-punctuality and no-shows.

*Keywords:* queueing models; non-punctual customers; outpatient service operations; no-shows.

# *Approximation of transient performance measures of service systems with retrials*

Raik Stolletz

## **Abstract**

This presentation proposes an approach for the time-dependent analysis of stochastic and non-stationary queueing systems with retrials based on the Stationary Backlog-Carryover (SBC) approach. Many customer service systems have to cope with impatient customers, for example call centers, airport check in, or services like automated teller machines. In call centers, impatient customers leave the queue before receiving service dependent on the behavior of the customers and the

current or expected waiting time. A fraction of those customers retry again later on. This feature of retrials is often found in combination with a non-stationary behavior of the system. This can be due a transient phase after the start of the system or time-dependent capacities, for examples varying number of staff or breakdowns of the system. Especially in service system the customer demand varies highly over the time.

The main contribution of this paper is the development of a new approximation method for the  $M(t)/M/c + M$  queueing model with retrials. We describe the main idea of the SBC approach and show how it could be extended to scope with impatient customers. Because of the lack of stationary closed form solutions for retrial systems we integrate retrials as additional carryovers. A numerical study shows the reliability of this approach.

*Keywords:* call center analysis; retrial queues; nonstationary systems.

## *On priority queues with gradual preemption*

Tom Maertens, Joris Walraevens, Marc Moeneclae and Herwig Bruneel

### **Abstract**

Priority scheduling is still a hot topic in queueing theory. In many queueing systems, real-life situations involving human beings as well as computer systems, different types of customers require different kinds of services. By prioritising the service of a certain type, it is possible to achieve the required service differentiation. Priority scheduling disciplines can be distinguished by how they deal with arriving customers having a higher priority than the customers that are currently being served. In a non-preemptive priority queue, the service of a lower-priority customer is not interrupted when a higher-priority customer arrives at the system; once the service of the lower-priority customer is finished, the server starts servicing the higher-priority customer. In a preemptive priority queue, on the contrary, the service of a lower-priority customer will be interrupted at once if a higher-priority customer arrives, and will not be resumed until the system is again void of higher-priority customers. It is easily seen that the preemptive category is favourable to higher-priority customers, because they are not influenced by lower-priority customers at all. On the other hand, with non-preemptive priority, lower-priority customers are at least sure of being served completely once their service is started. Both categories, however, also have several drawbacks in practical applications. Under the non-preemptive strategy, higher-priority customers may have to wait even when the service of a lower-priority customer has just started, while under the preemptive disciplines, the almost completed service of a lower-priority customer may be interrupted due to the arrival of higher-priority customers (possibly causing a large extra delay). In our research, we propose and study a priority scheduling discipline in which the two above-mentioned situations are avoided as much as possible. In particular, we introduce a parameter which is defined as the fraction of the service time that already has to be elapsed so that the service of a lower-priority customer is no longer interrupted when a higher-priority customer arrives at the system. If, upon arrival of a higher-priority customer, the ratio of the elapsed service time of a lower-priority customer to its total service time is smaller than this parameter, the service of the lower-priority customer is interrupted; otherwise, its service is completed before the service of a higher-priority customer can start. In this way, we aim for a gradual preemption level between different types of customers. The value of the parameter can moreover be adapted according to the intended service differentiation. To study this priority queueing system, we opt for an analytical method based on probability generating functions.

*Keywords:* service differentiation; priority queueing; performance analysis.

## *Analytical study of a queueing system with non-geometric tail behaviour*

Mark Van Lokeren, Bart Steyaert and Herwig Bruneel

### **Abstract**

We consider a queueing system with two types of customers whose arrivals are modelled by two independent Poisson processes. Arriving customers of type A enter the system surely, whereas the probability that an arriving customer of type B enters the system depends on the total number of customers already present in the system (discouraged arrivals). Different dependencies on the total number of customers are studied. Service times are exponential and do not depend on the type of customer. Assuming the system reaches an equilibrium state, we obtain analytical expressions for several performance measures such as the total number of customers in the system, the average arrival rate, the average load of the system, the system times for each type of customer. The non-geometric tail behaviour of the total number of customers in the system (and the queue length) is discussed in detail.

*Keywords:* queueing system; non-geometric tail behavior.

## *Residual service times in the M/G/1 queue conditioned on the queue length: revisiting an old problem*

Michael Zazanis

### **Abstract**

Using techniques of Palm Calculus we revisit classic results on the distribution of the age and the residual service time conditioned on queue length in the M/G/1 queue which we also extend to the multiserver case. Further generalizations to non Poisson arrival processes are given as well as analogous results for networks. Applications to production control are discussed.

*Keywords:* M/G/1; conditional residual service time.

## *Optimal stopping of Markov chain, Gittins Index and Related Optimization Problems*

Isaac Sonin

### **Abstract**

It is well known that a connection exists between three problems in Applied Probability Models, all related to Optimal Stopping (OS) of Markov Chain (MC) and that their key characteristics are equal. They are correspondingly: the ratio (cycle) maximization with the classical Gittins index, the Kacchak-Veinot (KV) Restart Problem with the KV index, and the Whittle family of Retirement Problems with the Whittle index. In a paper of author published in 2008 in Statistics & Probability Letters these three problems and corresponding indices were generalized in such a way that it is possible to use the so called State Elimination (SE) algorithm developed earlier by the author to solve OS of MC and to calculate this common index  $\alpha$ . This generalization also sheds a new light on the meaning of this index, which we call the Generalized Gittins index (GGI), and relates this index to an index introduced earlier by L. Mitten in J. of Industr. Eng. in 1960 and thus to a few papers authored by D. Granot, D. Zuckerman, E. Denardo, U. Rothblum, U. and L. Van der

Heyden, for which Mitten's paper was a starting point. In these papers GGI plays an important role in the description of the optimal strategy. The main goal of our talk is to demonstrate that the equality of these indices is a special case of a similar equality for three simple abstract optimization problems. By an abstract optimization problem we mean a problem with maximization over an abstract set of indices without any specifics about this set.

*Keywords:* optimal stopping; Markov chain; Gittins index; the state elimination algorithm.

## *Stochastic Inventory Models with an Option in Delivery Time Upgrade*

Houmin Yan, Xiaoying Liang

### **Abstract**

Motivated by real-life business issues of Toyota China dealerships, we consider a stochastic inventory model with an option in delivery time upgrades, in which the seller allocates its on-hand inventory to price and delivery-time sensitive customers. The seller has two decisions: inventory commitment and inventory replenishment. The former addresses, within an inventory cycle, how on-hand inventories are allocated between the two classes of customers. The latter addresses, between inventory cycles, how the inventory is replenished. In this paper, we develop a stochastic dynamic programming model to characterize the optimal inventory allocation and upgrade, and inventory replenishment policies, and to demonstrate that the optimal control can be characterized by a switching curve. We extend our analysis to include cases of upgrade cost, stock-out substitution, and capacity constraint. Finally, we use the Toyota dealership data to calibrate the required parameters and demonstrate the potential of the optimal inventory allocation and upgrade control.

*Keywords:* Stochastic Inventory Models; Dynamic Programming and Optimal Control

## *Structured Optimal Policies in Robust Dynamic Programming*

Zeynep Turgay, Fikri Karaesmen and Lerzan Ormeci

### **Abstract**

In classical stochastic dynamic programming, the transition probabilities of the underlying Markov Chain are assumed to be known with certainty. We focus on the case where the transition probabilities have to be estimated from data and therefore are uncertain. Robust dynamic programming addresses this problem by defining a structured game between the nature and the controller. Considering examples from inventory and queuing control, we examine the effects of this game on the structure of the controller policy when reward and/or arrival/service times are uncertain. We identify the cases where certain monotonicity results still hold and form of the optimal policy is still threshold type.

*Keywords:* dynamic programming; robust optimization.



## *A Modeling Framework for Control of Preventive Services*

Lerzan Ormeci, Derya Kunduzcu and Evrim Didem Gunes

### **Abstract**

We present a modeling framework for the optimal control of systems offering preventive services using the event-based dynamic programming (EBDP) introduced by Koole (1998). The framework considers a facility consisting of a group of machines and/or a team which provides both screening and diagnosis services. We model the facility as a single server receiving two types of customers: one corresponds to screening services and the other to diagnosis needs. The facility operates in a random environment that can be affected by screening services. This environment represents the condition of the system for which screening and diagnosis services are provided. The workload of this facility can be controlled through admission and scheduling policies. Admission control can be performed by declining some of the requests for prevention services, while scheduling control concerns the prioritization of screening versus diagnosis demand. We define appropriate event operators and specify the properties preserved by these operators. As a result, we characterize the structure of optimal policies for all models that can be built within this framework.

*Keywords:* Markov decision processes; event-based dynamic programming; preventive services; healthcare services.

## *Application of the new OPLS-DA statistical modeling technique to manage large number of variables in a burn injury case control study*

Homayoun Sadeghi-Bazargani, Shrikant Bangdiwala, Reza Mohammadi and Kazem Mohammad

### **Abstract**

Using modern statistical methods to overcome the known pitfalls of classical regression models in analysis of large number of highly correlated data for small sample sizes, is well considered recent years. This has been done mainly for OMICS and chemometrics studies. Recently in 2002 statisticians in field of chemometrics and OMICS research have developed and presented a new method as Orthogonal projections to latent structures(OPLS). It is a modification of NIPALS PLS algorithm. The OPLS compared to the regular partial least squares regression modeling provides simpler method with the additional advantage that the orthogonal variation can be analyzed separately. Such techniques although not known in injury epidemiology, seemed to be suitable also for the analysis of risk factors in burn injury research which is quite a different field of study compared to chemometrics and OMICS. We have successfully applied OPLS-DA to analyze large number of variables( more than 500 variables including the dummies) in a case control study to assess determinants of burn injuries. We checked for model fitness and diagnostics, and successfully defined the possible risk indicators of burn injuries in a given population studied through a case control research. We also compared the OPLS-DA with PLS-DA regarding model fitness, diagnostics and interpretability and found the OPLS-DA to be preferable.

*Keywords:* orthogonal projections to latent structures(OPLS-DA); megavariate analysis; injury epidemiology; discriminant analysis; application of Statistical models.

# *Adaptive Sampling Under Incomplete Information and a Sample-Path Cost Constraint*

Odisseas Kanavetas and Apostolos Burnetas

## **Abstract**

Consider the problem of sequential sampling from  $k$  statistical populations. The outcomes of population  $j$  are i.i.d. with unknown distribution  $F_j$ . Sampling from population  $j$  incurs a known cost  $c_j$  per sample. The objective is to maximize the expected long run average outcome per sample under a constraint on the sampling cost.

In this framework a sampling policy is consistent if it is feasible in terms of the cost constraint and the expected average outcome per sample is equal to that under complete information, for any collection of the unknown distributions. When the cost constraint requires that the expected long-run average cost per sample is below a given upper bound  $c_0$ , the problem of constructing a consistent policy is almost as easy as the unconstrained problem. However a constraint of this type is not very realistic, since it allows the average cost to be above  $c_0$  for arbitrarily long periods of time.

In this talk we impose a stricter form of the cost constraint, which requires the average sampling cost not to exceed  $c_0$  at any intermediate step and not only in the limit. We prove that a consistent policy exists under this more stringent requirement. The policy is based on sparse sequences of forced sampling blocks and the repeated solution of an appropriately defined linear program with constant feasible region.

*Keywords:* sampling under incomplete information; stochastic optimization.

# *Diffusion processes over products of simplices*

Panayotis Mertikopoulos and Aris Moustakas

## **Abstract**

Dynamical systems that evolve over products of simplices arise as the natural way to model evolution in a wide array of problems, ranging from game theory and economics, to population biology and the theory of networks. As such, the convergence and stability properties of dynamics of this type have been studied extensively, chiefly under the umbrella of evolutionary game theory.

Nevertheless, relatively little is known when these dynamics are subject to constant stochastic fluctuations, arising e.g. from the unpredictable interference of "nature". To account for disturbances of this kind, we study the long-term behavior of diffusion processes that evolve over products of simplices and which have the natural property never to leave the face from which they start. The only traps of these diffusions are the vertices of the simplices but, of course, these points are not necessarily stable. Our first result is to derive a set of (surprisingly lax) sufficient conditions which determine when the process drifts away from a vertex or, complementarily, when such a vertex is stochastically asymptotically stable.

To extend these local results to global ones, we make the (global) assumption that the diffusion is tied to a (convex) potential function. When this is the case, we show that the diffusion is recurrent and that it admits an invariant distribution which concentrates mass in the vicinity of the potential's minimum point (which is also the only attracting equilibrium of an associated deterministic dynamical system).

As a direct application of these results, we consider the evolution of selfish routing in networks where delays fluctuate unpredictably due to random external factors. If users are sufficiently

patient in learning the network and the network has no "redundancy" (an important concept which measures the interdependence of the users' routes), we show that the long-term averages of their traffic distributions are concentrated close to a socially stable equilibrium point.

*Keywords:* diffusion process; invariant distribution; Nash equilibrium; stochastic asymptotic stability; stochastic differential equation.

## *Bayesian real swing option on the geometric random walk*

Katsunori Ano

### **Abstract**

We study a Bayesian multiple stopping problem on the geometric random walk. The optimality equation for this Bayesian multiple stopping problem can be reduced to the corresponding optimality equation on the sufficient statistics sequence generated from the history of the observations. As an application, we investigate a Real swing option, in which a decision maker wants to maximize the expected cumulative discounted return from a certain project and he can make at most  $l$ -th ( $l$  is a fixed positive integer) investments to the same project (i.e., swing option type). We assume that the performance of the project varies according to the geometric random walk. Decision maker's subjective probability of the future upward probability is imposed as the parameter of the prior Beta density of the upward probability of the geometric random walk. We show that the optimal multiple investment rule is only based on the number of the upward observed so far, and the optimal multiple investment rule is characterized by the multiple threshold sequences, under some condition on the prior density's parameter.

*Keywords:* Bayesian; real option; swing option; multiple stopping.

## *Results on convolutions of compound geometric distributions*

Georgios Psarrakos

### **Abstract**

Let  $G(x)$  be a compound geometric distribution function of a random variable  $S$ , defined by  $G(x) = Pr(S \leq x) = \sum_{n=0}^{\infty} (1 - \phi) \phi^n F^{*n}(x)$  ( $0 < \phi < 1$ ), and let  $A(x)$  be the d.f. of a random variable independent of  $S$ . In this work, we derive new results concerning stochastic comparisons of the function  $K_x(y)$  introduced by Willmot and Cai (2004), which is strongly related to the compound geometric convolution  $W(x) = G * A(x)$ . We also obtain asymptotic formulas for heavy-tailed distributions generalizing known results by Cai and Tang (2004). Moreover, in the case of light-tailed distributions, we provide the moment generating function of  $K_x(y)$  at a point  $R$  that satisfies a Lundberg type equation.

*Keywords:* defective renewal equation; reliability classes; stochastic order; heavy-tailed distribution.

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## *Flow Time Analysis of a Continuous Sampling Plan Policy*

George Mytalas and Michael Zazanis

### **Abstract**

We examine the operation of a quality control unit that uses a Continuous Sampling Plan (CSP) policy, placing particular emphasis on the delay aspects of the inspection station and on the effects of the inspection process on flow times. In particular, we examine markovian models of the inspection station and analyze the delay and queueing aspects of the CSP policy assuming exponential inspection times using matrix geometric techniques. Finally, we also examine the indirect effects on the inspection process on flow times due to the modulation of the downstream arrival process by the inspection process and the corresponding increase of variability.

*Keywords:* quality control; continuous sampling plan; queueing; flow time analysis.

## *GI/M/1 Markov chains with a level-phase independent stationary distribution*

Guy Latouche and Safieh Mahmoodi

### **Abstract**

*GI/M/1* Markov chains make up a class of two-dimensional Markov chains. One dimension is usually called the level, the other called the phase. When the number of phases are finite, for given transition probabilities in the interior of the state space that satisfy special conditions, it is always possible to define the boundary transition probabilities in such a way that the level and the phase are independent under the stationary distribution. In this paper we will construct the boundary transition with independency property under a weaker assumption.

When the number of phases are infinite, the process exhibits unusual behavior. This result will be extended to *GI/M/1* Markov chains with infinite phase space. We undertake the property of independency in QBD processes with infinite phase spaces in advance.

*Keywords:* *GI/M/1* processes; stationary distribution; independent variables; eigenvalue and eigenvector; infinite dimensional space.

## *Continuous-time Markov Chains with Binomial Transitions: Modeling, Analysis and Applications to Queueing Systems with Synchronized Events*

Stella Kapodistria and Antonis Economou

### **Abstract**

We study queueing systems which are characterized by synchronization, that is at certain opportunities, that occur according to a Poisson process, every present customer in the system decides upon an action (i.e. to repeat service, to abandon the system, etc) with probability  $p$ , independently of the others. This implies that there exist binomial transition rates of the form

$\binom{n}{n'} p^{n-n'} q^{n'}$   $\times$  rate of the Poisson process, from a state of  $n$  present customers to states of  $n'$  customers, for  $0 \leq n' \leq n$ .

Similar Markov chains occur in Mathematical Biology in the study of population processes subject to binomial catastrophes (see e.g. Artalejo et al. (2007), Brockwell et al. (1982), Economou (2004) and Economou and Fakinos (2008)). Moreover, Neuts (1994) studied a 1-dimensional discrete-time model with similar dynamics. In the same framework, Economou and Kapodistria in (2009) studied a model with synchronized services, while Adan et al. (2009) studied a model with server's vacations and synchronized abandonments and Economou and Kapodistria (2010) studied a single server unreliable queue with synchronized abandonments.

For this type of models we will show that by employing generating function methods we carry out the equilibrium analysis of the system state and derive several exact formulas and iterative algorithmic schemes. Some limiting results regarding the behavior of the system in the extreme cases of the synchronization level will be discussed in detail. And also we will study the sojourn time of a customer, and treat the system busy period distribution of the model.

*Keywords:* queueing system; synchronization; stationary distribution; busy period; sojourn time.

## *An $(s - 1, s)$ Inventory System with General Product Lifetimes and Customer Impatience*

Stratos Ioannidis, Oualid Jouini, Angelos A. Economopoulos and Vassilis S. Kouikoglou

### **Abstract**

This work addresses problems of inventory and admission control for a stochastic  $(s - 1, s)$  perishable inventory system with impatient customers. Arrivals are assumed to follow a Poisson process, and lead times are exponentially distributed. Finished item lifetimes and customer patience times follow general distributions. Using a decomposition method and results from the literature of queueing systems, we derive expressions for the system steady-state probabilities and performance measures, such as profit from sales, cost of inventory, and cost of delay in filling customer orders. We use these expressions to find optimal base stock and admission policies, and investigate the impact of product lifetimes and customer patience times on system performance.

*Keywords:* queueing; perishable inventory; customer impatience; base-stock policy; admission control.

## *Optimal $(r, nQ, T)$ Inventory Control under Stationary Demand*

Athanasios Lagodimos, Ioannis Christou and Konstantina Skouri

### **Abstract**

We consider the control of a single-echelon inventory system under the  $(r, nQ, T)$  ordering policy. Demand follows a stationary stochastic process and, when unsatisfied, is backordered. Under a standard cost structure, our aim is the minimization of the total average cost. In contrast to previous research, all policy variables (i.e. reorder level  $r$ , batch size  $Q$  and review interval  $T$ ) are simultaneously optimized. While total average cost is not convex, two new convex bounds together with a Newsboy characterization of the optimal solution lead to an exact algorithm with guaranteed convergence to the global optimum. Computational results demonstrate that the inclusion of the review interval as a decision variable in the optimization problem can offer serious cost savings.

*Keywords:* inventory; newsboy; stochastic demand; optimal.

## *Periodic review $(R, T)$ inventory control policy for stochastic demand and yield*

Konstantina Skouri, Athanasios Lagodimos and Ioannis Konstantaras

### **Abstract**

We consider a single-echelon inventory system under the periodic ordering policy. Demand is stationary normal and, when unsatisfied, is backordered. There are uniformly distributed yield losses associated with the supply process, so receipts are routinely smaller than respective orders. Under the multiplicative yield model and a standard cost structure, we determine the policy variables (order-up-to level  $R$  and review interval  $T$ ) that minimize total average cost. Analysis of the system dynamics leads to an exact total average cost model in terms of the augmented demand (lead-time demand plus yield losses). Based on the properties of a newly analyzed stochastic process, we show that augmented demand distribution is stationary normal and determine its parameters. We then show that total average cost consists of a finite series of elements jointly convex in both policy variables. This, together with a Newsboy characterization of the optimal solution, leads to an exact algorithm that guarantees the global optimum. Computational results demonstrate the important consequences that random yield may have on the system cost and service performance.

*Keywords:* supply chain; newsvendor; random yield; periodic review.

## *A stochastic delivery-pickup problem*

Dimitrios Pandelis, Constantinos Karamatsoukis and Epaminondas Kyriakidis

### **Abstract**

We consider the problem of finding the optimal routing of a single vehicle that delivers new products to  $N$  customers according to a predefined order and collects expired products from them. It is assumed that for each customer the demand for new products and the quantity of expired products are known random variables that are smaller than the capacity of the vehicle. The vehicle starts its route from a depot and after visiting each customer may proceed to the next customer or may return to the depot in order to unload the expired products and to load the new ones. Using a suitable dynamic programming algorithm we find the optimal policy for the service of all customers. We also prove that this policy has a specific threshold-type structure. The theoretical results are illustrated by numerical examples.

*Keywords:* logistics; routing with pick up and delivery; dynamic programming.

## *Markov Decision Processes with Applications*

Ulrich Rieder

### **Abstract**

Markov Decision Processes are considered w.r.t. the total reward criterion. We present general verification and structure theorems for finite-stage and infinite-stage MDP's. Special attention is given to the computation of optimal policies. In the second part, stochastic optimization problems with partially observable Markov processes and with piecewise deterministic Markov processes are investigated. We show how these problems can be solved by the theory of MDP's. As applications we treat a queueing problem, bandit problems and consumption-investment problems from finance. The talk is based on the recent book of Baeuerle and Rieder (2010).

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