UDC 005.336.3:655.3

ANALYTICAL MODELING OF A DYNAMIC DISCRETE SYSTEM FOR MANAGING JOB-TASKS IN SHORT-RUN PRINT PRODUCTION

T. V. Neroda

Institute of Printing Art and Media Technologies
in Lviv Polytechnic National University
19, Pid Holoskom, St., Lviv, 79061, Ukraine

The efficiency of production processes in on-demand printing is addressed by optimizing job-task management systems operating under variable demand, technological heterogeneity, and continuous reconfiguration of production routes. Existing approaches in industrial infrastructure design provide a foundation for adaptive systems supporting small and medium-sized production with forecasting and analytical evaluation, yet they do not fully meet the specific requirements of short-run printing, where time constraints, order heterogeneity, and operational asynchrony demand synchronization of data flows across customer interaction, prepress preparation, route configuration, and executive subsystems. In this research the discrete-event modeling and stochastic Petri nets are applied to represent sequences of events, state transitions, and concurrent, distributed, resource-constrained processes. The constructed state-transition matrix enabled the design of an analytical model encompassing data flow structuring, job-task prioritization, route adaptation criteria, and real-time decision-making. This model provides a basis for predictive scenarios, enhances production loop controllability, and stabilizes processing of heterogeneous orders while advancing digital technologies in on-demand printing.

Keywords: *discrete-event modeling, stochastic Petri nets, job-task management, adaptive production routing, short-run print production*

Problem statement. Despite the active use of computational networks to integrate workstations as nodes within the production workflow, the organization of data flows in on-demand printing facilities currently faces inherent limitations, resulting in repeated and inefficient utilization of available resources. Nevertheless, one of the key means of minimizing delays and costs for a printing company, as well as optimizing production methods in accordance with prevailing market conditions, is an effectively configured production workflow for order fulfillment [1]. Consequently, there is a timely and pressing need for the design of optimal job management systems in on-demand printing.

Analysis of recent research and publications. The design of an effective production infrastructure remains a current challenge in contemporary research, including the combined simulation-optimization approach for reconfigurable manufacturing systems, which allows simultaneous maximization of productivity and minimization of buffer costs under variable production volumes, demonstrating the potential for adaptive configuration [2], a strategy of flexible modeling with templates and parameterization, enabling rapid reconfiguration of models for different production scenarios without significant expenses on model development for enterprises with fluctuating demand [3], and dynamic production routing through simulation that accounts for demand changes to enhance throughput under unstable production loads [4]. In the implementation of optimization methods for small and medium-sized enterprises in the printing industry, production program simulation is actively applied to generate resource- and energy-efficient order fulfillment plans, allowing informed decision-making without interfering with actual production [5] under variable market conditions [6] with unstable demand and resource constraints [7]. The organization of data flows within adaptive production is realized through combined DES-based approaches [8] and the use of digital twins [9, 10] for dynamic reconfiguration of production lines following disruptions or changes in load, demonstrating the effectiveness of automatic real-time response with high precision.

The conducted analysis of thematic studies demonstrates the intensity of scientific research in the areas of adaptive production infrastructure design, small and medium-sized enterprise management optimization, and data flow organization within digitized manufacturing environments. The results obtained by both domestic and international researchers and engineers reveal significant achievements in the integration of simulation, optimization, and digital twin approaches, which enable increased flexibility of production lines, minimization of resource consumption, effective response to variable workloads, and maintenance of technological process stability in real time. The cumulative scientific evidence convincingly confirms the established trend towards the integration of discrete-event models with intelligent control methods and simulation analytics, laying the foundation for the development of high-performance manufacturing systems. At the same time, the presented review identifies a number of gaps that limit the practical applicability of existing approaches in the context of on-demand printing as a sector characterized by heterogeneous technological loads, short production cycles, and high dynamics in order queues. In particular, insufficiently studied remain the issues of developing end-to-end job management models at the level of micro-operations, integrating production data flows with real-time decision-making systems, and creating analytical apparatus capable of reproducing the stochastic nature of waiting, blocking, and reconfiguration processes inherent in on-demand printing operations. The number of studies addressing the modeling of interactions between production and organizational operation queues within a single discrete-event loop is also limited, which is especially important for evaluating throughput and optimizing production workflows. Therefore, there is a pressing need for the development of specialized models capable of reproducing the dynamics of discrete job management systems during order preparation in on-demand printing, ensuring the possibility of obtaining reliable analytical metrics, assessing load scenarios, forecasting blockages, and optimizing production queues.

Aim article is to enable quantitative analysis of printing production behavior in real time, where the characteristics of print queues, resources, and operator decisions change discretely, unevenly, and interdependently.

Presentation the main research material. For the stratification of processes within the designed network printing system and the identification of potential data format compatibility issues, it is first necessary to examine the prepress stages of publication processing carried out by printing services in typical operational environments, prepared by the functionality of the desktop publishing (DTP) installed on the end automated workstation as a component of the printing enterprise's network infrastructure.

For graphics services of standard application software, all graphical devices, monitors and printers, are represented as virtual canvases, on which the layout environment can "draw" any information using the universal commands of the current operating system's graphics API (Fig. 1). In the present study, attention was given to popular operational printing environments of the *Windows* (), *MacOS* (), *Linux* () та *OES* (), families, whose application programs, from the user workstation perspective, do not interact directly with drivers, being limited to printer selection dialogs and configuration of order-specific printing settings.

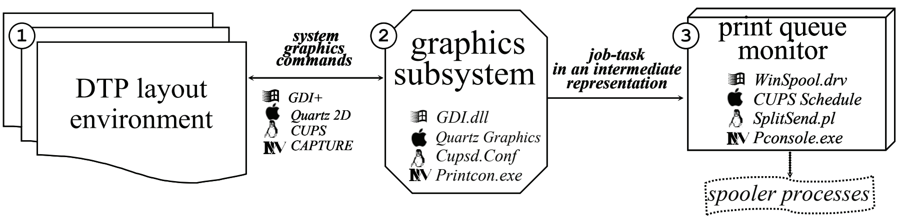

Fig. 1. Specification of network resources of typical operating systems in *user processes*

Upon receiving from the operating system a sequence of graphics commands initiated by the DTP system's requests, the *graphics device interface* passes them through the *driver* to obtain another sequence of commands, specific to the selected printer. Changing the driver at this stage may lead to the disruption of the layout grid for the entire order. Thus, the *print queue monitor* detects task execution issues at the initial stages, providing the *spooler* with information about its status.

Next, the job enters the print queue corresponding to the selected printer. At this stage of the production workflow, the *print spooler service* (spooler) loads from the driver specified in the job description a block of instructions that defines the interaction with the physical printing device and the transmission of service information to it (Fig. 2).

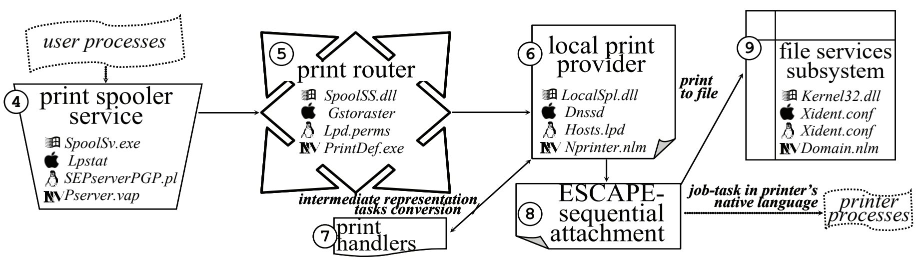

Fig. 2. Handling of a job-task by standard *spooler processes*

The *print router* determines the logical address of the target device, access time, and job-task priority. Subsequently, the *local print provider*, using the appropriate *print handlers* and leveraging the workstation's OS resources, converts the job-task received via the *routing* service from the *intermediate representation* (enhanced metafile, Fig. 1) into printer-understandable code, including separator codes and other necessary ESCAPE sequences for imposed signatures. In addition to sending the prepared job-task to the target device, it can be *print to file*. This file can later be printed without reprocessing, requiring neither the original application that created the file, nor the fonts used, nor the original publication itself. Overall, at the stage of job-task processing by the spooler, a final verification of the correct execution of the job-task takes place, with a temporary copy (shadow file) stored directly on the primary storage medium.

To send the prepared job-task (implemented in the language of the respective printer) to the end equipment, print monitors are used. These are specialized drivers for the printing protocol, enabling the transmission of data to peripheral devices via a given interface (but not the driver of that interface itself). Print monitors are classified into *language monitors* and *port monitors* (Fig. 3).

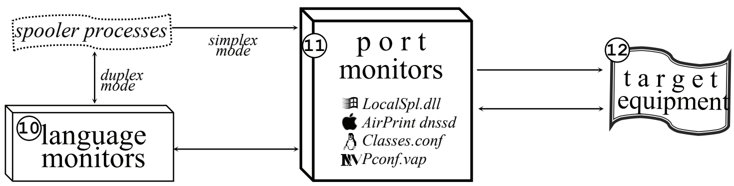

Fig. 3. Final emulation of a job-task by the service functions of *print monitors*

Language monitors perform bidirectional data transfer, receiving information from the target resource about the current status of the device, including readiness, paper availability, toner level, and so on. *Port monitors* regulate the transmission of information at the hardware level through an intercepted gateway, sending data packets upon receipt-ready signals. If multiple identical printers are available, they can be grouped into a pool, functioning as a single entity and distributing job-tasks among the devices. Devices within the same pool must be located in the same room, as it is not possible in advance to determine which device will receive the current job-task.

The stages of the production workflow for job-task execution, in the case of shared access to the respective end resource (Figs. 1–3), are typically implemented using a *print adapter* connected to a network port. Equipped with an onboard microcomputer, the network adapter can generally support remote printing; however, its functionality is very limited, and the corporate network remains peer-to-peer, with all the consequences of using a local target printing device.

In general, the built-in graphics device subsystems such as GDI+, as well as Quick Draw/Quartz 2D in *MacOS*, allow the color model to be specified only as RGB, excluding direct control of CMYK colors, which is unacceptable for printing tasks. The end devices predominantly used for typical office orders in small printing facilities represent hardware with a simplified page description language, lacking built-in capabilities for imposition, color separation, and screening, and requiring a control sequence from the workstation, meaning that their functionality is almost entirely implemented in software drivers. Being service-limited, such printers, by offloading resource-intensive tasks to the workstation's central processor in user processes (Fig. 1), cannot receive a fully completed page raster from the DTP system until they obtain the complete array of microcommands from the workstation's operating environment, retaining only a basic bootloader in the embedded firmware. This significantly complicates the design of a flexible network printing system based on a *print adapter*. Accordingly, a workstation in a peer-to-peer network must continuously monitor the status of local printer, especially an electrophotographic one, to send next data array in a timely manner due to the absence of duplex communication with the photoreceptor mechanism.

In the present project, a basic reference model of the Open Systems Interconnection (OSI) was used to study and optimize communications within the network infrastructure of a printing corporation, the main drawback of which is the inadequacy of its transport layer. This situation necessitates that most of the computational procedures described be executed by the workstation of the layout operator, due to the inability of the print adapter to buffer large job-tasks, perform resource-intensive screening, and so forth, overloading the workstation's RAM and increasing the likelihood of failures.

Therefore, in designing the network printing system, it was decided to abandon the peer-to-peer mode, in which data packets, fully processed using the workstation's computational resources, are sent directly to the print adapter as the network port of a local end device. In the designed network infrastructure, for the efficient, flexible, and high-quality execution of a wide range of short-run original job-tasks, a dedicated computer (*print server*) has been introduced, to which end devices are connected and which provides shared access, allowing printing, loading their drivers for different workstations, and so forth, relieving the workstations of unnecessary load. For configuring production job-tasks within the adapted OSI model, a client-server interaction architecture has been implemented, where the end device is remote from the workstations' perspective and only directly local at the hardware level for the print server itself. The specified *print server* is positioned within a domain service cluster after *user processes* (Fig. 1), controlled by application program services, and the initial components of *spooler processes* (Fig. 2), serviced by messaging services; these processes remain under the supervision of the workstation (Fig. 4).

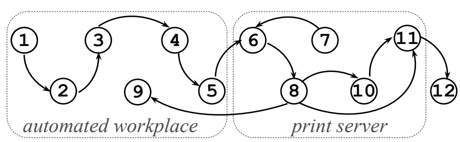

Fig. 4. Identification of components of the dedicated *print server*

Thus, the designed network infrastructure based on a *print server*, implemented with the computational power, memory for job-task storage, and service software of a dedicated computer, allows the optimization of job-task execution by determining a rational cost/quality ratio during the operational selection of the production workflow, ensuring full adequacy of service functions and avoiding compatibility issues between the data structures of different operating systems.

For the further design of a multi-tier network infrastructure of a printing enterprise and its flexible administration, there arose a need to develop an analytical apparatus for managing the production process of job-task execution. Finding an optimal solution to a technological job-task based on available data is possible only with correct forecasting of potential events. This framework must support decision-making in near real-time, requiring the identification of patterns in the job-task flow and forecasting events that affect the selection of the production workflow. In particular, it is necessary to account for the probabilistic nature of print queues, time delays associated with format conversions, possible driver failures, latent conflicts between services of different operating systems in cross-platform interaction, as well as the behavior of users who concurrently initiate printing operations. Forecasting in such a system cannot be limited to static characteristics; it must consider the adaptability of the print server, its ability to reallocate resources, restore job-task contexts, and support heterogeneous protocols.

This situation is appropriately addressed through a formalized system for forecasting and analyzing production processes, enabling the evaluation of potential scenarios in the network infrastructure of on-demand printing. Such a system must provide tracking of discrete events, interrelations between heterogeneous components, and nonlinear state transitions, as well as account for the dynamics of resource loading, queues, processing priorities, and the possibility of reallocating job-tasks between services of different operating systems. On this basis, the analytical apparatus allows forecasting the development of the production process, assessing risk situations, and making informed decisions regarding the optimization of job-task execution workflows.

The next stage in developing the analytical apparatus involves the formal structuring of cross-platform infrastructure mechanisms into a state model that reflects the sequence and interrelations of events. Each node of the graph (Fig. 4) is interpreted as a state of the production process, and the arcs represent discrete events that alter the configuration or load of components. This approach enables quantitative analysis of job-task flows, accounting for priorities and queues, as well as forecasting scenarios for the development of the production process, thereby providing a technical foundation for the construction of the framework. Based on the coordination graph, a state and transition matrix (table) is formed, in which each row corresponds to a specific system state, and the columns represent possible events and transitions between states.

The matrix explicitly defines the conditions for event activation, changes in resource load, and the relocation of job-tasks between components of different operating environments. Such formalization allows the distributed cross-platform infrastructure to be transformed into a computable model, in which each state and transition has a precise interpretation in the context of job-task execution. The matrix serves as the initial structure for constructing a stochastic Petri net (SPN), ensuring accurate representation of discrete events, processing priorities, and the possibilities for reallocating job-tasks between services (Fig. 5).

State and Transition Matrix of Job-Tasks

Current State	Event / Transition	Next State	Resource / Note
S1	E1	S2	workstation generates task
S2	E2	S3	GDI processing
S3	E3	S4	intermediate task language
S4	E4	S5	print queue monitor
S5	E5	S6	print server transition
S5	E6	S8	ESCAPE sequence processing
S6	E7	S7	print router
S7	E8	S8	local print provider
S8	E9	S9	print handlers
S8	E10	S11	language monitors (via server)
S9	E11	S10	ESCAPE sequence attachment
S10	E12	S11	job-task
S11	E13	S12	target equipment / completion

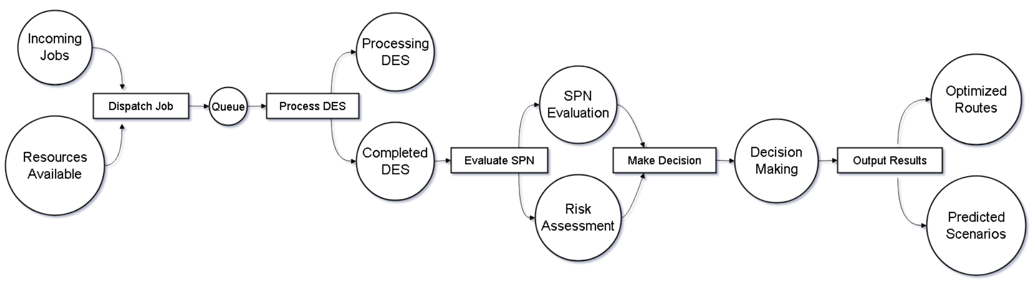

Fig. 5. Analytical apparatus for modeling a dynamic discrete job-task management system

The constructed stochastic Petri net reflects the structure of the analytical apparatus of the cross-platform infrastructure of a printing enterprise, taking into account job-task flows and forecasting logic. The places of the model, represented as circles, denote key system states: “Incoming Jobs” captures incoming job-tasks, “Resources Available” represents resources available for processing, “Queue” illustrates the state of the waiting queue, “Processing DES” indicates the execution of discrete events, “Completed DES” represents completed processing stages, “SPN Evaluation” and “Risk Assessment” provide scenario evaluation and risk analysis, “Decision Making” corresponds to the decision-making process, and “Optimized Routes” and “Predicted Scenarios” accumulate the results of route optimization and scenario forecasting. Transitions, represented as rectangles, correspond to events that change the system state: “Dispatch Job” handles job-task distribution, “Process DES” implements the execution of discrete event computational processes, “Evaluate SPN” performs evaluation and scenario forecasting, “Make Decision” models the decision-making process, and “Output Results” generates the optimization and forecasting outcomes. Arcs provide token flows between places and transitions, illustrating job-task movement, information accumulation, and interconnections between infrastructure components. The visual differentiation of places by radius emphasizes the relative importance of resources and critical system states, providing a clear representation of load, processing priorities, and potential event scenarios in the cross-platform production system.

Based on the constructed SPN analytical model, a set of specific analytical metrics can be developed to assess the efficiency and robustness of the cross-platform infrastructure of a printing enterprise. Each metric is grounded in the token flows within the network and the probabilities of transitions between states, formalizing the dynamics of job-task loading and processing. Resource load is defined as the average number of tokens in the places corresponding to resources ("Resources Available," "Processing DES"). This metric enables the assessment of the utilization level of computational and intermediate resources, the identification of critical nodes, and the planning of workstation allocation. The probability of bottlenecks is calculated based on the frequency of token accumulation in the queue places ("Queue") and completed job-tasks ("Completed DES"), reflecting potential delays due to limited throughput or resource access conflicts. Analysis of these probabilities allows the identification of processing bottlenecks and the anticipation of potential downtime scenarios.

Optimal processing routes are determined by analyzing token pathways through the network, from incoming job-tasks to output results ("Optimized Routes," "Predicted Scenarios"). The network allows modeling of different transition combinations, calculation of the probabilities of reaching final states, and identification of routes with minimal likelihood of bottlenecks and delays, ensuring efficient distribution of job-tasks across services of different operating systems. In this context, the presented SPN serves not only as a formal state model but also as a tool for obtaining quantitative indicators that form the basis of the analytical apparatus for forecasting and optimizing the operation of the cross-platform production system, providing a foundation for informed decision-making in on-demand printing [11].

Conclusions. Thus, the formalized model of the cross-platform infrastructure for executing printing tasks incorporates a task flow graph and a stochastic Petri net as an analytical apparatus for discrete event management, supporting flexible task routing and precise assessment of the efficiency of the cross-platform production system. The identified key components of the technological contour, places for task accumulation and processing, state transitions, as well as interrelations between heterogeneous resources and services of typical operating systems with print-oriented software, reflect the discrete dynamics of the production environment while enabling automatic responses to changes in load parameters, processing priorities, and equipment status. Based on the SPN, metrics for resource load, probability of bottlenecks, and optimal task processing routes are identified, providing the capability to forecast event scenarios and make informed decisions for optimizing the execution routes of printing orders. This approach also enables further project development through the generation of quantitative scenarios derived from the stochastic Petri net as a mechanism for predicting the behavior of complex technological contours.

LIST OF USED SOURCES

1. Neroda T. Designing of multilevel system the distributed resources administration in polygraphically oriented network infrastructure. Computer technologies of printing, Vol. 42, 2019. P. 64-72. doi: 10.32403/2411-9210-2019-2-42-64-72.
2. Barrera-Diaz C.A., Nourmohammdi A., Smedberg H., et al. An enhanced simulation-based multi-objective optimization approach with knowledge discovery for reconfigurable manufacturing systems. Mathematics Vol. 11(6), 2023. 1527. DOI: 10.3390/math11061527.
3. Elbasheer M., Longo F., Mirabelli G., Solina V. Flexible Symbiosis for Simulation Optimization in Production Scheduling: A Design Strategy for Adaptive Decision Support in Industry 5.0. Journal of Manufacturing and Materials Processing, Vol. 8(6) 2024. 275. DOI: 10.3390/jmmp8060275.
4. Mohanavelu T., Krishnaswamy R., Mannepu V.R., et al. Dynamic layout optimisation through simulation: enhancing machine utilisation for fluctuating demand. The International Journal of Advanced Manufacturing Technology, Vol. 138, 2025. P. 983–998. DOI: 10.1007/s00170-025-15554-3.
5. Smagowicz Ju.,Szwed C., Berlec T. An Assortment–Quantity Optimization Problem in Printing Industry Using Simulation Modelling. Sustainability, Vol. 16(4), 2024. 1693. DOI: 10.3390/su16041693.
6. Ghasemi A., Farajzadeh F., Heavey C. Simulation optimization applied to production scheduling in the era of industry 4.0: A review and future roadmap. Journal of Industrial Information Integration, Vol. 39, 2024, 100599. DOI: 10.1016/j.jii.2024.100599.
7. Ghaedy-Heidary E., Nejati E., Ghasemi A., Torabi S. A. A simulation optimization framework to solve Stochastic Flexible Job-Shop Scheduling Problems—Case: Semiconductor manufacturing. Computers & Operations Research, Vol. 163, 2024, 106508. DOI: 10.1016/j.cor.2023.106508.
8. Derlini D., Annisa S., Lubis Z. Optimizing Production Scheduling in Smart Manufacturing Systems Using Hybrid Simulation-Based Multi-Objective Optimization. In Optimizing Production Scheduling in Smart Manufacturing Systems Using Hybrid Simulation-Based Multi-Objective Optimization with the theme "Engineering for Suistanable Future: Innovation in Renewable Energy, Green Technology, and Circular Economy", July 23-24 2025. P. 105-108. DOI: doi.org/10.30743/icst.
9. Fu B., Bi M., Umeda Sh., et al. Digital Twin-Based Smart Manufacturing: Dynamic Line Reconfiguration for Disturbance Handling. In IEEE Transactions on Automation Science and Engineering, vol. 22, 2025. P. 14892-14905. DOI: 10.1109/TASE.2025.3563320.
10. Gamdha D., Saurabh K., Ganapathysubramanian B., Krishnamurthy A. High-Resolution Thermal Simulation Framework for Extrusion-based Additive Manufacturing of Complex Geometries. Finite Elements in Analysis and Design, Vol. 251, 2025. 104410. DOI: 10.1016/j.finel.2025.104410Moreno-Lumbreras D., Gonzalez-Barahona J. M, Robles G. BabiaXR: Facilitating experiments about XR data visualization. SoftwareX, Vol. 24, 2023, 101587. doi: 10.1016/j.softx.2023.101587.
11. Neroda T. Methodology for adapting successful decision algorithm in modeling optimal strategy for publishing and printing enterprise. In O. H. Cherep, Yu. O. Ohrenych (Eds.),

Artificial Intelligence and Digital Technologies in the Transformation of Ukraine's Economy During the War and Post-War Recovery : collective monograph. Baltija Publishing, Riga, 2025. P. 171-215. DOI: 10.30525/978-9934-26-584-6.

REFERENCES

1. Neroda, T. (2019). Designing of multilevel system the distributed resources administration in polygraphically oriented network infrastructure. Computer Technologies of Printing, 42, 64–72. https://doi.org/10.32403/2411-9210-2019-2-42-64-72 [in English].
2. Barrera-Diaz, C. A., Nourmohammdi, A., Smedberg, H., et al. (2023). An enhanced simulation-based multi-objective optimization approach with knowledge discovery for reconfigurable manufacturing systems. Mathematics, 11(6), 1527. https://doi.org/10.3390/math11061527 [in English].
3. Elbasheer, M., Longo, F., Mirabelli, G., & Solina, V. (2024). Flexible Symbiosis for Simulation Optimization in Production Scheduling: A Design Strategy for Adaptive Decision Support in Industry 5.0. Journal of Manufacturing and Materials Processing, 8(6), 275. https://doi.org/10.3390/jmmp8060275 [in English].
4. Mohanavelu, T., Krishnaswamy, R., Mannepu, V. R., et al. (2025). Dynamic layout optimisation through simulation: enhancing machine utilisation for fluctuating demand. The International Journal of Advanced Manufacturing Technology, 138, 983–998. https://doi.org/10.1007/s00170-025-15554-3 [in English].
5. Smagowicz, J., Szwed, C., & Berlec, T. (2024). An Assortment–Quantity Optimization Problem in Printing Industry Using Simulation Modelling. Sustainability, 16(4), 1693. https://doi.org/10.3390/su16041693 [in English].
6. Ghasemi, A., Farajzadeh, F., & Heavey, C. (2024). Simulation optimization applied to production scheduling in the era of industry 4.0: A review and future roadmap. Journal of Industrial Information Integration, 39, 100599. https://doi.org/10.1016/j.jii.2024.100599 [in English].
7. Ghaedy-Heidary, E., Nejati, E., Ghasemi, A., & Torabi, S. A. (2024). A simulation optimization framework to solve Stochastic Flexible Job-Shop Scheduling Problems—Case: Semiconductor manufacturing. Computers & Operations Research, 163, 106508. https://doi.org/10.1016/j.cor.2023.106508 [in English].
8. Derlini, D., Annisa, S., & Lubis, Z. (2025, July 23–24). Optimizing Production Scheduling in Smart Manufacturing Systems Using Hybrid Simulation-Based Multi-Objective Optimization. In Engineering for Sustainable Future: Innovation in Renewable Energy, Green Technology, and Circular Economy (pp. 105–108). https://doi.org/10.30743/icst [in English].
9. Fu, B., Bi, M., Umeda, Sh., et al. (2025). Digital Twin-Based Smart Manufacturing: Dynamic Line Reconfiguration for Disturbance Handling. IEEE Transactions on Automation Science and Engineering, 22, 14892–14905. https://doi.org/10.1109/TASE.2025.3563320 [in English].
10. Gamdha, D., Saurabh, K., Ganapathysubramanian, B., & Krishnamurthy, A. (2025). High-Resolution Thermal Simulation Framework for Extrusion-based Additive Manufacturing of Complex Geometries. Finite Elements in Analysis and Design, 251, 104410. https://doi.org/10.1016/j.finel.2025.104410 [in English].

11. Moreno-Lumbreras, D., Gonzalez-Barahona, J. M., & Robles, G. (2023). BabiaXR: Facilitating experiments about XR data visualization. SoftwareX, 24, 101587. https://doi.org/10.1016/j.softx.2023.101587 [in English].
12. Neroda, T. (2025). Methodology for adapting successful decision algorithm in modeling optimal strategy for publishing and printing enterprise. In O. H. Cherep & Yu. O. Ohrenych (Eds.), Artificial Intelligence and Digital Technologies in the Transformation of Ukraine's Economy During the War and Post-War Recovery: collective monograph (pp. 171–215). Baltija Publishing. https://doi.org/10.30525/978-9934-26-584-6 [in English].

doi: 10.32403/2411-3611-2025-2-48-26-37

АНАЛІТИЧНЕ МОДЕЛЮВАННЯ ДИНАМІЧНОЇ ДИСКРЕТНОЇ СИСТЕМИ УПРАВЛІННЯ РОБОЧИМИ ЗАВДАННЯМИ В ОПЕРАТИВНІЙ ПОЛІГРАФІЇ

Т. В. Нерода

Національний університет «Львівська політехніка»,
Інститут поліграфії та медійних технологій,
вул. Під Голоском, 19, Львів, 79061, Україна
tetyana.v.neroda@lpnu.ua

Розглянуто проблематику підвищення ефективності виробничих процесів оперативної поліграфії шляхом оптимізації систем управління робочими завданнями, що функціонують в умовах варіативного попиту, технологічної неоднорідності та високої залежності від перманентного переналаштування виробничих маршрутів. Наголошено, що висвітлені у публікаціях відкритого доступу напрацювання у напрямку проєктування індустріальних інфраструктур формують підґрунтя для розроблення адаптивних систем підтримки малого і середнього виробництва, здатних забезпечувати прогнозування та аналітичну оцінку виробничих процесів, не повною мірою охоплюють специфічні вимоги оперативної поліграфії, де часові обмеження, різнорідність замовлень і значна асинхронність операцій формують унікальні умови функціонування та створюють потребу синхронізації потоків даних між модулями роботи з замовниками, препрес-підготовки, автоматичного конфігурування технологічних маршрутів і виконавчих виробничих підсистем. Обґрунтовано застосування концепцій дискретно-подієвого моделювання для опису поведінки виробничого середовища у вигляді послідовностей подій та переходів між станами, а також використання апарату стохастичних мереж Петрі для формального подання конкурентних, розподілених, синхронізованих і ресурсообмежених процесів, характерних для оперативної поліграфії. На основі побудованої матриці станів і переходів робочих завдань виконано проєктування аналітичної моделі, що охоплює структурування потоків даних, механізми пріоритезації робочих завдань, сформульовані у матриці критерії адаптації маршрутів *виконання замовлень та поведінку підсистеми прийняття рішень у режимі реального часу. Показано, що застосування такої моделі створює підґрунтя для побудови прогнозних сценаріїв, підтримки керованості виробничого контуру та підвищення стабільності обслуговування різнорідних замовлень з розширенням цифрових технологій оперативної поліграфії.*

Ключові слова: *дискретно-подієве моделювання, стохастичні мережі Петрі, управління робочими завданнями, адаптивні технологічні маршрути, оперативна поліграфія.*

Стаття надійшла до редакції 04.09.2025.
Received 04.09.2025.