RAIRO Operations Research
RAIRO Oper. Res. **38** (2004) 85–88
DOI: 10.1051/ro:2004019

ADVANCES IN MODELLING OF COMPLEX SYSTEMS: PREFACE TO THE SPECIAL ISSUE

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This special issue of *Recherche Opérationnelle* is devoted to recent research which significantly enhances our ability to model, either mathematically or algorithmically, increasingly complex service systems. All the papers in this issue are methodological in nature, even though the first paper addresses a very practical approach.

This collection of papers begins with a survey by Dr Khaled Hussain and Mr Varol Kaptan of recent advances which allow modelling and simulation to be conducted in a very realistic visual setting. We all know how frustrating it can be to deal with the need to determine whether the objects we model are represented in a realistic manner, and whether the simulation conditions are indeed realistic. The approach described in this first paper is based on the premise that the system being simulated has a realistic visual counterpart, *e.g.* some natural scenery (as in a military tactical simulation), a room (as when people's behaviour may be simulated), some roads or an airport (as when a transportation system has to be simulated), a hospital operating room (as when a surgical procedure needs to be simulated), and so on. In all of these cases, the real world being simulated can be based on an actual video sequence of the real world setting. It can be even more realistic and the simulation can be conducted within a video viewing of the real world itself. This paper shows how this can actually be done and describes a system that has been designed and developed at the University of Central Florida and at Imperial College to achieve this. In such a simulator, the simulated conditions are the real world itself, while the behaviour of synthetic objects or synthetic changes to real objects is what is being simulated. The value of such simulations can be tremendous, and can allow testing of complex behaviours in a fully realistic setting with the possibility of the human viewer actually observing different operating conditions. In addition to the visual aspects, the authors also discuss how different objects in the simulation can be coordinated using on-line learning and control algorithms that imitate intelligent reactive behaviours, based on both deterministic and randomized algorithms.

The remaining four papers address original research on stochastic service models, where the emphasis is either analytical or algorithmic.

In the area of job shop like queuing models, the basic paradigm is to consider a set of customers which request service from a set of servers or workstations, moving from one workstation to another after completing service at one of them and requesting service at the next one. Customers are generated from some outside source and typically leave the system after some time, or they remain indefinitely within the system. One can say that work on such models started at the beginning of this century with A.K. Erlang in Sweden, but most of the theory until the late 50's dealt with systems with a single. These models have well recognised and very wide applications, which we need not dwell on, in computer system performance evaluation, transportation systems and road traffic, telecommunication networks and the Internet, automated manufacturing systems, and human service systems such as offices, bureaucracies, hospitals and so on. Thus they have generated a large body of literature both with respect to simulation techniques and tools, and with respect to mathematical models and approximate or exact solution methods.

The main milestones in the development of mathematical models for such systems since the late 1950's started with the work of J.R. Jackson [1,2] who first showed that it is possible to solve in closed form special instances of these stochastic models for the stationary joint queue length, followed by Jeff Buzen [3] more than ten years later who derived a polynomial time algorithm to obtain the solution in the "closed" case with a finite number of customers indefinitely circulating in the system. The main property that was shown and exploited was the "separability" or product form nature of the stationary solution when the service times are exponential and customers move from one queue to another using Markovian transition rules. Another important milestone was achieved with the BCMP Theorem [4] when it was established that closed product form solutions can be obtained for certain service disciplines other than first-come-first served, as well as for customers of multiple classes having distinct service time distributions. Much effort was expended on "insensitivity results" with respect to service time distributions. However F.P. Kelly [5] showed that reversibility in time of the stochastic process is intimately related to product form. Over the years, many approximate solution techniques have been suggested for queuing systems, including the approach using information theory which was pioneered by D.D. Kouvatsos [11].

The next major breakthroughs in product form queuing networks have come with the introduction of new types of customers to represent control functions in queuing networks: "negative customers" [6,7,8], then "signals" [9,10] and more recently "resets" [12]. Initially motivated by the desire to model excitation (positive customers) and inhibition (negative customers) in neural networks [7], negative customers [8] came to model requests to destroy customers and hence future work, as when it is decided that there is excessive congestion at some queue, or when one considers that some specific work need not be done. Negative customers with the ability to destroy random batches of positive customers have been introduced in [9]. Signals cover both negative customers and "triggers", the latter being customers which order another customer to move from some queue to another. Finally, the most recent addition is the "resets" customer [12] introduced to represent actions by special customers which can reset a service centre when it has failed or when it is depleted of its workload. In all of these cases, with exponential service times and Markovian customer movements, it has been shown that these corresponding "G-Networks" have the useful and remarkable property of product form.

Three papers in this special issue deal directly with significant and challenging theoretical developments of G-Networks. The first one by Professors Botcharov, D'Apice, Gavrilov and Dr. Pechinkin combines a stochastic representation of normal customer behaviour, with negative customers and state dependent service processes, to derive product form results.

The following two papers by Professors Artalejo and Economou and by Dr. O.V. Semonova, both consider the stationary behaviour of a system with batch arrival of negative customers, similar to the batch removal process discussed in [9]. Both papers derive the stationary probability distributions for related systems and under some optimal control policies. Professors Artalejo and Economou use Poisson and batch Poisson arrival processes. Dr. O.V. Semonova on the other hand considers an optimally controlled queuing system with a Markov Modulated Arrival Process where some of the arriving customers cause "disasters", *i.e.* with negative customers that can delete all of the positive customers in the queue.

Many practical problems arising in communication networks or transportation systems require that only a sub-system be understood in detail. Thus much work has been devoted to techniques that allow one to approximate some properties of specific sub-systems, such as the queue length distribution or the output process from a queue. Thus the last two papers in this collection deal with analytical techniques that support approximate solutions to queuing network models. Mr Jayesh Kumaran, and Professors Mitchell and van de Liefvoort, consider a single server queue in which both inter-arrival times and service times are characterised by matrix exponential (ME) distributions. The interest of such ME distributions lies in the fact they can cover all Markovian arrival processes, are identical to distributions with a rational Laplace-Stieltjes transform, and the resulting queuing systems can be treated in a linear algebraic framework. More specifically, they consider distributions where a ME distribution characterises the joint probability distribution between k events (*e.g.* k successive inter-arrival times). In their paper the authors develop an elegant formulation to characterise the output process for any finite k. Since any practical arrival and service process can only be known with some finite memory, their approach provides in principle a general framework to study traffic in networks. This paper provides a methodological insight into techniques that can be used to analyse large networks by isolating some of their components.

Thus with a small set of high quality papers, this special issue offers a broad perspective and useful insight into the algorithmic and mathematical techniques that will be used to analyse large scale communication, transportation or manufacturing networks in the future.

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