Editorial: Applied Probability Modelling in Continuing Engineering Education

Maria F. Ramalhoto

Technological University of Lisbon (Instituto Superior Técnico),
Avenida Rovisco Pais, 1096 Lisboa Codex, Portugal.
Tel. +351-1-714 3311. Fax: +351-1-849 9242

The *International Journal of Continuing Engineering Education* (IJCEE) is a facilitator of the international movement of ideas and courses. I am pleased that this special issue of the IJCEE was able to attract as contributors professors of statistics, operations research, industrial engineering and management who are well known both inside and outside the academic world. It is also interesting to note that the five continents are also represented by the 17 authors.

The plan of this issue is as follows. It starts with the more philosophical and teaching-oriented papers, then the papers concentrating more on methodologies, and the later ones deal with more concrete applications to engineering and management.

Let me very briefly outline what seem to me to be the messages and the main points considered in these invited papers.

Tapiero states that, although stochastic engineering and management modelling and analysis is a science, it is also an art, for it requires that we distinguish the known from the unknown and construct models that account for behaviours and evolutions which we might not, *a priori*, be aware of. He provides a number of approaches to construct stochastic models that demonstrate that there is a relationship between the way a hypothesis regarding a process is formulated and the resulting quantitative framework adopted.

Neuts states that the computer is the first tool in history to enhance the capabilities of the mind in a major way, and that to develop the skills needed for its productive use is an ongoing task in the life of the contemporary engineer. To allow educational programs to fulfil this task he argues that at all teaching levels, among other actions, innovation in textbook material and a concurrent change in the way the courses are taught, are necessary. He stresses that a genuine emphasis on algorithmic thinking, nurtured through substantial modelling practice and exercised in hands-on computer experience, are essential ingredients of today's educational programs.

Cox and Davison point out that there is probably no branch of mathematics in which it is so easy to advance plausible sounding arguments that are in fact wrong! They concentrate on the teaching of stochastic processes to engineers. They stress the central importance of careful model formulation and call attention to the fact that to resort to simulation does not remove the need for careful assessment both of assumptions and of the most appropriate specification of state. The interplay of analytical solution and simulation is discussed in detail through a queueing model example.

Gani stresses that stochastic methods should pass increasingly into the standard courses of engineering schools. He gives two examples of the importance of probabilistic methods in engineering practice: one in civil engineering and the other in traffic engineering. Those examples also illustrate that relevant applied probability material which has been published for more than 34 years in two well known books by 'user-engineers', is still waiting to be adopted as part of the standard syllabus of our undergraduate or even postgraduate engineering degrees.

Perhaps I should point out here that SEFI (Societé Européenne pour la Formation des Ingenieurs) has been concerned with this matter for some time now. In 1990, a special issue of the *European Journal of Engineering Education* (EJEE), the SEFI scientific journal (Vol. 15, No. 3, Guest Editor Peter Nüesch) was dedicated to 'Stochastics in Engineering Education'. The SEFI Working Group on Mathematics also produced in 1992 a 'Core Curriculum in Mathematics for the European Engineer' which will be continuously updated.

Berg states that the terminology of probability is rather obscure for most user-engineers, and as a result they may not use effectively mathematical models that have been available for some time in the literature, or may even avoid them altogether. He suggests an approach that bridges the gap between probability-based modelling and the perception and needs of the user-engineer. To achieve it he proposes to formulate the basic assumptions of the model through physical quantities and to form the exact mathematical model only in the next stage, through translation of these qualitative assumptions into probability terms and functions. He illustrates his approach through systems maintenance.

Peña discusses the importance of time series in engineering practice. He also states that some important areas of application of statistics to engineering can benefit from using time-series ideas; for instance, in the case of standard control charts, when the process goes out of control smoothly because of deterioration or slow changes in the raw material or intermediate products. He presents three courses (including an introduction to optimal control theory), to fill the gap between the present knowledge of time-series models among most engineers and the needs of their professional work.

Liu Ke presents a simple description of the Markovian decision process. He uses it in the following two applications in China – an evaluation of the optimal regulation of a hydropower station reservoir, and of the time-delay inspection model for machine maintenance.

Ramalhoto deals with a concept of continuing engineering and management education (CEME) which essentially involves 'transfer of current research work' and 'teaching of stochastics methodologies targeted to industrial needs' in an interdisciplinary/integrated environment. She uses current research (on the value of embedding the 1st and 2nd Erlang formulae in the superstructure of the finite-waiting-capacity Markovian queue to obtain a number of results in the optimal design of manufacturing and service-industry congestion systems) to exemplify a situation in which a quick transfer of useful knowledge to engineers and managers could be easily achieved, if an easy-to-use channel of communication was available. It is stressed that involvement in CEME activities also has the advantage of allowing an expansion in the scope of stochastics postgraduate instruction.

Jun and Ross illustrate the fact that by combining simulation with stochastics analysis we are often able to obtain improved simulation estimators that are far more efficient than the raw estimators. They develop the 'total hazard' as a control variate in the simulation of a state-dependent queueing system, to obtain the expected number of customers during a busy period. They compare the performance of the 'total hazard' with the usual control variates. The mean squared error is used as the performance measure of their estimators, since 'controlled estimators' may not be unbiased. They use the bootstrap method to evaluate the mean squared error.

Upadhyay and Smith review how the computational difficulties of the Bayesian approach to complex models (like the failure behaviour of sophisticated engineering systems) can be overcome by the use of simulation techniques. They state that simulation techniques in Bayesian computation are very simple, close in spirit to standard Monte Carlo methods, and proceed by obtaining samples from posterior distributions. Once these samples are available they claim that any inference can easily be drawn, whether it relates to simple parametric inferences, complex censoring situations or even the prediction of future characteristics. They briefly discuss two important Markov Chain Monte Carlo (MCMC) methods, namely the Gibbs and Metropolis–Hastings algorithms. They analyse two real data sets using such simulation approaches.

Let me stress that, given the ever-increasing importance of Bayesian methodology in engineering and management practices, it is very encouraging to see appearing tools which are more straightforward for practitioners to implement and to explore. Perhaps I should mention here that another method, currently being studied, for generating samples that can be used to construct posterior distributions and Bayesian inferences is the Weighted Likelihood Bootstrap (WLB) method, introduced by Newton and Raftery [1]. The principal advantages of this method in comparison with MCMC methods, according to Gilks (discussion of Newton and Raftery paper), are that it requires very little programming, it seems to work well for small but intricate problems, and it generates independent posterior samples. However, because a general-purpose software for MCMC methods has been developed (for Gibbs sampling) the WLB, in its present form, may prove useful only in situation such as the optimal Bayesian design of complex system.

Velazco describes a general, robust, decision-making process in manufacturing, and mentions queueing theory and computer simulation as the most successful approaches for predicting the behaviour of manufacturing systems. He concentrates on simulation, and discusses a methodology which provides the simulation analyst with a simple road map to follow when attempting to find the individual and global optima of all the main performance measures. He briefly presents a case study concerned with the robust design of a flexible manufacturing system, which illustrates the methodology and the necessary statistical concepts.

Odoni states that the ability to deal with uncertainty is fundamental to the success of any activity related to planning for, investing in, operating and managing airports and air traffic control (ATC). The costs of the inability to adequately deal with this uncertainty amount to several billion dollars a year, in the form of unnecessary or premature investments, wasted time of aircraft and passengers, excessive fuel consumption, etc. He describes the types of uncertainty encountered, and illustrates them through four cases studies. He advocates the use of dynamic queueing systems and sophisticated Monte Carlo simulations to model some of these uncertainties. He stresses the importance of training airport and ATC specialists, at all levels, in some fundamental probabilistic concepts and providing them with decision-support tools that will allow them to cope with uncertainty in performing their professional tasks.

Bergman and Klefsjö describe the TQM movement as being about leadership and employee participation. The Deming approach to quality is briefly outlined. The concepts of variation and uncertainty and their relations to TQM are discussed. They also concentrate on the importance of providing well structured Continuing Engineering Education programs on stochastics in a TQM environment, specially tailored to give engineers and managers a very practical set of tools for coping with uncertainty in industrial practice. They stress that the current practice in industry with respect to continuing education, which is to send someone on a course for a week, assuming that this person will be updated on an area of interest to the company, doesn't work very well. They describe their own experiences and future developments for CEME.

Table 1 is an attempt to summarise the topics covered in the papers of this Special Issue.

Let me conclude this editorial by emphasizing that the European Forum for Continuing Engineering Education [2], as well as many other international events, show clearly that engineers and managers need applied mathematicians. As the president of Exxon R&D, Edward David, points out in a recent report to the National Science Foundation of the US: "Two few people recognize that the high technology so celebrated today is essentially a mathematical technology". In fact, there are several situations where it is becoming increasingly difficult to distinguish between the applied mathematician and the engineer. It is also becoming common to find statisticians and operations researchers in very high decision positions in industry.

This Special Issue intends to show that we, the 'stochastics people', have a lot to offer to the user-engineer and to the research engineer, as well as to the middle and the top manager, and we are willing to do so.

For instance, Velazco stresses that, although simulation is reported as one of the most popular techniques, it is estimated that simulation is used in less than 1% of the cases where it could play an important role in analysing critical decisions within an enterprise. Moreover, there are several examples of applications of simulation where it has been misused and also where its results have been taken with more confidence than it is justified. The main reasons for all these facts seem to be that the user-engineers and managers have difficulties in using the present simulation tools available, and that engineers and managers lack the stochastics background to appreciate all modelling assumptions and guide the design and analysis of simulation experiments. He also stresses the benefits that can come from the fact that since 1990 ABET (Accreditation Board for Engineers and Technology), which certifies all US engineering programs, officially requires probability and statistics courses in engineering curricula.

Perhaps it is fair to say that there is nowadays not only a waste in material resources and environmental terms, but also in intellectual terms, i.e. in terms of 'knowledge creation and the use of knowledge'. Therefore, as a first step, I would like to take this exceptional opportunity to ask the readers of this issue (authors included) to write to the IJCEE, reporting their own success in stochastics 'knowledge creation / use of knowledge' activities for engineers and managers.

I also would like to suggest, if I may, that readers more often advertise meeting on stochastics in engineering and management publications, as well as submitting papers to their meetings and periodicals. Perhaps the importance of any paper is not only due to the reputation, in one's own research environment, of the publication where it has been accepted but, most likely, also due to its impact and usefulness to others.

To the engineering and management community I would like to say that it is not always clear what can reasonably be expected of an OR/statistics consultant, or any other consultant for that matter. The consultant, usually, is not able to provide ready-made solutions that can be implemented without any effort on the part of the client organization and its staff. Very often, the client organization has to carry out all the really important and definitive activities to implement the given solution. Therefore, the client organization is left with the most important part of the project, without, in many cases, actually having jointly created it or having a feeling for the solution that has to be implemented. Even when the organization does already have a deep know-how, most likely, the consultancy by itself is also not the best path to follow. A tailor-made CEME program, which could also include a kind of guided consultancy, whose relationship should be of the enterprise-regular-supplier type, could perhaps be a more suitable road to exploit.

However, in my opinion, any stochastics unit that decides to be seriously and deeply involved in this type of CEME program has to consider it, on the one hand, in equal terms with its traditional duties – academic teaching and research – and on the other, to bear in mind that this type of CEME is a new concept which is likely to demand a different approach to its teaching, administration and financing. Furthermore, it is necessary to become a partner in the adventure of learning how to work in an interdisciplinary/-integrated environment and also, most likely, to start to use telematics and to network with enterprises and other national and international research groups. It is also necessary to know how to interact with the 'right people' in industry and governmental institutions.

References

1 Newton, M.A. and Raftery, A.E. (1994) 'Approximate Bayesian Inference with the Weighted Likelihood Bootstrap', J. R. Statistic. Soc. B., Vol. 56, No. 1, pp.3–48.

2 Ramalhoto, M.F. (1993) 'Second European Forum for Continuing Engineering Education scans the European Community Scene', *Int. J. Continuing Engineering Education*, Vol. 3, Nos 1/2, pp.17–25.

Table 1 Summary of the topics dealt with by authors in this Special Issue.

Authors:	Tapiero	Neuts	Cox & Davison	Gani	Berg	Peña	Liu Ke	Ramalhoto	Jun & Ross	Uphadyuay & Smith	Velazco	Odoni	Bergman & Klefsjö
Matters discussed													
Bootstrap									√				
Experimental design								√			√		√
Quality control						√							√
Time series						√							
Bayesian approach						√				√			
Simulation/ experimentation		√	√						√	√	√	√	
Algorithms		√								√			
Optimization/control						√	√	√					
Markov process	√		√	√			√	√	√	√	√	√	
Queues			√	√				√	√		√	√	
Reliability					√					√			√
Engineering	√	√	√	√	√	√	√	√	√	√	√	√	√
Management	√							√			√	√	√