J.W. Cohen: his Scientific Career

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A brief account of J.W. Cohen's scientific career is presented*. The text is extracted from the introductory pages of the book 'Queueing Theory and its Applications - Liber Amicorum for J.W. Cohen', edited by the present authors and published by North-Holland Publ. Co. (1988) to celebrate the 65th birthday of Jacob Willem Cohen.

Wim Cohen was born in Leeuwarden, The Netherlands, on August 27, 1923. After completing highschool he spent a considerable part of World War II in hiding, with friends. During these years he acquired a deep knowledge of large parts of physics and mathematics by self-study. After the war, he decided to study mechanical engineering at Delft University of Technology. In 1949 he completed his Master Thesis (cum laude), and in 1955 he graduated cum laude, again at Delft University of Technology, with a Ph.D. Thesis [B1] entitled *On Stress Calculations in Helicoidal Shells and Propeller Blades.* Just as Cohen's later work, this thesis research had a fundamental character, but was also directly related to practical applications.

In the period 1950-1957 Cohen worked as a 'teletraffic engineer' in the Philips Telecommunication Group. Around 1950 Philips entered the field of telephone engineering. Teletraffic, or congestion theory as it was then called, had already built up a tradition, and several theoretical and experimental techniques had been developed. The available theoretical studies were nearly all of a pioneering type, using seemingly *ad hoc* techniques. The book of Th.C. Fry, *Probability and its Engineering Uses,* of 1928 was the only available text which tried to present a coherent account of the available models and to explain what are currently referred to as birth-and-death processes. The publication of Feller's famous *An Introduction to Probability Theory and its Applications* in 1950 was a landmark in the development of stochastic modeling. It removed several hazy notions in the basic definitions of probabilities and stochastic variables. At the same time, the possibilities for Operations Research became

* For further details on Cohen's life and his scientific views we refer to the autobiographical paper [A22], which has also been beneficial to us in writing this account.

clear. In the late fifties probabilistic modeling became a tool in industrial engineering and management, and randomness was accepted as a phenomenon that could be modeled.

During his Philips years, Wim Cohen published several papers on telephone systems. His 1957 papers [A1-6], in particular, make fundamental contributions to existing congestion theory, and some of them are still cited quite often. In [A5] for instance Cohen investigated the loss system with a finite number N of servers and a finite number $M>N$ of sources (subscribers), every source having its individual characteristics with respect to calling rate and service time distributions. Using Kosten's technique of the supplementary variable, Cohen obtained the stationary distribution of specified idle and busy sources. This distribution appeared to be *insensitive* in the sense that only the first moments of the service time distributions were involved. Moreover, the distribution exhibited a *product form.* Some twenty years later, when the concepts of insensitivity and product forms had been firmly established as basic elements of queueing network theory, Cohen was to make further fundamental contributions to these concepts [A16,B3].

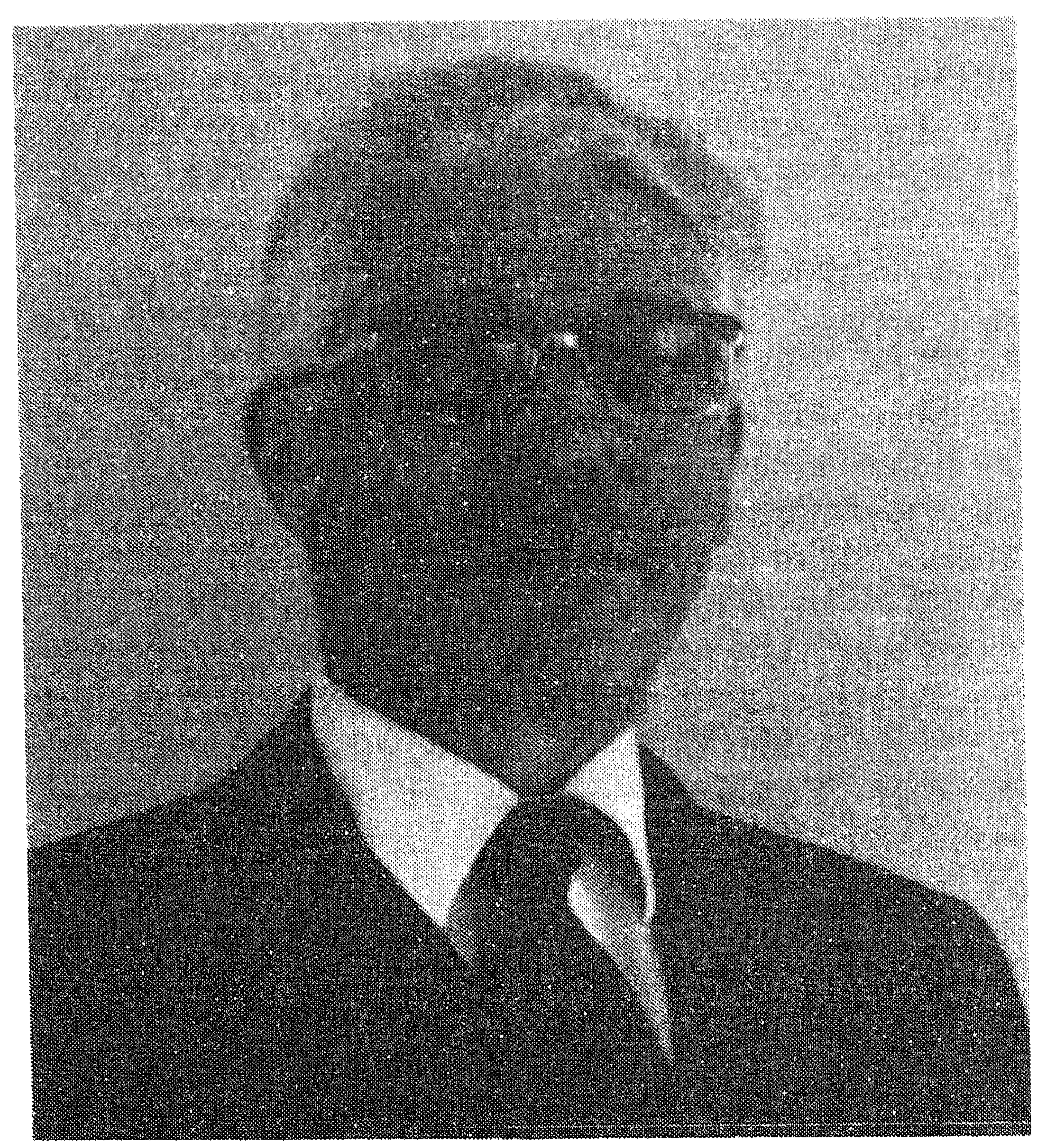
In the late fifties research workers in congestion or queueing theory had a fairly good set of basic models and appropriate mathematical techniques at their disposal. At that stage, professional mathematicians became interested in the subject. In line with this development, in 1957 Wim Cohen was appointed to a chair of Applied Mathematics in the Mathematics Department of the Delft University of Technology. He did not completely leave Philips, though; until 1987 he has served as a consultant for the Philips Telecommunication Group.

Among the papers he wrote in his early Delft period were several studies on derived Markov chains [A7-10]. The randomization or uniformization technique, which has recently become a popular tool in the analysis of the transient behavior of complex systems, is strongly related to these derived Markov chains.

In 1964 Wim Cohen married Annette Waterman, the daughter of a distinguished Dutch professor in chemistry. She created an ideal atmosphere for research and scholarship, which enabled Cohen to undertake the immense task of writing *The Single Server Queue* [B2] (the author index contains the name A.B. Waterman, as a tribute). The book contains much original research in the theory of stochastic processes; one of its many virtues is also that it beautifully demonstrates the power of the method of Pollaczek in queueing theory. This method basically describes a physical queueing situation in a natural way by analytic expressions (in terms of simple contour integrals), and thus transforms the probabilistic problem into a problem in complex analysis. In [B2] Cohen converts this approach into a powerful practical tool. The book is still considered to be the standard work in the area of mathematical queueing theory; a second revised edition appeared in 1982.

Soon after the completion of the book, in 1968, Wim Cohen became head of the Mathematics Department. As this occasion coincided with the student revolt (in The Netherlands as well as elsewhere), which led to a drastic change in the hierarchical structure of the University of Delft, Cohen did not have an easy time. The atmosphere in the department became such that he found it increasingly hard to devote his energy to research, and he took the difficult decision to leave his Alma Mater; on September 1, 1973, he took up the chair of Operational Analysis at the Mathematics Department of the University of Utrecht. He has stayed in Utrecht ever since, enjoying its special atmosphere which enables one to concentrate almost fully on research and teaching.

Cohen's scientific curiosity and creativity seemed to increase rather than decline over the years, and he grabbed the opportunity offered by the Utrecht environment to start novel ambitious research projects. Characteristically, these were mainly solo operations; in the period 1973-1978 Boxma was his only local graduate student and, later, cooperator.



Cohen's first research project in Utrecht concerned level crossings for regenerative processes. In queueing theory many of the involved stochastic processes are regenerative, and quite often this regenerative character provides the key to the analysis of the queueing model to be studied. In the monograph [B3], J.W. Cohen derives a number of *stochastic mean value theorems*. Such theorems express the stationary distribution of a regenerative process, if it exists, as a time average of the process over a regenerative cycle. The formulation of these stochastic mean value theorems makes it possible to apply immediately the sample function relations which exist between the involved stochastic processes. By this approach many well-known basic relations in queueing theory, like Little's formula, can be derived in an extremely simple and elegant way. A large part of [B3] is devoted to the application of stochastic mean value theorems to the M/G/K queueing and loss systems. In particular, a lengthy but essentially simple proof is presented of the insensitivity property of Erlang's formula for the distribution of the number of busy servers in the M/G/K loss system. The last part of [B3] starts exploring the possibility of obtaining relations between queueing quantities by using a *level crossing analysis.* In a series of papers [A11-15,A18] this technique is further developed. The level crossing method finds its applications in such fields as inventory and production theory, data communications and reliability.

At the end of the sixties queueing theory got a new stimulus from the field of computer engineering. At that time, computer technology had reached a level of development which required a good insight into the data flow inside a computer, as well as in computer networks. For the latter in particular, the classical single service facilities did not suffice; networks of service facilities had to be analyzed. The pioneering work of J.R. Jackson turned out to be extremely useful in this respect. Jackson had studied open queueing networks with Poisson arrival streams (and later on, basically, closed networks) in which the service time distributions at all service centres are exponential. He showed that the stationary joint queue length distribution at the centres has a simple *product form,* which in principle allows a straightforward determination of all quantities of interest. However, the usefulness of Jackson's results for computer performance analysis was still severely limited by the restrictions that all customers follow the same rules of behavior, and that only exponential service time distributions occur. Furthermore, computer technology created a new type of service discipline, viz. the time sharing discipline, in which each job receives a quantum Δq of service and, when the total service request is not yet fulfilled, returns to the end of the queue. Kleinrock made the important observation that in the limit $\Delta q \to 0$ a queueing model results which is more amenable to a detailed mathematical analysis; the resulting service discipline is coined *processor sharing.* The stationary queue length distribution of an M/G/1 queue with processor sharing is independent of the service time distribution, apart from its first moment: the intriguing insensitivity phenomenon reappears! Baskett, Chandy, Muntz and Palacios, in their celebrated 1975 paper, proved that the product form property is not destroyed if, in a Jackson network, the service discipline at one or more of the centres is processor sharing - with not necessarily negative exponentially distributed service times. In fact they also allowed multiple classes of customers, with different characteristics. Cohen's interest in the concepts of product form and insensitivity was strongly revived by this BCMP paper, and by the beautiful studies of the young Cambridge mathematician Frank Kelly. A short but vigorous research effort led to the publication of 'The multiple phase service network with generalized processor sharing' [A16] and two other papers [A17,19]. We consider [A16] to be one of Cohen's best papers. It develops a general theory for a broad class of processor sharing models. The generalization of the ordinary processor sharing concept leads to a pleasing unification and extension of many of the known product form and insensitivity results.

Over the many years that J.W. Cohen had been involved in the analysis of queueing models, he had often come across apparently unsolvable, deceptively simply formulated 'two-dimensional' queueing models: the M/G/2 queue; the model of two servers and two queues, arriving customers choosing the shortest queue; the model of two queues, alternatively attended by one server; two servers with related speeds ('two coupled processors'); etc. In a fundamental publication in 1977, Fayolle and Iasnogorodski showed that the coupled processor problem can be analyzed by applying a boundary value technique from mathematical physics. The idea is to transform the problem of determining a two-dimensional Laplace transform or generating function into the problem of solving a (Dirichlet, Riemann or Riemann-Hilbert) boundary value problem. In its simplest form this requires the determination of a function which is analytic inside (and in some cases also outside) a simple closed contour, with prescribed discontinuities on that contour.

Cohen became absolutely fascinated by this technique. He started to study the books of Russian authors like Gakhov and Mushkelishvili on boundary value problems and (related) singular integral equations. Applying and extending the theory developed in those books, he was finally able to develop a method for the analysis of a large class of 'two-dimensional' random walk and queueing models. One of us (OJB) participated in the project, but Cohen was the driving force; countless mathematical difficulties were encountered, and they would not have been solved if Cohen had not devoted all his ingenuity and analytical skills to them. As a result the monograph [B4] was published (a Russian translation appeared in 1987). Cohen also supervised the Ph.D. theses of Hans Blanc (1982), Jan de Klein (1988) and Henk Nauta (1988) in the same area. The boundary value technique is still in its infancy, but it has disclosed an important research area and already several long-standing open problems have been successfully tackled; moreover, the approach allows for a fairly straightforward numerical evaluation. A major drawback is that there is so far no real clue as to an extension to 'higher-dimensional' problems. In the last few years Cohen has spent a tremendous amount of time and energy trying to accomplish such an extension, but he was not able to obtain a really manageable solution for, say, 'three-dimensional' problems (cf. [A20-21]). Characteristically, on several occasions in private he optimistically expressed his hope of 'almost being there', only to say the next day that something crucial was still missing. As is not unusual in fundamental research, there were unexpected spin-offs; in this case, some very elegant identities for entrance times in random walks [A23-26].

On September 1, 1988, following Dutch regulations, J.W. Cohen retired from the University of Utrecht. In view of the fact that his interest in queueing theory remains undiminished and that, anyway, he has done most of his research in his study at home, it seems likely that his 65th birthday and retirement will not mark the end of his research. Shortly before this retirement, in June 1988, Cohen received a honorary doctorate from the Technion Israel Institute of Technology in recognition of his research achievements. Two years earlier, the Dutch Society of Sciences had honoured Cohen by awarding him the AKZO prize. This prestigious prize is awarded once a year for scientific research done over the preceding ten-year period. There are no particular restrictions on the area of research.

This short account of Cohen's scientific career would not be complete without a few words about his organizational activities in the international scientific community. He has been a member of the International Advisory Council for Teletraffic Congresses from the very beginning, in 1955, and he was elected an honorary member of this Council in 1988; the ITC has always been particularly dear to him. He has also been one of the founding editors of *Stochastic Processes and their Applications,* and he has served as an editor for a number of other leading journals. In these ways, and also as an organizer of workshops and conferences [B5], and as teacher of a few generations of Dutch probabilists, he has made a strong contribution to the scientific community.

However, there are two even more lasting contributions, we believe. First of all, in his scientific writings he has set a standard of mathematical rigour which has strongly enhanced the maturing of queueing theory as a mathematical discipline. And secondly, due to the combination of an engineering background and a strong mathematical ability he was able to understand all those people interested in queueing theory: probabilists, teletraffic engineers, operations researchers and computer performance analysts - and to bridge the gaps between them. In this way he has helped to make queueing theory an indispensable tool in the design and performance analysis of computer and communication systems. For these contributions, the queueing community will always owe a debt to J.W. Cohen.

Scientific publications by J.W. Cohen

A. Papers*

1957 1. The full availability group of trunks with an arbitrary distribution of the inter-arrival times and a negative exponential holding time distribution. *Simon Stevin 26,* 169-181.

* A complete list of J.W. Cohen's scientific publications appears in the book 'Queueing Theory and its Applications - Liber Amicorum for J.W. Cohen'.

2. With M.M. Jung. Calculations on a method for signal setting. *Philips Telecommunication Review 17,* 81-89.

3. With B.J. Beukelman. Call congestion of transposed multiples. *Philips Telecommunication Review 17,* 145-154.

4. Basic problems of telephone traffic theory and the influence of repeated calls. *Philips Telecommunication Review 18,* 49-100.

5. The generalized Engset formulae. *Philips Telecommunication Review 18,* 158-170.

6. A survey of queueing problems occurring in telephone and telegraph traffic theory. *Proc. 2nd Int. Conference on Operational Research,* Oxford, 138-146.

1962 7. Sur les chaines de Markov derivées et leur application à la théorie des queues. *Ann. des Telecommunication 17,* 164.

8. On derived and nonstationary Markov chains. *Theory of Probab. and Applications 7,* 402-423.

9. Derived Markov chains I, II, III. *Indag. Math. 24,* 55-92.

10. A note on skeleton chains. *Nieuw Arch. v. Wiskunde 10,* 180-186.

1976 11. On the optimal switching level for an M/G/1 queueing system. *Stoch. Proc. Appl. 4,* 297-316.

1977 12. On up- and downcrossings. *J. Appl. Probab. 14,* 405-410.

13. With M. Rubinovitch. On level crossings and cycles in dam processes. *Math. Oper. Res. 2,* 297-310.

1978 14. On the maximal content of a dam and logarithmic concave renewal functions. *Stoch. Proc. Appl. 6,* 291-304.

15. Properties of the process of level crossings during a busy cycle of the M/G/1 queueing system. *Math. Oper. Res. 3,* 33-144.

1979 16. The multiple phase service network with generalized processor sharing. *Acta Informatica 12,* 245-284.

17. On networks with generalized processor sharing and a new property of the Erlang B-formula. *Proc. 9th ITC.*

1980 18. With M. RUBINOVITCH. Level crossings and stationary distributions for general dams. *J. Appl. Probab. 17,* 218-226.

19. Sensitivity and insensitivity (Lecture Symp. Professor Kosten retirement). *Delft Progress Report 5,* 159-173.

1984 20. *On a Functional Relation in Three Complex Variables; Three Coupled Processors,* Report 359, Math. Institute, Univ. Utrecht.

21. *On the Analysis of Parallel, Independent Processors,* Report 374, Math. Institute, Univ. Utrecht.

1986 22. Some samples of modelling. J. GANI (ed.). *The Craft of Probabilistic Modelling,* Springer Verlag, Berlin, 88-108.

23. *On Entrance Times of Homogeneous Semi-Bounded N-Dimensional Random Walks: an Identity,* Report 440, Math. Institute, Univ. Utrecht.

24. *On Entrance Times of a Homogeneous N-Dimensional Random Walk; an Identity,* Report 442, Math. Institute, Univ. Utrecht.

1987 25. On entrance time distributions for two-dimensional random walks. G. IAZEOLLA, P.J. COURTOIS, O.J. BOXMA (eds.). *Computer Performance and Reliability,* North-Holland, Amsterdam, 25-41.

26. Continuation of: *On Entrance Times of Homogeneous Semi-Bounded N-Dimensional Random Walks: an Identity,* Report 460, Math. Institute, Univ. Utrecht.

B. Books

1955 1. *On Stress Calculations in Helicoidal Shells and Propeller Blades,* Thesis, Waltman, Delft.

1969 2. *The Single Server Queue,* North-Holland, Amsterdam, 2nd revised edition 1982.

1976 3. *On Regenerative Processes in Queueing Theory,* Lect. Notes in Econ. and Math. Systems, Vol. 121, Springer Verlag, Berlin.

1983 4. With O.J. BOXMA. *Boundary Value Problems in Queueing System Analysis,* North-Holland, Amsterdam. Russian transl. Mir Publishers, Moscow, 1987.

1986 5. With O.J. BOXMA and H.C. TIJMS (eds.). *Teletraffic Analysis and Computer Performance Evaluation,* North-Holland, Amsterdam.