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EDITORIAL

Editorial introduction to the special issue "Masakiyo Miyazawa—75"

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This Special Issue is in honour of Professor Masakiyo Miyazawa, who has been one of the most active and influential members of the Editorial Board of QUESTA over the years and has the longest service time in the role of Associate Editor: 29 years, from 1993 to 2021 (inclusive). He has handled many dozens of submissions and reviewed more than 70 papers. He has published 24 papers (including 1 invited paper) in the journal and edited two Special Issues (in 1994, jointly with H. Takagi, and in 2013, jointly with Y.Q. Zhao).

This Special Issue contains invited papers from researchers who have scientific relations with Masakiyo Miyazawa and/or share his research interests. The papers span recent achievements in a broad variety of areas of queueing theory.

Masakiyo Miyazawa finished his Ph.D. studies under supervision of Hidenori Morimura at Tokyo Institute of Technology in 1976. At that time, the performance evaluation of single buffer queueing systems with renewal (GI-) arrivals was one of the most popular subjects in queueing theory, and the complexity of the analysis of such systems was broadly recognised (e.g., see "On the algebra of queues" by J.F.C. Kingman). On the other hand, it was clear that a renewal arrival process may not well capture actual arrivals. In his Thesis, Masakiyo cracked this situation by introducing and analyzing queueing models based on point processes and their Palm distributions. Independently, this approach had been also studied by the group of Dieter König in Freiberg, East Germany. It is interesting that this approach had been developed inde-

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pendently at two distant local places at the same time. However, one should mention that both Japan and the east European counties, including Russia, have long traditions in the mathematical study of stochastic processes.

In the queueing theory, stochastic processes are considered as basic mathematical models. However, before the 70's of the last century, the theory was mostly devoted to finding the distributions of characteristics (such as queue length and waiting time) using relatively simple stochastic processes such as a reflecting random walk and Markov chains. These simplifications allowed to reduce the problems of interest to solving corresponding analytical equations.

Masakiyo's contributions to the queueing theory come from introducing and considering queueing models under very general stochastic setting, where the sample-path behavior plays a major role and may be described in terms of stochastic point processes. For example, the Rate Conservation Law, which is one of Masakiyo's innovations, is based on the consideration of the Palm distribution of a point process. We list below the major contributions of Masakiyo to the queueing theory, based on classification of models and stochastic processes.

1. **Single server queue:** stochastic order, buffer truncation, last-come first-service (with Genji Yamazaki).
2. **Many server queue:** approximation of the stationary distribution of $M/G/s/k$ queue, distributional relationship of queue length and waiting time,
3. **Queueing network with stationary input:** distributional relationship of characteristics at embedded instants and stationary point of time.
4. **Re-allocatable generalized semi-Markov processes** (with Rolf Schasberger & Volker Schmidt): structural properties, characterization of insensitivity, characterization of the stationary distribution.
5. **Product form queueing network:** extension to a linear network, characterization by quasi-reversibility (with Xulli Chao, Richard Serfozo & PhD student), extension to those with signals (with Xulii Chao) and batch movements (with Peter Taylor).
6. **Quasi-birth-and-death (QBD) processes:** QBD with infinite phase space and the tail decay rate of its stationary distribution (with Yiqiang Zhao & his PhD students), two-dimensional QBD process and its decay rate problems, parallel queues with joining shortest queue (with PhD students).
7. **Multidimensional reflecting processes:** The light tail asymptotics of the stationary distribution, Markov renewal approach, Wiener-Hopf factorizations for a multidimensional Markov additive process (with Bert Zwart), multidimensional reflecting random walk with arbitrary boundary reflection, Levy driven tandem queue (with Tomasz Rolski), risk and queueing network processes, martingale and change of measure technique, the heavy tailed asymptotics of the sojourn time in a feedback queue (with Sergey Foss).
8. **Semi-martingale reflecting Brownian motion:** Tail decay rate of the stationary distributions (with Jim Dai), diffusion approximation of the stationary distributions of the generalized Jackson networks using basic adjoint relationship (with Jim Dai & Anton Braverman).

Masakiyo's most notable contribution may be viewed as opening the door to the light tail asymptotic study of multidimensional stationary distributions through char-

acterizing the decay rates by geometric curves. Currently, its applicability is limited mainly to the two dimensional distributions, but it may be applied to higher dimensions. Masakiyo has collaborated with many colleagues. He said: "I have benefited by collaborations, so my contributions should be shared with my collaborators".

The Special Issue in honour of Masakiyo Miyazawa includes 12 research papers.

Ivo Adan, Onno J. Boxma and *Jacques Resing* study a functional equation for generating functions of the form $f(z) = g(z)\sum_{i=1}^{M} p_i f(a_i(z)) + K(z)$, i.e. a recursion with multiple recursive terms. They derive and analyze the solution of this equation in the case where the $a_i(z)$ terms are commutative contraction mappings. The results are applicable to a wide range of queueing, autoregressive and branching processes for the purpose of, for example, computing steady-state distribution.

Mihail Bazhba, Chang-Han Rhee and *Bert Zwart* consider a stochastic fluid network where the external input processes are compound Poisson with heavy-tailed Weibullian jumps. Their results comprise the large deviations estimates for the buffer content process in the vector-valued Skorokhod space which is endowed with the product J_1 topology. Explicit results for a tandem queue are given to illustrate the theoretic framework. At the heart of the proof are two results, a recent sample-path large deviations result and a novel continuity result for the Skorokhod reflection map in the product J_1 topology.

The work by *Krzysztof Bisewski, Krzysztof Dębicki* and *Tomasz Rolski* investigates the expected supremum of fractional Brownian motion which plays an important role in the theory of Gaussian-driven queueing models. In particular, the H-derivative of function $\mathcal{M}_H(a, T)$, which equals to the expected supremum of fractional Brownian motion with Hurst index $h \in (0, 1]$ and drift $a \in \mathbb{R}$ over time horizon $T > 0$, is found for $H = 1$. As a by-product, the authors establish a weak limit theorem in $C[0, 1]$ for fractional Brownian bridges, as $H \to 1$.

The work by *Onno J. Boxma* and *Michel R.H. Mandjes* analyzes various stochastic recursions that arise in queueing and insurance risk models with a 'semi-linear' dependence structure. This structure appears where, for example, the interarrival time may depend on the workload or the capital of a company, immediately after the previous arrival; or the customer service time of may depend on her waiting time. The Laplace-Stieltjes transforms of key performance measures of the model, like waiting time or ruin time, are obtained via solving the corresponding fixed-point equations.

The work by *Chang Cao, Jim G. Dai* and *Xiangyu Zhang* studies the moment state space collapse (moment-SSC) property of the steady state queue length for multiclass queueing networks under static buffer priority service policies. The result is crucial for establishing steady-state diffusion approximation of queueing model in the heavy traffic. The authors show that the moment-SSC holds under the corresponding state space collapse condition in the fluid model. It is also shown that the fluid state space collapse holds for various networks, including last-buffer-first-serve and first-buffer-first-serve re-entrant lines, Dumas networks and a two-class five-station priority network.

Sandro Franceschi and *Kilian Raschel* study a transient reflected Brownian motion. They compute the absorption probability, as a function of the starting point, of a multidimensional reflected Brownian motion in an orthant, which is either absorbed at the apex of the cone or escapes to infinity. A necessary and sufficient condition called

"dual skew symmetry" is found for the absorption probability to admit an exponential product form. The condition is analogous to the well-known skew symmetry condition introduced by Harrison, which characterizes the exponential stationary distributions in the recurrent case. In particular, the partial differential equation of the absorption probability is dual to that associated with the stationary distribution in the recurrent case.

Motivated by observed similarity among different multiserver models, *Isaac Grosof, Mor Harchol-Balter1* and *Alan Scheller-Wolf* propose a new work-conserving finite-skip (WCFS) framework that encompasses a broad class of important models. This class includes the heterogeneous $M/G/k$ queue, the $M/G/1$ queue with Limited Processor Sharing policy, the Threshold Parallelism model, and also the Multiserver Job model under a novel scheduling algorithm. The authors prove that, for all WCFS models, the scaled mean response time $E[T](1-\rho)$ converges to the same value in the heavy-traffic limit, which is also the heavy traffic limit for the $M/G/1$ FCFS queue. Moreover, they obtain additively tight bounds on mean response time for the WCFS class and for all loads ρ, which are the first known bounds on mean response time in the four models mentioned above.

The work by *Hiroyuki Masuyama* studies the stationary distribution vector of asymptotically block-Toeplitz and upperblock-Hessenberg (UBH) Markov chains. The UBH Markov chain typically arises in semi-Markovian retrial queues as, say, the queue-length process or its embedded process, or appropriately time-scaled versions of these processes. This work presents subexponential and locally subexponential asymptotic formulas for the stationary distribution vector of UBH Markov chains. The locally subexponential asymptotic formula is extended to continuous-time UBH Markov chain by uniformization and change of time scale.

Yoni Nazarathy and *Zbigniew Palmowski* investigate critical $GI/G/1$ queues under finite second moment assumptions. They show that the busy period distribution is regularly varying with index $1/2$. This result covers previously known results for $M/G/1$ and $GI/M/1$ models. The authors further use the result to demonstrate the so-called BRAVO phenomenon (Balancing Reduces Asymptotic Variance of Outputs) for the busy-time and yield new insight on the BRAVO effect. Their result also contributes to the literature by settling conjectured results about $GI/GI/1$ and $GI/G/s$ BRAVO. The current paper strengthens known results, with relaxing assumptions on moments and the tail of the busy period.

Toshihisa Ozawa considers a discrete-time two-dimensional quasi-birth-and-death process and studies asymptotic properties of the stationary tail distribution. His work extends existing results on decay rate of the stationary tail distribution in the coordinate directions to arbitrary directions, using the matrix analytic methods of queueing theory and the complex analytic method. The result can be viewed as an extension of known results on the stationary tail distribution of two-dimensional reflecting random walks without background processes.

The work by *Guodong Pang, Andrey Sarantsev* and *Yuri Suhov* studies birth-and-death processes in interactive random environments where the birth and the death rates and the dynamics of environment state are dependent on each other. Two models for the random environment are considered: a continuous-time Markov chain and a reflected jump diffusion process. The background is determined by a joint Markov process

carrying a specific interactive mechanism, with an explicit invariant measure whose structure is similar to a product form. A number of queueing and population-growth models are discussed along with conditions under which the above-mentioned invariant measure can be derived. In addition, the authors analyze the rate of convergence to stationarity for the models under two different settings, leading to exponential and polynomial convergence rates via coupling techniques.

Motivated by applications in service systems, *Li Xiao, Susan H. Xu, David D. Yao* and *Hanqin Zhang* study the so-called ticket queue, in which each customer receives a ticket upon arrival and enters service according to the ticket number. There is no physical queue and customers may walk away and return later before entering service. They investigate the optimal staffing problem in a ticket queue with two capacity levels, where the staffing decision can only be based on ticket numbers, as opposed to the physical queue length. Using renewal reward theorem, they first derive the long-run average total cost including customer delay and abandonment costs, operating cost and cost for changing staffing levels, and obtain the optimal solution using fractional programming. In addition, they pursue a random walk analysis, which leads to some highly accurate approximation.