Summary of professional achievements

Personal data

Przemysław Korytkowski, PhD

Diplomas and degrees

1. Technical University of Szczecin,
   Faculty of Computer Science and Information Technology
   PhD in computer science, speciality: modelling and simulation, 2005.
   Thesis: *Modelling and optimization of the output capacity of an intangible production system*

2. Technical University of Szczecin,
   Faculty of Computer Science and Information Technology
   MSc in computer science, speciality: programming techniques, 2005.
   Thesis: O*ptimization model of a queuing system for a virtual organization*

Information about employment

2007 – now West Pomeranian University of Technology in Szczecin, Faculty of Computer Science and Information Technology, Department of Information Systems Engineering,
position: assistant professor, head of Industrial Engineering Group since 2013.

2006 – 2012 Stargard School Stargardinum, Faculty of Composed Sciences, Department of Computer Science
position: associate professor

2005 – 2007 Technical University of Szczecin, Faculty of Computer Science and Information Technology, Department of Information Systems,
position: assistant professor.

Science profiles

- Web of Science: H-3621-2012
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Scientific achievement

Models and algorithms for performance evaluation of stochastic discrete-event systems

Six works comprise the scientific achievement:

A1 **Korytkowski P.**, T. Wiśniewski, O. Zaikin (2010) Multi-criteria approach to comparison of inspection allocation for a multi- product manufacturing system in make-to-order sector, *Control and Cybernetics*, **vol. 39 (1)**, 97-116.
IF = 0.3, 20 points, own share 75%
Number of citations: 2 WoS, 3 Scopus, 3 Google Scholar
The contribution of the author: author of the idea and assumptions in the developed mathematical model, preparation of the manuscript.

A2 **Korytkowski, P.** (2011) A genetic algorithm with tournament selection for optimizing inspection allocation in multiproduct multistage production systems, *International Journal of Simulation and Process Modelling*, **Vol. 6 (3)**, 238-244.
0 points,
Number of citations: 0 WoS, 0 Scopus, 2 Google Scholar

A3 **Korytkowski, P.**, T. Wiśniewski, S. Rymaszewski (2013) An evolutionary simulation-based optimization approach for dispatch scheduling, *Simulation Modelling Practice and Theory*, **Vol. 35**, 69-85.
IF = 1.05, 25 points, own share 70%
Number of citations: 8 WoS, 11 Scopus, 15 Google Scholar
The contribution of the author: author of the idea and assumptions, development of the optimization algorithm, building of the simulation model, preparation of the manuscript.

A4 **Korytkowski P.**, S. Rymaszewski , T. Wiśniewski (2013) Ant Colony Optimization for job shop scheduling using multi-attribute dispatching rules, *International Journal of Advanced Manufacturing Technology*, **Vol. 67**, 231-241.
IF = 1.78, 30 points, own share 70%
Number of citations: 4 WoS, 6 Scopus, 14 Google Scholar
The contribution of the author: author of the idea and assumptions, development of the optimization algorithm, building of the simulation model, preparation of the manuscript.

A5 **Korytkowski, P.**, R. Karkoszka (2016) Simulation based efficiency analysis of an in-plant milk-run operator under disturbances, *International Journal of Advanced*

Manufacturing Technology, **Vol. 82 (5)**, 827-837.
IF = 1.568, 25 points*, own share 75%*
Number of citations: 0 WoS, 2 Scopus, 2 Google Scholar
The contribution of the author: author of the idea and assumptions, literature review, experimental result analysis, preparation of the manuscript.

A6 Małachowski, B., **P. Korytkowski** (2016) Competences-based performance model of multi-skilled workers, *Computers & Industrial Engineering*, **Vol. 91**, 165-177.
IF = 2.086, 35 points, own share 50%
Number of citations: 0 WoS, 1 Scopus, 1 Google Scholar
The contribution of the author: co-author of the idea and assumptions, literature review, model of performance evaluation, preparation of the manuscript.

Five of the listed scientific achievements were published in scientific journals from the Journal Citation Reports list, with one paper published in a scientific journal not included in the lists of the Ministry of Science and Higher Education. The International Journal of Simulation and Process Modelling issued by InderScience Publishers is indexed by Scopus.

Table 1. Bibliometric indicators of publications included in the scientific achievement

Parameter	Value
Total IF	6.784
Number of points	135
Number of weighted points	88.8

Scientific activity

The beginning of my scientific work was devoted to intangible production models, comprising the production of products in a digital form. I developed an algorithm to optimize production capacity, defining the number of machines and the size of the buffers. The results were presented in the doctoral thesis *The optimization model of queuing system for a virtual organization.*

After finishing my PhD, I undertook research in Stochastic Discrete-Event Dynamic Systems (SDEDS). SDEDS are dynamic systems where asynchronous state changes are initiated by events, state space is discrete, and variables are random. SDEDS can operate in discrete or continuous time. SDEDS are modelled using: Markov chains, queuing theory and discrete-event simulation (Cassandras, LaFortuna 2008; Zimmermann 2008). Tasks related to SDEDS are: modelling, analysis, synthesis, control, performance evaluation and optimization. SDEDS are usually human-made systems and have a complex, hierarchical structure. Typical examples of SDEDS are: telecommunication and computer networks, production systems, logistics and transportation. The results of

research on SDEDS are used in decision support systems and enterprise resource planning software.

Overview of the scientific goals and achieved results with a discussion of their utilization

In 2006-2011 I worked on multi-class re-entrant SDEDS with stochastic streams of tasks. Stochastic is understood here as random times of task arrivals to the system and random sizes of the tasks, which results in a random amount of work required to handle them. Both dimensions are modelled using probability distributions. A multi-class system is one in which two or more types of tasks (product) are processed. Every class of task is characterized by a different technology. An interesting feature of this kind of systems is the appearance of additional internal workflows that are a result of the inspection operations. These additional streams of tasks may overload the system and precipitate it from a steady state, resulting in an increased server (workstation) workloads resulting in a non-linear increase in the number of jobs in the buffers.

The idea of undertaking this research was the result of a project for a company operating in precision assembly of electromechanical devices. The task was to ensure the required quality of the finished products while minimizing control costs, minimizing the production cycle and maximizing station workloads. The quality of the final product is a result of control by inspection station, being specialized stations that perform one or more control operations. The proper allocation of inspection stations ensures fulfilling the constraint on the Average Outgoing Quality Level.

In the first stage I developed a mathematical model of a multi-class (multi-product) job shop production system with inspection stations. The model was based on an open Jackson network (Gross & Harris 1998) and discrete-event simulation (Banks et al. 2009). In the next stage I developed a generalized open Jackson network as a basis for the synthesis of servers (nodes) in the form of GI/G/m queuing systems.

The decision problem of inspection station allocation is an integer-programming problem. It has a large number of decision variants $\prod_{i=1}^{t}(h_i + 1)!$, where h_i is the number of operations, and $i = 1,2,3, \dots, t$ is the index of the task class. This is an NP-hard problem, assuming that the number of inspection stations can vary (from 1 to the number of nodes). This problem belongs to the multi-criteria decision-making class due to the multiplicity of criteria: workstation utilization, duration of the production cycle, and inspection operations costs, which include: the cost of testing, cost of repairs, cost of dismantling and cost of wrong decisions in control. The criteria have a hierarchical structure, and the problem belongs to a category chosen by the best options among a finite set of feasible solutions. Using the AHP method (Saaty 2005) I identified the decision maker's preferences and created a ranking of decision variants.

The evolutionary algorithm developed was used in optimization of the system structure (inspection station allocations). Due to the large number of feasible solutions, exhaustive enumeration is pointless as it would require calculation for each of them the values of the criterion functions and creation of the ranking. The results of research on SDEDS with re-entrance and stochastic streams of tasks have been presented in eight scientific publications [12, 14, 16, 17, 24, 37, 40, 41][1].

In 2011-2013 I worked on the problem of dynamic scheduling in multi-class SDEDS with synchronization of tasks. A dynamic scheduling algorithm is short-term planning, where the next task to handle is selected from those waiting, based on priority rules at the time of release of a resource (server, machine). Dynamic scheduling assigns tasks to processors during the execution of programs (run-time). Dynamic scheduling is also called processor load balancing. The purpose of dynamic scheduling is autonomous adaptation to change. Dynamic scheduling is used because of the speed in determining the next task to handle (Dolgui & Proth 2010). In literature, more than one hundred single and multi-attribute priority rules are known, such as: FIFO, EDD, SPT, LPT, MOR, LOR, S/RPT, PT + WINQ + SL. Studies I have undertaken have shown that the dynamic scheduling algorithms used in practice and presented in literature did not provide satisfactory results. With an assignment of rules to a server, there is an improvement in system parameters such as total processing time, and number of delayed tasks.

Due to the complexity of the analysed system, Markov chains and queuing theory are not sufficient to reflect events occurring in this class of system, in particular the problem of modelling: division of tasks, synchronization of divided tasks, setups and re-entrance. Thus discrete-event simulation was chosen.

The problem of priority rules selection is in integer-programming optimization. The number of variants is equal to k^m, where k is the power of the priority rule set, and m is the power of the node set (workstations). This is an NP-hard problem due to the number of nodes. This is a prerequisite for optimizing using heuristic algorithms.

To solve that problem indirect encoding was used. A sequence of multi-attribute priority rules was coded in the chromosome for the genetic algorithm, or the path of ants for the ant colony algorithm, rather than the schedule itself, as is the direct approach. This reduces the search space. Instead of handling every task we move to the level of priority rules. With direct encoding the algorithm should work in real time. With indirect encoding the optimization algorithm is executed only when the intensity of the job streams or routings changes.

[1] The numbering in accordance with the list of published scientific papers after obtaining a doctoral degree (Annex 3).

I developed a SDEDS control algorithm using evolutionary algorithms. The optimization algorithm provides the data to the module simulator in which the calculations are performed using; the warm-up time, replication time and number of replications. After statistical analysis the simulation module returns results to the algorithm module, which generates the next set of data until a stop condition appears. The results of the dynamic scheduling using SDEDS have appeared in nine publications [7, 8, 19, 20, 21, 33, 34, 35, 36].

The models and algorithms developed for the problem of dynamic scheduling in multi-class SDEDS were implemented in the company Print Group for the production of short-run on-demand books as part of a project co-financed by PARP.

In 2012-2013 I was manager of a research project using SDEDS commissioned by Cargotec in Stargard, whose aim it was to optimize the logistics processes in one of their factories. At the same time I had 6 weeks scientific internship funded by the Government of France at the Ecole des Mines de Saint-Étienne (France) in the Décision en Entreprise: Modélisation, Optimisation group. During the internship and as a result of the industrial project we focussed on studying a complex SDEDS consisting of asynchronously interconnected production and logistics systems. It was an interesting scientific problem due to the requirements, which brought the company into implemented lean management concepts (Ohno 1988 Liker & Meier, 2006). Lean management assumes: work according to the principle of delivery on time (just-in-time), and minimum buffer capacities that still assure a continuous availability of semi-finished parts. Therefore, it was critical to ensure continuous operation of the production system and internal logistics in the absence of additional supply capacity in advance. The results of the work were published in four scientific papers [2, 18, 26, 32].

Since 2014 I have been working on the problem of incorporating the human factor into SDEDS. To this point, I had examined only technical systems, assuming that the human factor does not affect their work, reliability and performance. The scope of my research then was in the models and algorithms for performance evaluation of operators performing repetitive jobs, taking into account competences. Existing models and algorithms (learning curves models, see Anzanello, Fogliatto 2011) describing changes in operator performance over time (or the number of repetitions) ignored the fact that parts of the process are similar to each other (requires similar competences). The performance of persons trained on one working post, after moving to another post requiring similar competences will be much higher than those who had no earlier experience in performing that type of work. I proposed an approach based on a hierarchical competence model and performance evaluation algorithm. The results of this work have been published in [3].

The approach using a hierarchical model of competences has met with interest from the industry. Currently I am working on prototype software for monitoring and forecasting

the performances of employees using these algorithms. The estimation of employee productivity using competences has great scientific and commercialization potential in response to the lack of tools on the market for employee scheduling that can use information about employee competences.

Contribution to development in computer science

Articles **A1** and **A2** are in the research stream of multi-class SDEDS with re-entrance and stochastic streams of tasks. Article **A1** developed SDEDS in which workstations were modelled as M/M/n/∞/FIFO queuing systems with the entire system as a multi-class open Jackson network. As a result of the inspection operations, re-entrances arise where streams of tasks go back to a certain node. The model takes into account the uncertain result of the inspection operation. Feasible solutions are the ones that fulfil a constraint on the minimum acceptable quality level. Inspection station allocation is a multi-criteria decision-making problem with non-linear criteria and constraints. The AHP method was used to identify the preferences of the decision-maker in the multi-criteria evaluation of the decision variants.

Results of further research are presented in article **A2**, in which I developed an evolutionary algorithm to solve a computationally difficult NP-hard problem of optimizing inspection station allocation. I developed a more universal model of the system. The workstation was modelled as a GI/G/n/∞/FIFO queuing system, with the entire production system synthesized in the form of a multi-class open queuing system. In the article I examined the convergence and optimum setting of the genetic algorithm.

The originality of my research was in the high versatility of the model. I developed models that took into account multi-class tasks and the network structure of the production system, where the vast majority of the work is devoted to structures with single-class tasks and sequential structure. My models take into account the uncertain result of the operation control (error I and type II), and the limit of a minimum level of acceptable quality.

Articles **A3** and **A4** are in the research stream of dynamic scheduling of multi-class SDEDS with synchronization and divided tasks. In this kind of SDEDS are task splitting into subtasks, synchronization and integration of tasks, and re-entrance. After splitting, subtasks are processed independently and in parallel on separate technological routings. In one of the last steps the task is synchronized and re-integrated from its components. Re-entrances are due to technological processes. Due to these features discrete-event simulation was used.

Article **A3** presents method of controlling SDEDS models using a genetic algorithm with tournaments. This algorithm controls the settings of the simulation model and collects the experimental results. The developed genetic algorithm uses indirect coding of multi-attribute priority rules in the chromosome, two-point crossing, and permutation of

chromosome mutation. Article **A4** presents an ant colony algorithm developed for optimisation of a multi-attribute dispatching rule sequence. The algorithm also uses indirect coding. Instead of coding tasks, a path was coded as a digraph. The algorithm uses a pseudo-random proportional rule for the sequence construction to move the ants and the local and global level pheromone update. The algorithm converges at a specified time at a low risk of getting stuck in a local minimum.

The scientific novelty was the development of evolutionary algorithms to solve a computationally difficult NP-hard problem of priority rule selection to optimize production system efficiency. The evolutionary algorithms enable finding sub-optimal solutions in a given time. Validation studies have shown that in both cases the developed evolutionary algorithms give better results than optimization using the Monte-Carlo method.

Article **A5** presents a sensitivity analysis of complex asynchronous SDEDS composed of two subsystems: an assembly line and internal logistics using discrete-event simulation. The assembly line is organized according to the principles of lean management: only those resources to be utilized are supplied; there is only a one-piece flow (without production lots); buffers between the operations are at minimum levels (no more than a few pieces of semi-finished products); the number and range of materials positions is strictly defined. Materials are supplied to the assembly line by logistics in fixed cycles, which must be synchronized with the production system. Disturbances in that or another system interact, affecting the entire system efficiency. So far in literature there has not been an analysis of interactions of this type in subsystems.

Article **A6** presents a new approach to performance evaluation of multi-skilled employees based on the possessed and required competences. The proposed algorithm calculates performance using information from competences modelled as an acyclic weighted digraph. The competence update algorithm starts after the completion of the work and updates the levels of experience for all those that have been used. The results of the algorithm are transferred to the performance estimation algorithm, which calculates working times, that in turn are passed to the SDEDS model.

The presented scientific achievement "*Models and algorithms for performance evaluation of stochastic discrete-event systems*" helps in a better understanding of complex SDEDS with a more precise performance estimation of workers and technical systems. The obtained results are used in planning and scheduling algorithms and optimization. The areas of applications are: decision support systems, advanced planning and scheduling systems, and enterprise resource planning software.

Summary

The most important of my scientific achievements contributing to the development of computer science include:

1. Development of a performance estimation method for multi-class, discrete-event dynamic systems with re-entrance and stochastic stream tasks.
2. Development of an evolutionary algorithm for optimal inspection station allocation to provide a minimum acceptable quality level.
3. Development of two evolutionary algorithms (genetic and ant colony) to solve optimal task selection multi-attribute priority rules for dynamic scheduling of complex stochastic discrete-event dynamic systems.
4. Sensitivity analysis of a complex asynchronous system composed of two subsystems: assembly line and internal logistics using a discrete-event simulation.
5. Development of the original concept of hierarchical competence modelling of production workers in order to estimate their performance.
6. Development of a productivity estimation algorithm of employees using a hierarchical competence model.

These scientific achievements have contributed to the development of computer science, in particular to the area of modelling and simulation of stochastic discrete-event dynamic systems, dynamic scheduling, competence modelling and operational research.

Other scientific activity

In 2005-2007, I conducted research in distance learning information systems. I was a contractor in the EU-project "e-Quality - Quality Implementation in open and distance learning in a multicultural European environment", financed by funds from Socrates / Minerva. I developed an algorithm for sequencing learning objects. This work was published in the conference series Lecture Notes in Computer Science [15] and in two book chapters [28, 31].

In 2012-2014, I worked with a team from the Medical University of Lodz in research on the tobacco epidemic in Poland. Within this theme I developed and analysed multivariate regression models, and performed statistical analyses. The results of the work were presented in five papers published in: BMC Public Health [4, 10], International Journal of Occupational Medicine and Environmental Health [9] Occupational Medicine [9] and the Annals of Agricultural and Environmental Medicine [11].

In 2013, I worked with a team from ICM University of Warsaw on the first whole cell computer simulation model of a living organism mycoplasma genitalium (Karr et al. 2012). Results of the work were published in PLoS Computational Biology [5].

Since 2015 I have worked in the area of precise colour reproduction for cultural heritage digitization using spectrophotometric and photographic methods. As part of this research I participated in COST Actions, project TD1201 Colour and Space in Cultural Heritage - COSCH (www.cosch.info). The results of the work were published in the journal Color Research & Application [1].

Summary of scientific activity

I am the author of 4 and co-author of 39 post-doctoral papers published from 2006-2016 (Annex 3). Among them, 12 have been published in journals indexed in Journal Citation Reports (JCR). The total two-year impact factor IF = 20.729. Total number of points is 444, and weighted number of points is 182.

Table 2. Bibliometric indexes[2] (post-doctoral)

Type of publication	Total IF (2 years)	Number of publications	Points	Weighted points
Indexed in ISI Web of Science	20.729	15[3]	370	133.5
List B	–	7	50	30.7
Conference proceedings not indexed in ISI WoS	–	13	0	0
Book chapers – in Polish	–	4	12	5.8
Book chapters – in English	–	2	12	12
Not indexed Foreign journals	_	2	0	0
Total	**20.729**	**43**	**444**	**182**

Table 3. Number of publications indexed by scientific bases and number of publications

Scientific base	Number of publications	Number of publications	Number of publications without self cites	h-index
Web of Science	18[3]	42	38	4
Scopus	25[3]	57	52	4
Google Scholar	43	127	105	6

[2] Impact factor (IF) and the number of points were given according to the year of the article publication.

[3] Paper in *Color Research & Application* awaiting indexing.

Bibliography

1. Anzanello, M. J., & Fogliatto, F. S. (2011). Learning curve models and applications: Literature review and research directions. *International Journal of Industrial Ergonomics*, 41(5), 573–583.
2. Banks, J., J.S. Carson II, B.L. Nelson, D.M. Nicol (2009) *Discrete-event system simulation*, Pearson, New York.
3. Cassandras C.G., S. Lafortune (2008) *Introduction to Discrete Event Systems*, Springer, New York.
4. Dolgui, A., and , J.M. Proth (2010) *Supply chain engineering: useful methods and techniques*, Springer, London.
5. Gross, D. & Harris, C.M. (1998). Fundamentals of Queuing Theory, *Willey*, New York.
6. Karr JR, Sanghvi JC, Macklin DN, Gutschow MV, Jacobs JM, *et* al. (2012) A whole-cell computational model predicts phenotype from genotype. *Cell* 150: 389–401.
7. Liker JK, Meier D (2006) *Toyota way fieldbook*, McGraw-Hill, New York.
8. Ohno T (1988) *Toyota production system: beyond large-scale production*. Productivity Press, Cambridge.
9. Saaty, T.L. (2005) The Analytic Hierarchy and Analytic Network Processes for the Measurement of Intangible Criteria and for Decision-Making. In: J. Figueira, S. Greco and M. Ehrgott, eds., *Multiple Criteria Decision Analysis*. Springer, New York, 345-405.
10. Zimmermann A. (2008) *Stochastic Discrete Event Systems, Modeling, Evaluation, Applications*, Springer, Berlin.

Przemysław Korytkowski