

SOME REMARKS ON RECENT DEVELOPMENTS IN APPLIED PROBABILITY

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Applied probability has finally achieved the recognition it deserves. The recent 211th Meeting of the Institute of Mathematical Statistics (IMS) in Sheffield, England, between August 16 and 19, 1989, stands out as a landmark in its acceptance as a well defined field of mathematical research.

There have been conferences specifically dedicated to applied probability before: possibly the earliest was the Seventh Symposium in Applied Mathematics, jointly sponsored in April 1955 at the Polytechnic Institute of Brooklyn by the American Mathematical Society and the Office of Ordnance Research. It was here that the term *Applied Probability* was first coined to describe the proceedings of speakers on Mathematical Probability and its Applications [1]. Not that applications of probability had been lacking previously. In June 1949, for example, at the Royal Statistical Society's Symposium on Stochastic Processes [2], in London, three pioneering reviews of the application of stochastic processes to statistical physics, evolutionary processes and population growth had been presented by Jo Moyal, Maurice Bartlett and David Kendall respectively. But the concept of applied probability, as a discipline somewhat distinct from probability theory, does not appear to have crystallized until 1955.

The 1989 Sheffield symposium in Applied Probability, coming soon after the IMS announcement of its new journal, the *Annals of Applied Probability* due to begin publication in 1991, marks a new chapter in the history of applied probability. Any remaining doubts among fellow professionals as to the legitimacy of the discipline will have been laid to rest. Applied probability may now be regarded as an area of importance commensurate with that of the overlapping fields of probability theory and mathematical statistics. Some of us had adopted this position many years ago, but our perception was far from universal.

The main themes of the initial symposium in *Applied Probability*, held in Brooklyn in 1955 were related to the physical sciences: the theory of diffusion, the phenomenon of turbulence, and the uses of probability in classical and modern physics. The participants included a highly distinguished group of probabilists and applied mathematicians who gave lectures on the following topics:

Paul Levy on Brownian motion depending on n parameters,

Joe Doob on the first-boundary problem,

Willy Feller on boundaries defined by stochastic matrices,
Eberhard Hopf on the statistical theory of turbulence,
Guido Münch on stochastic processes in astronomy,
George Batchelor on homogeneous turbulence,
Mark Kac on probability in classical physics,
Stan Ulam on infinite models in physics, and
B. O. Koopman on quantum and the foundations of probability.

Remarkably enough, this very promising start does not appear to have been followed up in the U.S.A. In Britain, however, Maurice Bartlett must have shared the symposium organizers' views: in the late 1950s, he named the Methuen series of which he was the general editor *Monographs in Statistics and Applied Probability*. By 1963, research in applied probability had intensified, and it became clear that a new publishing outlet was essential for the work of researchers who were exploring applications of probability to problems in the biological, physical, social and technological sciences.

In 1964, there was a sufficient number of papers being written in applied probability to justify my launching the *Journal of Applied Probability (JAP)*, a periodical jointly sponsored by the Applied Probability Trust (a foundation) and the London Mathematical Society. The distribution of JAP, which initially totalled roughly 250 copies per issue, rose rapidly to about 1500. By 1969, the number of submissions had grown large enough to warrant the publication of a companion journal, *Advances in Applied Probability (AAP)*.

Interest in JAP in 1964 was greater among researchers in the U.K. and Australasia (together 48%), with their strong tradition of applied mathematics, than among those in North America (42%). But these relative positions have gradually altered: in the three years 1986-88, the majority of papers from the 41 countries represented in JAP and AAP (see regions in Table 1) originated from authors in North America (42%), followed closely by those in Eastern and Western Europe (together 30%), with UK and Australasian authors (17%) in third place.

Table 1

Numbers of papers in *JAP* and *AAP* with originating region of authors

	<i>JAP</i> 1964		<i>JAP/AAP</i> 1986-88	
	No.	%	No.*	%
USA and Canada	10.5	42.00	187	41.93
UK	2.5	10.00	51	11.43
Western Europe			115	25.78
Eastern Europe (incl. USSR)	1	4.00	21	4.71
Japan	1	4.00	15	3.36
Australia and New Zealand	9.5	38.00	23	5.16
Middle East, Africa, Asia	0.5	2.00	30	6.73
South and Central America			4	0.90
TOTAL	25.0	100.00	446	100.00

* The numbers in the third column contain minor inaccuracies due to rounding off errors when a paper has multiple authors. When a paper has two authors only, each gets credited with 0.5 of a paper.

During the 1970s, several new journals appeared which published material in applied probability: the *Annals of Probability* (1973), *Stochastics* (1973), *Stochastic Processes and their Applications* (1973), *Mathematics of Operations Research* (1976), *Stochastic Models* (1985), *Applied Stochastic Models and Data Analysis* (1985), and *Queueing Systems* (1986), to name but a few. The forthcoming *Annals of Applied Probability* demonstrates the IMS's strong commitment to the field, and will be welcomed by all applied probabilists.

Concern has been expressed that this new journal may attract some papers away from existing periodicals. I believe its more enduring effect will be to focus the efforts of young researchers on the varied and fascinating problems of applied probability arising in the biological, physical, social and technological sciences. I should be very surprised if the number of publications in applied probability did not grow substantially during the 1990s. The present journals may even find that they experience difficulties in accommodating all acceptable submissions, and I would expect some new journals to be started in the more specialized areas of the subject.

It is now possible, with hindsight, to trace the emergence of applied probability over the past 40 years; but its relevance to probabilistic and statistical stud-

ies was not always so readily accepted, even 15 years ago. This was apparent at the Conference on Directions for Mathematical Statistics [3] organized in Edmonton, Alberta, in August 1984 by Sudhish Ghurye. The conference was intended to discuss "... areas of current interest in which statistical methodology will yield substantive dividends."

Four of the twelve papers at the conference considered problems and issues in applied probability. Mark Kac in his paper 'Some reflections of a mathematician on the nature and role of statistics', spoke of applications of probability to physics, and to radar observations. He outlined Maxwell's statistical approach to problems in thermodynamics, and mentioned Siegert's work on the observation of radar signals during World War II. Ron Pyke, as the first editor of *Annals of Probability* wishing to encourage submissions in applied probability, reflected humorously on 'Applied probability: an editor's dilemma'. I took the opportunity to survey 'Theory and practice in applied probability', while Wendell Fleming gave an overview of 'Diffusion processes in population biology'.

Yet despite the unequivocal evidence placed before them, many of our statistical colleagues continued to treat applied probability as a field of marginal importance for a further decade. This seems to be the fate of many interdisciplinary areas in their earlier stages of development: biochemists have assured me that their difficulties have in many ways paralleled those experienced by applied probabilists. It is perhaps an unavoidable stage in the establishment of all new fields.

Has the scope of applied probability altered since 1955, when most of its problems were inspired by the physical sciences? A survey of published papers indicated that the areas of application have broadened steadily over the past 35 years. In 1971-3 for example, the main topics covered in *JAP* and *AAP*, ranked roughly in terms of decreasing numbers of papers, were stochastic models (branching processes, Markov chains and processes, other processes), queueing, storage and traffic theory, operations research, population processes in biology, epidemiology and mathematical genetics, distribution theory and limit theorems, and geometric probability. There were regrettably few contributions to the physical and social sciences.

Fifteen years later, in 1986-8, while the mix remained similar, there had been some new departures and substantial changes of emphasis: the number of biological papers had suffered a sharp reduction as more specialist journals in mathematical biology were published, but there had been an increase in the technological contributions, especially in queueing theory and networks, control

and reliability. Roughly half the papers were on topics in probability theory relevant to applications, while the other half were concerned with the applications themselves. Only 4 papers were inspired by the physical and social sciences, most such contributions having found their way to specialist journals.

The 1989 Sheffield symposium in Applied Probability covered an exceptionally wide range of interests. There were over 60 invited and contributed papers on

Probability problems inspired by physics,

Probability problems inspired by biology, including mathematical genetics,

Models in epidemiology,

Probability in the theory of algorithms,

Extreme value theory,

Probability problems of queueing, including queueing networks,

Mathematical models of finance,

Point processes: applications and inference,

Self-similar processes,

Random processes and fields subject to long-range dependence,

Branching processes, and

The metric structure of Euclidean shape spaces,

among other topics. It was a source of great personal pleasure to me that David Kendall, who had contributed to the 1949 Royal Statistical Society Symposium and had been one of the strongest supporters of *JAP* in 1964, spoke on the last topic.

What of future directions of research in applied probability? If I were to hazard any predictions on the most exciting areas of investigation, I should pick algorithmic theory and methods, geometric probability, image processing and inference on random processes. Problems in these areas will continue to arise in the analysis of the idealized stochastic models of biology, genetics, epidemiology, physics and engineering, which scientists are so skilled in building. The real world is rich in random events whose study cries out for the skills of applied probabilists: the problems they pose will continue to challenge researchers for many years to come. I therefore feel I am on safe ground in forecasting an increasingly important role for applied probability in the 21st century.

I have no fear whatever that the sources of problems in applied probability will dry up; but I view the future production of mathematicians, statisticians and probabilists in our society with far less confidence. Steady reductions in the numbers of students in these disciplines have been reported, particularly at the graduate level, in North America, Europe, Britain and Australia. These decreases jeopardize not only the future of our profession, but more generally that of our society, based as it is on science and technology. We must respond to this threat with the utmost vigour; not only must we encourage more young students to graduate in the mathematical sciences, but we must also alert the leaders of our society and our politicians to the dangers of subjecting education too freely to the forces of a market economy. In science and technology, it is often the long term that counts. We must stress this viewpoint with persistence, patience and a wealth of convincing historical examples, if we wish our society -- and applied probability within it -- to develop healthily in future.

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