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REVIEW AND ANALYSIS OF SOFTWARE FOR MODELING THE TECHNOLOGICAL PROCESS OF A RAILWAY STATION BASED ON SIMULATION MODEL

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Abstract. In the modern world, the efficiency and safety of railway systems are critical aspects of transport infrastructure. This study examines software tools for modeling the technological processes of railway stations and analyzes their advantages and limitations. Packages such as AnyLogic, Aimsun, AutoMod, and MvStudium were evaluated in terms of their functional capabilities, ability to conduct simulation experiments, optimize logistical processes, and manage operational activities. The results indicate that computerization and visual modeling of railway systems enhance operational efficiency, enable more effective resource utilization, and improve management of technological processes. Integrative modeling approaches allow for more accurate representation of technical and operational processes and provide a foundation for the future implementation of intelligent management systems. Moreover, the use of ergatic models enables consideration of human factors, improving modeling quality and allowing simulation of various operational scenarios. In conclusion, the study proposes new methods for developing functional models to assess and forecast the performance of railway stations, facilitating innovative, scientifically grounded solutions and supporting strategic planning in railway transport management.

Keywords: railway, modeling, computerization, station, logistics, operational efficiency, ergatic system

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ТЕМІРЖОЛ СТАНЦИЯСЫНЫҢ ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСІН БАЛАМАЛЫҚ МОДЕЛЬ НЕГІЗІНДЕ МОДЕЛЬДЕУГЕ АРНАЛҒАН БАҒДАРЛАМАЛЫҚ ЖАСАҚТАМАЛАРҒА ШОЛУ ЖӘНЕ ТАЛДАУ

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Аннотация. Қазіргі заманда теміржол жүйелерінің тиімділігі мен қауіпсіздігі транспорттық инфрақұрылымның басты мәселелерінің бірі болып табылады. Бұл зерттеу теміржол станциясының технологиялық процесін модельдеу үшін әртүрлі бағдарламалық қамтамасыз етуді талдайды, олардың артықшылықтары мен кемшіліктерін салыстырады. AnyLogic, Aimsun, AutoMod және MvStudium сияқты бағдарламалық пакеттердің функционалды мүмкіндіктері қарастырылды, сонымен қатар олардың симуляциялық тәжірибелер жүргізу, операциялық және логистикалық шешімдерді оңтайландыру қабілеттері бағаланды. Зерттеу көрсеткендей, теміржол жүйелерін компьютерлендіру және визуалды модельдеу операциялық тиімділікті арттыруға, ресурстарды тиімді пайдалануға және технологиялық процестерді басқаруға мүмкіндік береді. Модельдеудің интегративтік тәсілдері техникалық және операциялық процестерді нақтырақ сипаттауға, болашақта интеллектуалды басқару жүйелерін енгізуге негіз береді. Сонымен қатар, зерттеу ергатикалық жүйелерді қолдану арқылы адам факторының әсерін есепке алу мүмкіндігін көрсетеді, бұл моделдеу сапасын арттырады және нақты сценарийлерді симуляциялауға мүмкіндік береді. Қорытындысында, теміржол станцияларының тиімділігін бағалау және болжау үшін функционалды модельдерді құрудың жаңа әдістері ұсынылады, бұл инновациялық және ғылыми тұрғыдан маңызды шешімдерге жол ашады.

Түйін сөздер: теміржол, модельдеу, компьютерлендіру, станция, логистика, операциялық тиімділік, ергатикалық жүйе

Дәйексөздер үшін: Е. Майлыбаев. Теміржол станциясының технологиялық процесін баламалық модель негізінде модельдеуге арналған бағдарламалық жасақтамаларға шолу және талдау//Қазақстан өндіріс көлігі. 2025. Том. 22. № 86. 65–75 бет. (Ағыл. тіл.). https://doi.org/ 10.58420.ptk.2025.86.02.006

Мүдделер қақтығысы: Авторлар осы мақалада мүдделер қақтығысы жоқ деп мәлімдейді.

ОБЗОР И АНАЛИЗ ПРОГРАММНОГО ОБЕСПЕЧЕНИЯ ДЛЯ МОДЕЛИРОВАНИЯ ТЕХНОЛОГИЧЕСКОГО ПРОЦЕССА ЖЕЛЕЗНОДОРОЖНОЙ СТАНЦИИ НА БАЗЕ ИМИТАЦИОННОЙ МОДЕЛИ

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Аннотация. В современном мире эффективность и безопасность железнодорожных систем являются ключевыми аспектами транспортной инфраструктуры. В настоящем исследовании рассматривается программное обеспечение для моделирования технологического процесса работы железнодорожной станции, проводится анализ его преимуществ и недостатков. Оценивались пакеты AnyLogic, Aimsun, AutoMod и MvStudium с точки зрения их функциональных возможностей, способности проводить симуляционные

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эксперименты, оптимизировать логистические процессы и управлять операциями. Результаты исследования показали, что компьютеризация и визуальное моделирование железнодорожных систем способствуют повышению операционной эффективности, более рациональному использованию ресурсов и улучшению управления технологическими процессами. Интегративные подходы к моделированию позволяют точнее описывать технические и эксплуатационные процессы, а также создавать основу для внедрения интеллектуальных систем управления в будущем. Кроме того, использование эргатических моделей позволяет учитывать влияние человеческого фактора, что повышает качество моделирования и дает возможность симулировать различные сценарии работы станции. В заключение предлагаются новые методы построения функциональных моделей для оценки и прогнозирования эффективности работы железнодорожных станций, что открывает путь к инновационным и научно обоснованным решениям.

Ключевые слова: железная дорога, моделирование, компьютеризация, станция, логистика, операционная эффективность, эргатическая система

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Introduction.

For modeling the railway technological process of a railway station (RS) based on a simulation model, many software tools have been proposed, but they solve the problems of modeling technological processes one-sidedly and do not provide unambiguous answers to questions of logistics or modeling of railway technological processes.

The current stage of railway development can be defined as the period from the 1990s to the present. Over the past decade, significant shifts in railway design automation have not occurred. Researchers are faced with unconventional problems covering numerous design aspects, which are difficult to formalize. Traditionally, the quality of design solutions largely depends on the level of designer qualification.

SCADA or CAD (computer-aided design) systems have been developed to automate complex project design processes. These systems allow integrated solutions for railway systems, providing visualization of locomotive positions using GPS and global satellite navigation. However, rapid CAD development is hindered by the heuristics of railway circuit construction.

Abroad, studies focused on developing transport CAD systems, emphasizing the mathematical formalization of railway structures using combinatorial, topological, matrix, and graph models. Foreign researchers also highlighted the importance of graphical representation of railway technical equipment. Two main research directions were identified in railway design automation: technical design of track infrastructure and technical-technological modeling of railway elements and processes (Dong, 2010: 12–15).

Despite these efforts, a complete solution has not yet been achieved. Heuristic methods require active human involvement, as CAD systems alone cannot provide full interactive control over railway development. Ergatic and graphoanalytic methods can automate railway modeling, but human participation remains essential for analyzing technological processes and overall performance.

The urgent task for modern railways is to determine estimated volumes of work for which simulation of railway functional states allows assessing technical equipment and technology compliance under uneven transportation conditions. Computerization of technical and operational assessment of railway work is now recognized globally, with a focus on creating intellectualized, automated systems.

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Materials and methods.

The current stage of railway development can be conditionally defined as the period from the 1990s to the present. There have been no significant shifts in the direction of automation of railway design over the past ten years. An analysis of the results shows that researchers are faced with a rather unconventional problem that covers numerous aspects of design, and is difficult to formalize. The quality of the design solution with traditional approaches is determined, first of all, by the level of qualification of the designer (Maylybayev, 2024: 171).

The skills and experience of a professional solve the problem of linking the structure of the railway circuit with numerous internal and external factors, and there are no descriptive procedures for the designer's experience yet. During this period, a unified algorithmic approach to the interpretation of design requirements and rules for the implementation of station structures in the design begins to take shape. The so-called SCADA systems (or computer-aided design systems—CAD) are being developed (Maylybayev, 2024: 171; Harris, 2013: 172–174).

Such systems contribute to the introduction of automated forms of end-to-end development of the most complex projects. They cover all stages of design and allow obtaining integrated solutions for railway systems. The electronic circuits of the railway make it possible to track the condition of individual locomotives on the display screen at a point with coordinates determined by mobile GPS receivers via the global satellite navigation system (Li, 2020: 112936). The most important factor that began to hinder the rapid creation of an effective CAD railway was the heuristics of the very process of building a railway circuit. However, thanks to the efforts of scientists engaged in theoretical research in this field, and a number of theoretical and practical studies and publications, the cognitive orientation of the results obtained in this field of science has grown (Maylybayev, 2024: 171; Dong, 2010: 6–8).

Similar studies and works have also been conducted abroad (Goodman, 1998: 80–82; Kaakai, 2007: 5–7). For these works, a characteristic feature was the accumulation of materials on the problem of developing transport CAD systems. At the same time, the works of foreign colleagues were dominated by methodological works in the context of the development of mathematical methods, which formally described the structure of railway development. Combinatorial, topological, matrix, and graph models were used, which displayed essential features (Maylybayev, 2024: 171; Rohrer, 2000: 172–174).

Also, foreign researchers emphasized the importance of a correct graphical representation of the railway's technical equipment. All this combined made it possible to formulate a number of canonical requirements that are usually imposed on mathematical analogues of real railway circuits. The analysis of these works shows that there are two directions in which foreign scientists conducted their research in the field of railway design automation:

- technical design of the track infrastructure (Zauner, 2007: 3–5);
- technical and technological modeling of railway elements and processes (Karpov, 2006: 45–48).

Solving problems related to the CAD synthesis, domestic and foreign scientists did not focus only on a narrow range of problems of optimizing the geometric properties of projected objects. They also linked the models being developed with the development of wagon processing technologies. As a result of this dual orientation of research in the field of CAD of railway stations, scientists have so far failed to obtain a complete solution (Yatskiv, 2005: 237–239).

The heuristics of systems used for design automation at the beginning of the 21st century began to be associated with the need for direct active involvement in the design processes and analysis of design solutions for both performers and customers. In this case, design automation methods have become secondary and are used only as tools for reproducing the results of designers' activities.

In fact, the heuristic orientation of the design processes can be interpreted as the separation of the goals of designers and the CAD software environment itself. The capabilities of typical CAD systems turned out to be quite complete for the calculation and graphical modeling of railway

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circuits. However, practically no CAD system provides full-fledged interactive control functions for designers over the progress of the railway development process. The weak side of many CAD systems is only the actual visual monitoring of the development of object structures.

CAD implements standard computer modeling techniques that allow designing and simultaneously visualizing the design results directly during development. As a result, it turns out that using direct methods of standard CAD, it is possible to develop integral structures of visual forms of railway stations and some technological objects. However, it is necessary to seriously rebuild the basic environment, complementing it with active modules of special content (Harris, 2013: 176–178).

The problem can be solved by using ergatic or graphoanalytic methods that ensure the construction of a model of railway operation in an automated mode (Li, 2020: 112940). However, human participation in the process of building a model and analyzing not only the overall performance of the railway but also the course of its technological processes dramatically reduces the duration of the modeling period.

In these conditions, an urgent problem for railways is the development of methods for determining estimated volumes of work, for which the results of modeling the functional states of railways (for a limited period of time) would allow making reasonable conclusions about the compliance of their technical equipment and technology with promising volumes of work. The calculation is carried out for conditions of uneven transportation (Dong, 2010: 10–12).

An analysis of the conducted research and modern publications on the problems of railway research has shown that the trend of scientific research related to the computerization of technological processes at railway stations and procedures for making operational decisions in the tasks of technical and operational assessment of railway work has become generally recognized worldwide (Kaakai, 2007: 6–8).

The creation of new models of computerization of technical and operational assessment processes, methods, and hardware-oriented algorithms for the intellectualization of these processes, provides a basis for scientific research in the field of organization of modern information technologies for the synthesis of automated systems of technical and operational assessment of railway work (Goodman, 1998: 85–87).

Results and discussion.

According to the estimates of domestic and foreign scientists, a significant increase in the effectiveness of the use of modern computer technologies is possible only by studying the general properties of mathematical modeling, methods of building intelligent systems, algorithms used in control tasks, features of modern and promising intelligent technologies for railways, as well as architectural features of automation systems for technical and operational assessment of work at railway stations.

AnyLogic (Li, 2020: 112950) is a multifunctional package designed for building simulation models. AnyLogic software is capable of supporting all the approaches that are encountered in the simulation process (Dong, 2010: 15–17). Its interconnected modules are focused on building models such as process-oriented, system-dynamic, agent-based, and multi-agent models. AnyLogic is capable of supporting combinations of the above models. Since the AnyLogic environment is written in Java, the flexibility and versatility of this language allow considering a wide variety of nuances during model construction.

It is possible to take into account a wide variety of configurations when modeling the operation of railway stations (Fig. 1). Graphical interfaces, tools, and libraries of AnyLogic allow accelerating the synthesis of models for a wide range of tasks. In AnyLogic, you can model not only production or logistics sectors but also solve problems of finding optimal management options for complex transport systems. Its advanced multimedia tools and real-time simulation animation provide researchers additional advantages in developing research plans and conducting experiments (Goodman, 1998: 90–92).

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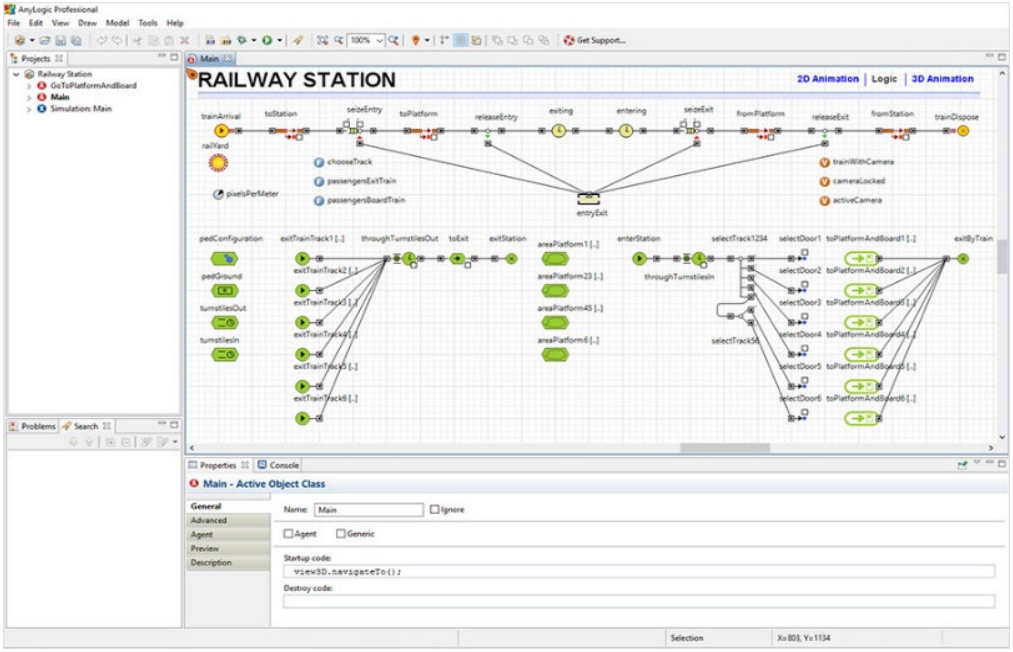

Fig. 1. General view of the AnyLogic modeling environment (Maylybayev, 2024: 173)

The Aimsun simulation package (Kaakai, 2007: 8–10) is software for traffic modeling. With thousands of licensed users in government agencies, universities, and consulting organizations worldwide, Aimsun stands out for its extremely high simulation speed.

AutoMod software (Rohrer, 2000: 180–182) is intended for building graphical models for visualizing logistics and production systems. AutoMod allows detailed analysis of operations and material flows in logistics and is widely used for analytical problems related to production processes. Its flexible structure makes it suitable for practical use across a wide variety of problem statements.

The AutoMod software, see Figure 2, has a fairly flexible structure, which makes it suitable for practical use for a wide variety of problem statements in a wide range of applied modeling by economic sectors.

Another interesting product in the field of production modeling is the MvStudium software (Fig. 3). This simulation environment allows you to analyze physical and dynamic systems. With MvStudium, you can quickly create and virtualize a wide variety of interactive models. Unlike other similar software products on the production modeling market, MvStudium allows us to consider multicomponent continuous, discrete and hybrid systems.

Systems built in the MvStudium environment can be analyzed using active computational experiments. Creating models, visualizing the results obtained during simulation experiments and the ability to manage computational experiments does not require researchers to write their own program code. Models can be described at the level of mathematical abstractions (Tolk, 2019: 135–152).

For example, a differential algebraic approach has been applied to describe the continuous behavior of a production or logistics system. In order to describe the discrete and hybrid (continuously discrete) behavior of the system, MvStudium uses the potential of visual behavior maps.

The advantages and disadvantages of the considered software packages are summarized in Table 1.

To simulate the operation of the station using these packages, a detailed railway model is required.

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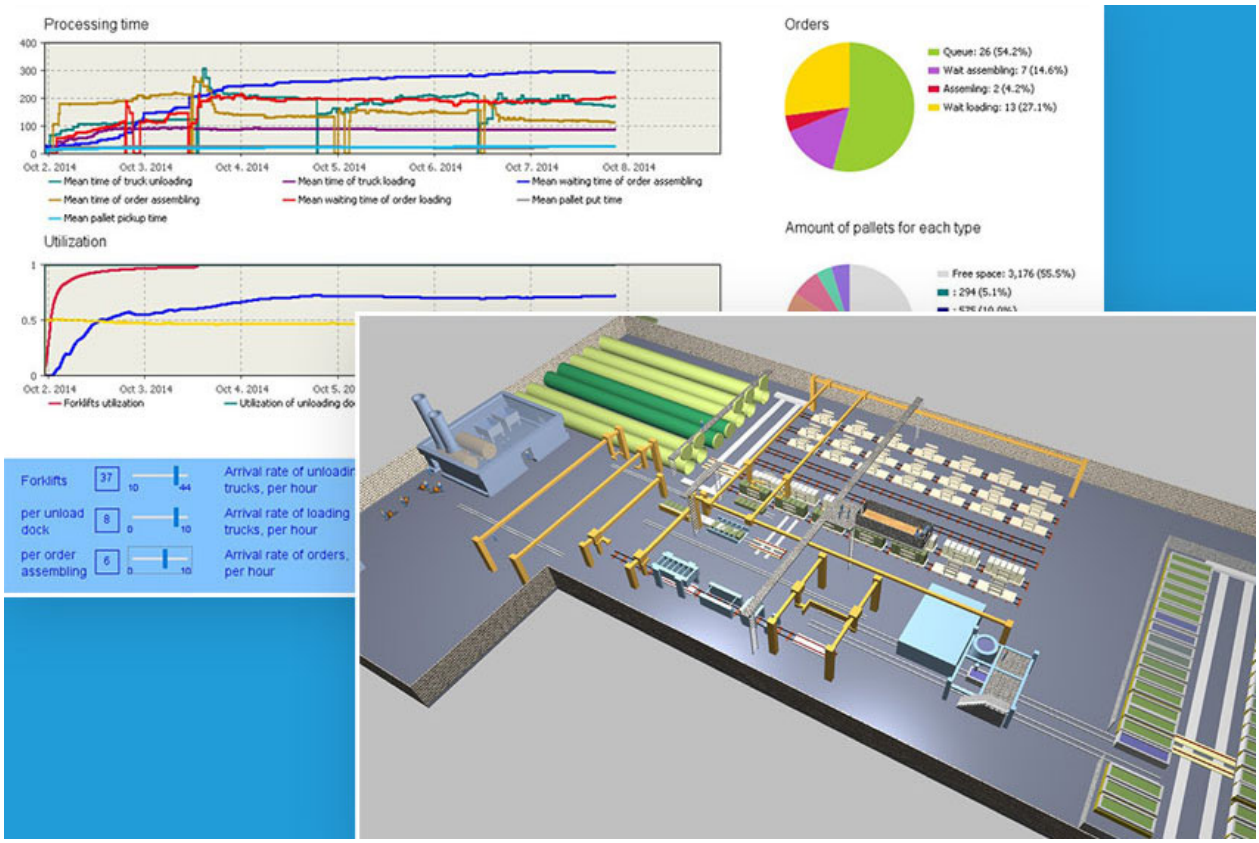

Fig. 2. General view of the AutoMod modeling environment (Maylybayev, 2024: 174)

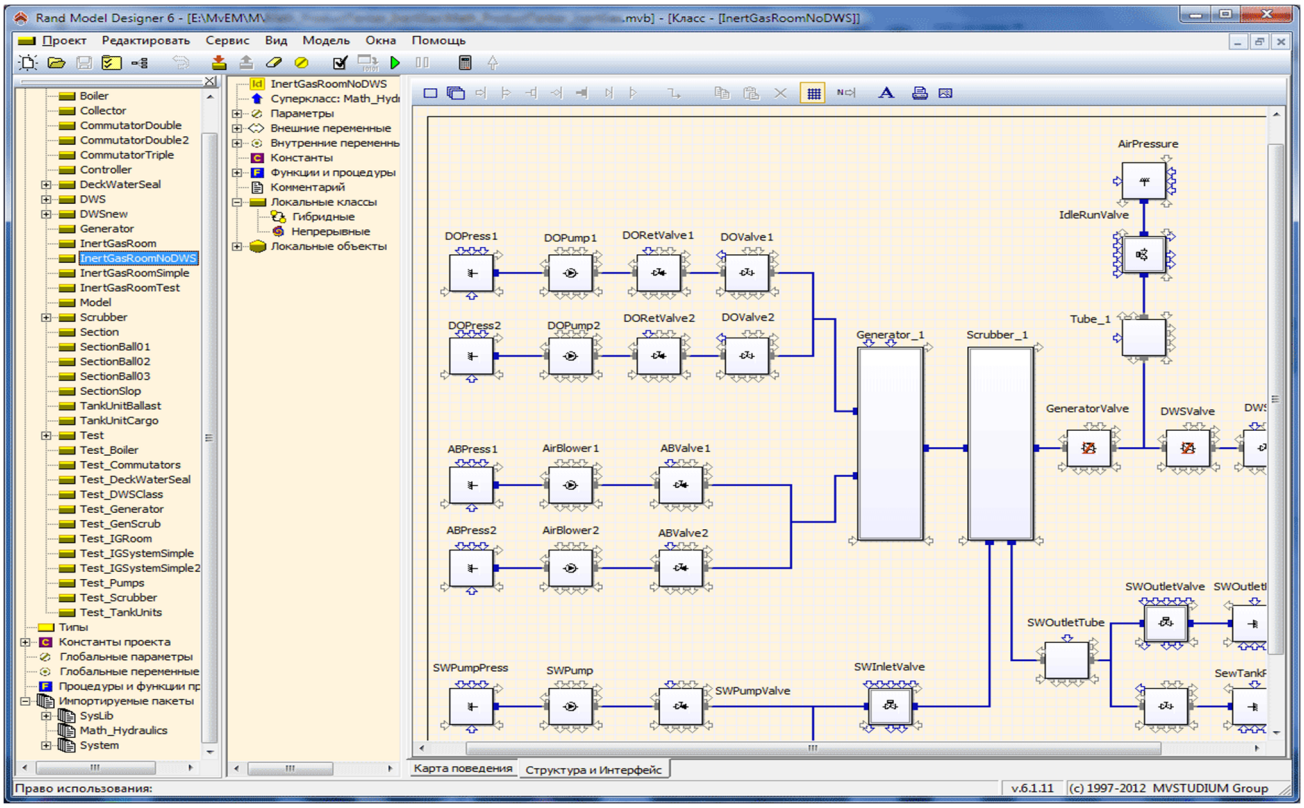

Fig. 3. General view of the MvStudium modeling environment (Maylybayev, 2024: 175)

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Table 1 - Advantages and disadvantages of the considered software packages (Maylybayev, 2024: 175)

The system	Approach to Modeling	Advantages	Disadvantages
Arena	Discrete-event (DE)	It is possible to create your own templates and modules. A device for simulation experiments.	Only 1 approach to the model.
AGNES	• A Agent-based (A). • E Events are discrete.	Cross-platform (Cross-platform). The possibility of simulation and full-scale modeling.	The cost of the license
GPSS	DE	An object-oriented modeling paradigm. The possibility of simulation and full-scale modeling.	Only 1 approach to the model. A complex interface.
AnyLogic	DE+A	Two approaches. Visualization, optimization, and proprietary libraries.	Only 1 approach to the model. The cost of the license.
Simplex3	DE	Chart visualization capabilities. Cross-platform	One approach. Subscribe to updates.
Simio	DE+A	Visualization of models, different forms of presentation of results.	Reduced functionality. A relatively small list of tasks to be solved.
SeSAm	A	Import vector and raster files, work with text files.	Only 1 approach to the model. Lack of support
SimPy	DE	The ability to run models in real time. Cross-platform.	Only 1 approach to the model. There is no visualization.
Aivika	DE+A	Cross-platform. Parallel computing.	A complex interface. A fairly long training period is required, taking into account the features

Note that these behavior maps are essentially extended state maps of the UML modeling language. MvStudium allows the automatic creation of computer models that correspond to a given mathematical formulation of the problem, and computational experiments can be conducted to verify the model's operability. The computer model can be implemented as a separate program or dynamic library, which allows it to be used independently of the MvStudium package. MvStudium supports an object-oriented modeling and programming paradigm, providing opportunities for users to create custom components based on the input language. The software also supports 2D and 3D animation, enabling a more comprehensive visualization of processes.

The railway station is a complex system closely integrated with the mainline railway transport system, shippers, and consignees, connected by numerous forward and backward flows that vary over time. Its technical infrastructure (tracks, shunting facilities, freight substations), control system (operational dispatch apparatus), and wagon traffic (VagT) are considered as enlarged elements of the station. Physical and information connections and corresponding channels are implemented between the system elements.

The external environment for the railway is the overall transport system. The state of the system is characterized by the degree of involvement of the station's technical facilities and operations in processing VagT. The input of the system is VagT and the information flow received by the railway station, while the output forms VagT and information streams sent from the station. The behavior of the system is determined primarily by the influence of the control system, which includes human dispatchers. Therefore, the railway can be interpreted as an ergatic system (Maylybayev, 2024: 176).

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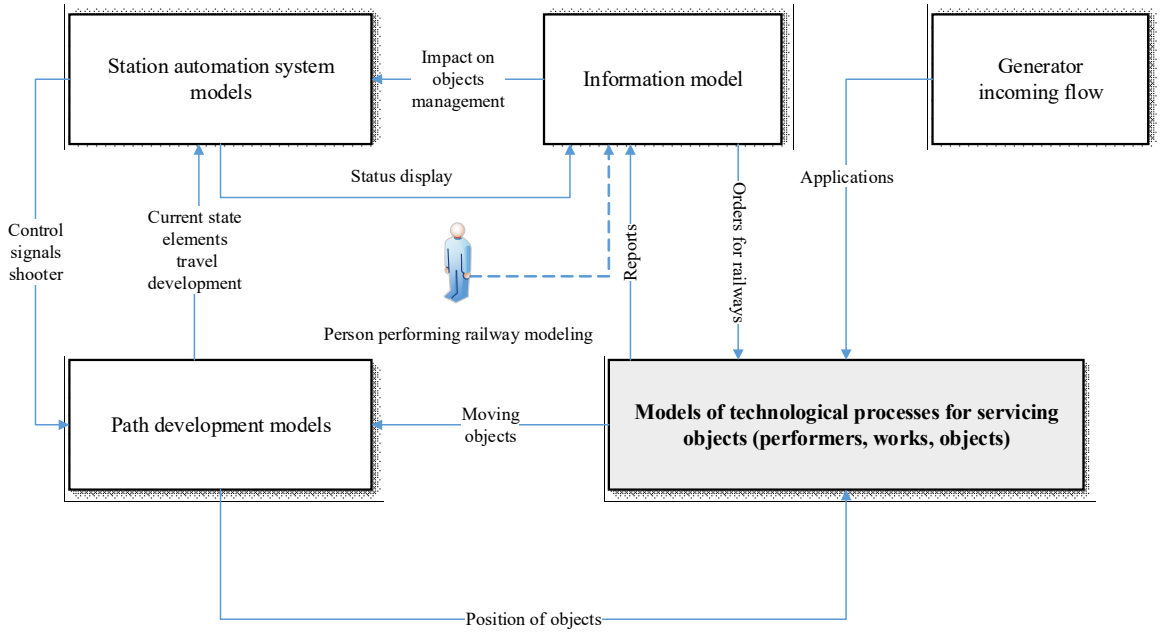

Fig. 4. Diagram of the ergatic railway system (Maylybayev, 2024: 176)

Taking into account the railway as a complex technical system and the degree of prior research, the following tasks are formulated for further research:

- development of procedures for identification of functional railway models;
- improvement of feasibility study methods for evaluating railway operations to account for changes in volume and structure over time;
- advancement of methods for functional modeling of railway operations using visual programming methods.

These tasks aim to enhance the accuracy, efficiency, and applicability of simulation models, ensuring that railway stations can be assessed, optimized, and managed effectively in real-world operational conditions (Maylybayev, 2024: 176).

Conclusion.

The review and analysis of software tools for modeling the technological processes of railway stations demonstrate that simulation modeling has become an essential method for the design, planning, and optimization of complex railway systems. The conducted study shows that modern railway stations represent highly interconnected technical systems, combining track infrastructure, shunting and freight facilities, operational dispatch control, and wagon traffic management. Each of these elements interacts with both internal and external factors, including fluctuating transport demand, seasonal variations in cargo and passenger flows, and real-time operational constraints.

The analysis reveals that traditional methods of railway planning and design, relying primarily on heuristic approaches and the experience of professional engineers, are insufficient to cope with the increasing complexity of modern railway operations. In particular, the reliance on manual calculations and static design principles often leads to suboptimal use of resources and reduced system efficiency. In contrast, simulation-based modeling allows for the comprehensive analysis of operational scenarios, evaluation of design alternatives, and prediction of system performance under variable conditions.

Among the reviewed software tools, AnyLogic demonstrates significant versatility due to its ability to integrate multiple modeling paradigms, including process-oriented, system dynamics, and agent-based approaches. Its Java-based environment allows for extensive customization and supports the modeling of highly detailed railway processes, from wagon dispatching to passenger flow management. Similarly, Aimsun and AutoMod provide high-speed traffic and logistics

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simulations that are critical for operational planning and optimization. MvStudium, with its capacity to model hybrid continuous-discrete systems, offers unique advantages for analyzing complex technological processes and performing computational experiments without the need for extensive programming.

Despite the capabilities of these tools, the analysis indicates several common limitations. Many existing simulation platforms provide only partial interactivity, with insufficient mechanisms for real-time monitoring and adaptive control during model execution. Furthermore, the integration of simulation models with operational decision-making remains challenging, as most tools focus primarily on structural or process modeling rather than on functional or ergatic system analysis. The concept of the railway as an ergatic system, in which human operators and automated subsystems interact dynamically, requires further research and specialized modeling techniques.

The practical implications of these findings are significant. By adopting advanced simulation tools, railway operators can optimize station layouts, minimize operational bottlenecks, and improve the reliability and safety of railway operations. The integration of modeling and simulation into the planning process allows for the evaluation of different scenarios before their real-world implementation, thereby reducing risks associated with infrastructural investments and operational errors. Moreover, the ability to perform detailed simulations of wagon handling, track utilization, and resource allocation contributes to more efficient management of labor and material resources, enhancing overall system performance.

From a scientific perspective, the study highlights the need for further development of methodologies for identifying and parameterizing functional models of railway stations. This includes the formalization of performance indicators, defining operational constraints, and establishing standardized procedures for conducting simulation experiments. In addition, there is a need to integrate real-time data from railway operations, such as GPS tracking and sensor networks, into simulation models to enhance their predictive accuracy and operational relevance.

Finally, the research emphasizes the dual orientation of modern railway simulation: combining technical infrastructure design with operational process modeling. The synergy of these two approaches allows for a comprehensive assessment of railway station performance, including both structural integrity and technological efficiency. The development of intelligent algorithms, visual programming tools, and ergonomic interfaces will further support the decision-making process, facilitating the creation of robust, adaptive, and optimized railway systems capable of meeting the demands of modern transport networks.

In conclusion, simulation modeling represents not only a tool for technical analysis but also a strategic instrument for operational planning and optimization of railway stations. The continuous improvement and integration of advanced modeling software, combined with empirical data and functional identification methods, will provide the foundation for the next generation of railway station design and management. This approach ensures enhanced system reliability, increased operational efficiency, and better adaptation to dynamic transport conditions, contributing to sustainable and effective railway operations in the 21st century.

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