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## Analysis of data flow management on the example of a medical institution

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**Abstract.** The relevance of the research is related to the increasing workload of medical institutions and the need to improve the efficiency of emergency rooms, where it is critical to take into account the dynamism and complexity of the processes of patient arrival and distribution. The analysis of such systems requires tools to model various scenarios and predict the consequences of management decisions. The development of BRICS+ cooperation creates the preconditions for joint investments in the digitalization of healthcare and the transfer of operational process management technologies. The aim of the study is to develop a methodological approach to create a simulation model of an admission ward that provides formalization of stakeholder requirements and comprehensive analysis of ward workload. The methods include a review of existing approaches to patient flow modelling (discrete event, system dynamics, agent-based and hybrid models) and justification of the choice of discrete event approach as the most relevant to the tasks of operational management. Additionally, architectural modelling tools (ArchiMate, TOGAF) were applied to build a motivational model, which allowed structuring the goals, drivers and constraints of the process participants. The results consist in formalizing the requirements for the simulation model, defining its architecture and confirming the economic efficiency of its application. The model is shown to identify bottlenecks, optimize resource utilization, reduce waiting times and reduce costs. The results obtained are of practical value for shaping new vectors of BRICS+ countries' cooperation in the field of high-tech medical services and management solutions. The novelty of the study lies in the combination of simulation and motivational modelling, which allows

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us to consider the emergency room as a complex adaptive system and create universal toolkits to support management decisions. This distinguishes this work from studies limited by separate methodological frameworks or lack of formalization of requirements.

**Keywords:** data management, simulation modeling, adaptive systems, medical organization, BRICS+, healthcare investments, management solutions

**Authors' contribution.** N.V. Trifonova — methodology, formal analysis, investigation, writing Original Draft, Review & Editing; A.I. Levina — conceptualization, investigation, writing Original Draft, Review & Editing, supervision; V.P. Gorelov — resources, visualization; T.N. Saurenko — Resources, writing Original Draft. All authors approved the final version of the paper.

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## Анализ управления потоками данных на примере медицинского учреждения

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**Аннотация.** Актуальность исследования связана с ростом нагрузки на медицинские учреждения и необходимостью повышения эффективности работы приемных покоев, где критично учитывать динамичность и сложность процессов поступления и распределения пациентов. Для анализа таких систем требуются инструменты, позволяющие моделировать различные сценарии и прогнозировать последствия управленческих решений. Развитие сотрудничества в рамках БРИКС+ создает предпосылки для совместных инвестиций в цифровизацию здравоохранения и трансфера технологий управления операционными процессами. Цель исследования — разработка методологического подхода к созданию имитационной модели приемного

покоя, обеспечивающей формализацию требований заинтересованных сторон и комплексный анализ загруженности отделения. Методы включают обзор существующих подходов к моделированию потоков пациентов (дискретно-событийное, системная динамика, агентное моделирование и гибридные модели) и обоснование выбора дискретно-событийного подхода как наиболее релевантного задачам оперативного управления. Дополнительно применены средства архитектурного моделирования (ArchiMate, TOGAF) для построения мотивационной модели, что позволило структурировать цели, драйверы и ограничения участников процесса. Результаты заключаются в формализации требований к имитационной модели, определении ее архитектуры и подтверждении экономической эффективности применения. Показано, что модель позволяет выявлять «узкие места», оптимизировать использование ресурсов, сокращать время ожидания и снижать издержки. Полученные результаты представляют практическую ценность для формирования новых векторов сотрудничества стран БРИКС+ в сфере высокотехнологичных медицинских услуг и управленческих решений. Новизна исследования состоит в сочетании имитационного и мотивационного моделирования, что позволяет рассматривать приемный покой как сложную адаптивную систему и создавать универсальные инструментальные комплексы для поддержки управленческих решений. Это отличает данную работу от исследований, ограниченных отдельными методологическими рамками или отсутствием формализации требований.

**Ключевые слова:** управление данными, имитационное моделирование, адаптивные системы, медицинская организация, БРИКС+, инвестиции в здравоохранение, управленческие решения

**Вклад авторов.** Н.В. Трифонова: методология, формальный анализ, исследование, написание оригинального черновика, редактирование, А.И. Лёвина: концептуализация, исследование, написание оригинального черновика, редактирование, авторский надзор, В.П. Горелов: ресурсы, визуализация, Т.Н. Сауренко: ресурсы, написание оригинального черновика. Все авторы одобрили окончательную версию статьи.

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## Introduction

Modern methods of managing operational processes in healthcare increasingly require tools that can not only record the current situation but also model the behavior of the system in various scenarios. At the stage of patient admission to a medical organization (emergency room), modelling methods are of particular importance, as they make it possible to reproduce the processes of patient admission,

triage and distribution, as well as to assess the impact of management decisions on key performance indicators. The practical application of such models requires a preliminary analysis of existing approaches and the selection of appropriate methodological tools. It is important not only to determine which classes of models are most applicable to the task of managing patient admissions, but also to justify how they address the real constraints, goals and requirements of stakeholders. This analysis is an important step in the subsequent design of models that can serve as a basis for informed management decisions.

**This study focuses** on systematization of existing methods of patient flow modelling and justification of the feasibility of simulation modelling for the tasks of waiting room workload analysis, which can then form the basis for the development of a full-fledged tool solution to support patient flow management. Enterprise architecture methods, in particular, motivational extension (based on TOGAF and ArchiMate) were used as a tool for requirements systematization.

## Materials and methods

### Literature review

The study of existing research and practical developments in the field of patient flow modelling in the organization of emergency rooms is a necessary step for the formation of the theoretical and methodological basis of this study. The modern healthcare system faces a number of complex challenges related to the increasing workload of medical institutions and the need to optimize resources, which makes it relevant to apply analytical and modelling approaches to improve the efficiency of primary care processes.

This section systematizes the results of scientific and practical research on the organization of reception rooms, methods of modelling medical processes and tools for their implementation, which will form the basis for the subsequent choice of methodology and setting of the research problem.

### *Simulation modelling in healthcare*

The paper (Davari et al., 2024) presents a comparative analysis of process mining and simulation modelling methods to reduce congestion and waiting times in waiting rooms. The use of ARENA to simulate different scenarios allows to evaluate the impact of changes in work organization on the efficiency of patient reception.

In (Hurwitz et al., 2014), a flexible simulation modelling platform is described to quantify and manage congestion in waiting rooms. The use of R and Gamma distributions to simulate patient and resource flows provides the opportunity to analyze different scenarios and optimize ward performance.

The paper (Vanbrabant et al., 2019) presents an overview of key performance indicators (KPIs) and operational improvement methods in emergency rooms using simulation modelling. Different approaches and their application to improve throughput and quality of patient care are discussed.

The authors (Chouba et al., 2019) propose a simulation model that combines the optimization of medical and paramedical resource allocation to improve the performance of the emergency room. The results show a decrease in the average waiting time and length of stay of patients, which indicates the effectiveness of the proposed approach.

The paper (Alenany, Cadi, 2020) discusses the application of machine learning combined with simulation modelling to improve patient flow in an emergency room. The use of a decision tree-based decision-making model allows predicting the probability of a patient's hospitalization and optimizing their path through the department. The paper deals with the creation of a simulation model of a hospital's admission department for the purpose of reconstruction design. The authors use specialized software FlexSim Healthcare and real data of hospital admissions, which allows to obtain sufficiently reliable results and to take into account the variability of patient flows. The model showed that increasing the number of registrars and clinicians reduces waiting and stay times, and separating the flows of planned and emergency patients significantly reduces the risks of hospital-acquired contacts, which is particularly important in epidemiological settings.

However, the use of FlexSim limits the transferability of the model to other institutions without significant refinement, and the detail of the processes remains insufficient to fully cover all factors affecting ward operations. In addition, the work pays little attention to the integration of the modelling with existing management and forecasting systems, which reduces the practical applicability of the results. These limitations highlight the need to develop a more versatile and flexible toolkit that can effectively analyze and forecast admission ward workload in a variety of settings.

The authors (Steen, Patriarca, Di Gravio, 2021) show that simulation modelling helps to identify bottlenecks in the work of emergency services and assess the consequences of management decisions, especially under extreme loads. However, the work pays insufficient attention to the integration of models with real information systems, and high complexity and resource intensity limit their wide application. This emphasizes the need for universal and adaptable tools, which is relevant to the development of the emergency room model in this study.

### Overview of approaches to patient flow modelling

The scientific literature presents a number of methodological approaches to modelling patient flows in healthcare facilities. One of the most common is discrete event simulation (DES), which is used to analyze the logistical processes within reception departments. This approach allows for a reasonably accurate description of queues, resource allocation and staff sequencing, making it particularly useful for tactical planning. However, its application is limited in the context of modelling agent behavior and system feedback analysis. For example, in a study (Fava et al., 2021) discrete event simulation was used to optimize schedules and assess the impact

of increasing the number of staff on waiting times, but such a model did not take into account patient behavioral responses or the dynamics of changes in the quality of care under congestion.

An alternative to DES is system dynamics (SD), which focuses on modelling aggregate patient flows and identifying long-term trends, including feedback between resource availability, quality of care and re-hospitalizations. This approach is particularly appropriate for strategic planning and analyzing the consequences of policy decisions. For example, a study (Sørup et al., 2019) demonstrates how SD-based estimates of inpatient workload can be made when the epidemiological environment changes or flows are redistributed between institutions. However, system dynamics does not allow for modelling individual patient trajectories and does not account for random variation in daily practice.

Agent-based modelling (ABM) provides a more flexible analysis tool, which allows taking into account individual patient behaviors, routes and decisions. The model presents simulation results considering different scenarios of patients leaving without receiving care, tardiness, and repeat visits, which is particularly relevant for high-burden admission departments. Despite being highly expressive, agent-based models require significant computational resources, especially when the number of agents is large, and depend on the amount of input data required to adjust behavior correctly.

Hybrid approaches combining elements of DES, SD and ABM are becoming increasingly popular. Such models seek to combine the advantages of each approach: the accuracy and structure of event-based models, the strategic depth of system dynamics, and the flexibility of agent-based systems. For example, models (Kar, Eldabi, Fakhimi, 2023; Vázquez-Serrano, Peimbert-García, Cárdenas-Barrón, 2021) use hybrid architectures to simulate emergency rooms in a pandemic environment, where both simulation of individual patient behavior and assessment of the overall resilience of the healthcare system to congestion are required. However, the complexity of development and the need to synchronize components significantly increase the threshold for entry into such a methodology.

Additionally, it is worth mentioning stochastic models, which are used to describe the probabilistic behavior of flows without strict detailing of the processes. The paper (Parnass et al., 2023) shows how stochastic modelling can be used to analyze the risks of congestion of receiving chambers under conditions of limited information. Although such models lack visual clarity and do not reflect the spatial characteristics of the flows, they remain useful in performing a rapid quantitative assessment of system stability.

Thus, the choice of methodological approach depends directly on the modelling objectives: short-term management decisions require event-based models, long-term strategic planning requires system dynamics, and behavioral response modelling requires agent-based and hybrid architectures. Given the complexity of emergency room operations and the need to integrate different levels of analysis, there is an increasing need for multi-paradigm models that combine the strengths of each approach in a single simulation environment.

Given the objectives of this study, discrete event modelling was chosen as the main approach. This type of modelling is the most appropriate for describing the sequence of operations and decision-making within hospital admission, registration, initial examination and other processes occurring in the emergency department. It allows to accurately reflect the dynamics of patient care, to vary flow parameters and to quickly assess the impact of different scenarios of organizational change.

In this context, studies in which simulation modelling is applied in practice to assess and optimize the functioning of emergency departments are of particular interest.

In healthcare, the emergency room is a critical node with highly dynamic and complex processes. Existing modelling methods in some cases do not cover a comprehensive view of processes, nor do they take into account the specific conditions and stakeholders. Simulation modelling offers a flexible and powerful tool for process analysis and prediction but requires careful goal setting and consideration of constraints. Integrating motivational and architectural models helps to formalise requirements and increase the practical value of the models. Thus, an integrated approach combining simulation modelling with requirements formalization is needed, which will be the subject of further research.

### *Reception center as a complex adaptive system*

From the standpoint of the theory of Complex Adaptive Systems (CAS), developed in the works of I. Prigogine (Prigogine, 1978), S. Kauffman (Kauffman, 1992) and J. Holland (Holland, 1992) and developed in the works of G.A. Rzhevsky and P.O. Skobelev, the emergency room of a medical organization should be considered as a typical complex adaptive system.

Firstly, the emergency room is characterized by a high degree of cohesion of elements. Patients, medical staff, administrative staff, diagnostic services and technical resources form a dynamic network of interactions, where changes in one subsystem (e.g., diagnostic delay) are immediately reflected in the entire system.

Second, the system exhibits agent autonomy. Patients independently decide whether to continue waiting or to leave without receiving care; doctors and nurses allocate priorities among patients under conditions of limited resources; administration forms organizational scenarios. Thus, under general normative regulation, key decisions are made in a decentralized manner.

The third property is emergent behavior. The aggregate functioning of the reception department is not a simple sum of actions of its elements: “bottlenecks”, staff overload or increased waiting time arise as a result of non-linear interactions of agents and therefore cannot be predetermined solely by normative algorithms.

The fourth property is non-equilibrium. Patient flows are subject to significant fluctuations due to seasonal changes, epidemiological situation or extraordinary circumstances. The system functions far from equilibrium and has to constantly adapt to changing external conditions.

Finally, the emergency room is characterized by non-linear dynamics. A slight increase in the incoming flow (e.g., the arrival of several heavy patients) can trigger an avalanche of waiting times, overloading of diagnostic units and, consequently, an increase in the number of patients leaving the ward without care.

In sum, the emergency room meets all the key characteristics of complex adaptive systems: multiplicity of interacting agents, absence of centralized control, emergent and non-linear behavior, functioning under conditions of uncertainty and disequilibrium. This fact predetermines the expediency of simulation modelling, including hybrid and multi-agent methods, which allow taking into account the adaptive and probabilistic behavior of system elements (Table 1).

Table 1

**Properties of complex adaptive systems and their manifestations  
in the emergency room of a medical organisation**

| CAS Property      | CAS Content                                               | Manifestation in the emergency room                                                                                      |
|-------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Connectivity      | The elements of the system form a network of interactions | Patients, staff, diagnostic services and resources are interdependent; failure in one subsystem affects the whole system |
| Agent autonomy    | Elements make decisions locally                           | Patients decide whether to wait or leave; physicians prioritize; administration adjusts resources                        |
| Emergentism       | Systemic behaviour arises from localised interactions     | The formation of queues, congestion and bottlenecks is not directly set, but occurs spontaneously                        |
| Non-equilibrium   | The system operates in an environment of volatile flows   | Load fluctuations due to seasonality, epidemics or emergencies; the ward is rarely stable                                |
| Nonlinearity      | Small changes cause disproportionate effects              | The arrival of several severe patients causes an avalanche of waiting times                                              |
| Self-organisation | The system adapts without centralised control             | Staff changes triage strategy, reallocates resources in response to congestion                                           |

Source: developed by N.V. Trifonova, A.I. Levina.

Consideration of the receiving rest as a complex adaptive system allows us to clarify the requirements for modelling tools. Since the system is characterized by non-linearity, emergent behaviour and autonomy of agents, traditional analytical methods are insufficient for its adequate description.

Simulation modelling, especially discrete event simulation, provides the ability to reproduce operational processes and queues. However, to take into account the adaptive and behavioral aspects of patient-staff interactions, the methodology needs to be extended by:

- Multi-agent modelling to describe autonomous behavior of patients, physicians and administrators under conditions of uncertainty.

- Hybrid architectures (DES + ABM), where DES is responsible for operational processes and the agent layer reflects decision-making at the individual level.
- Ontology formalization, which provides a unified conceptual framework for integrating data, requirements and modelling scenarios.

Thus, the consideration of the reception rest in the paradigm of complex adaptive systems justifies the need for a comprehensive approach: a combination of discrete event modelling, multi-agent methods and architectural ontological models. This creates prerequisites for the construction of a toolkit capable not only of reproducing processes, but also of reacting adaptively to the variability of input streams and limited resources.

## Methods

In this study, a simulation modelling approach based on discrete event simulation is chosen to analyze and predict the workload of the waiting room. This method allows for the most adequate representation of the dynamics and sequence of operations during admission and patient care, including the processes of registration, triage, initial assessment and hospitalization. DES provides accurate modelling of queues, resource allocation and patient flow management, which is critical for operational management decisions.

A systematic analysis of existing methodological approaches to modelling patient flows in healthcare was conducted to inform the choice of DES. Discrete event modelling, system dynamics, agent-based modelling, hybrid models and stochastic methods were considered and compared. The analysis showed that DES is optimally suited to the task of operational management of the reception area, as it provides a detailed reproduction of processes and rapid assessment of the impact of changes in organizational scenarios.

An important step was the formation of a motivation model based on an extension of the ArchiMate architectural modelling language adapted to the TOGAF methodology. The motivation model allowed structuring the key goals, drivers and constraints of stakeholders, which provided a transparent and comprehensive definition of requirements. This formalization of motivations and constraints is the basis for a relevant and applied simulation model.

Thus, the combined approach — a combination of system analysis, motivational modelling and simulation modelling with the application of discrete-event models — provides a comprehensive study of the functioning of the emergency room and serves as a basis for the development of an effective tool solution for optimizing operational processes in health care.

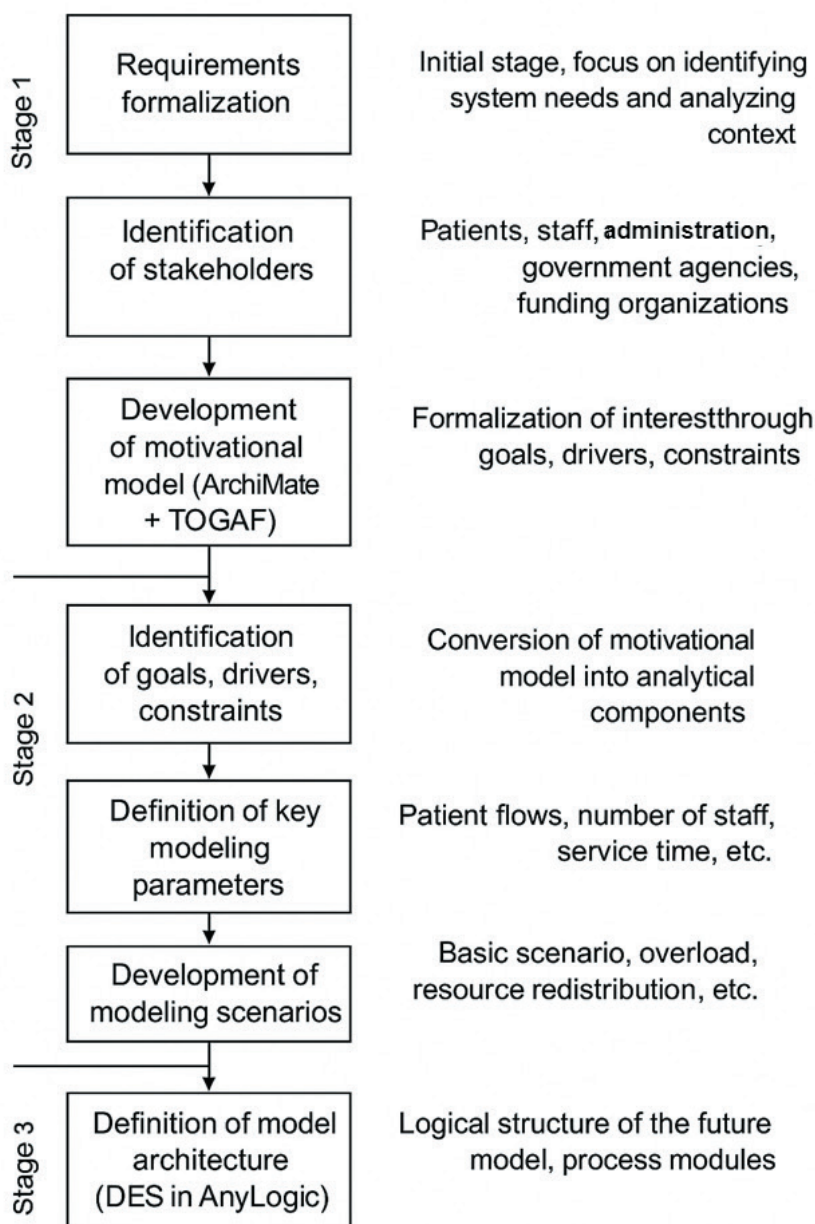
## Results

### *1. Methodological approach to model building*

Building a simulation model of a hospital emergency room requires a comprehensive and step-by-step methodological approach to ensure that the model corresponds to real processes and the interests of all stakeholders. Based on the

analysis and motivational model, we developed a conceptual approach that includes three interrelated stages: formalization of requirements, structuring of scenario parameters and definition of the model architecture.

The logic of solving the task is presented in Figure 1. It reflects the sequence of stages from formalizing requirements to defining the architecture of the future model, ensuring methodological rigor of modelling. This article presents the results of the first stage of the research.



**Figure 1.** Structure of the study

Source: developed by N.V. Trifonova, A.I. Levina.

*1.1. Formalization of requirements and constraints.* The first step is to systematize the goals, constraints and drivers of key stakeholders based on a motivational extension of the ArchiMate language. This approach allows structuring the initial expectations and formalizing the requirements for the model, taking into account the priorities of medical staff, administration, patients and regulators. This ensures methodological validity of the modelled processes and reduces the risk of distorting the real conditions of the emergency room functioning.

*1.2. Structuring of scenario parameters.* Based on the identified requirements, a list of key variables and parameters to be varied in the modelling process is formed. These include: the volume and structure of the incoming patient flow, the number and distribution of resources (doctors, medical staff, equipment), types of requests (emergency, planned), duration of service stages, routing algorithms and other factors. These parameters set the basis for building scenarios that allow testing hypothetical management decisions and their impact on the efficiency of the department.

*1.3. Definition of the model architecture.* It is assumed to use DES in AnyLogic as the main tool to reproduce the sequence of processes in the emergency room. The model architecture includes registration, triage, waiting, initial examination, consultation and hospitalization modules, as well as logical blocks for decision-making and resource allocation. The model is designed to be scalable, adaptable to different types of institutions and integrated with data from information systems of medical organizations.

Thus, the proposed methodological approach combines the logical formalization of requirements with simulation and analytical tools, which ensures the preparation of a reasonable model for subsequent application in the tasks of workload analysis and optimization of emergency room processes.

## *2. Formalisation of requirements*

The process of formalising the requirements for a simulation model of the emergency room is based on the need to ensure the accuracy, reproducibility and practical applicability of the simulation results. With the increasing pressure on the health care system and the high degree of uncertainty and complexity of the internal processes of emergency rooms, a clear definition of the characteristics of the future model is required. These characteristics should take into account both the specifics of the subject area and the objectives of the study.

In order to systematize the requirements, it is reasonable to identify several categories: functional, process, resource, analytical, scenario and interface. Each category reflects a certain aspect of design and subsequent application of the model. A summary table of requirements is presented in Table 2.

The formalized requirements for the simulation model reflect the main expectations and constraints of stakeholders, but they are mostly descriptive in nature. In order to make the problem statement more transparent and systematic, it is necessary to complement them with a conceptual model that will allow linking goals, drivers and constraints into a unified structure.

Table 2

**Summarized classification of requirements  
for the simulation model of the emergency room**

| Category<br>of requirements | Contents                                                                                                                                                                                                                                                                                                  |
|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Functional                  | <ul style="list-style-type: none"><li>- Reproduction of key processes (registration, triage, waiting, examination, consultation, hospitalization)</li><li>- Support for urgent and scheduled referrals</li><li>- Modelling of queues and competition for resources</li></ul>                              |
| Process                     | <ul style="list-style-type: none"><li>- Consideration of variability in the duration of medical procedures</li><li>- Reflection of patient routes in accordance with triage algorithms</li><li>- Ability to dynamically reallocate resources</li></ul>                                                    |
| Resource                    | <ul style="list-style-type: none"><li>- Taking into account the limitations of doctors, nurses, equipment and facilities</li><li>- Customization of the number of resources and their characteristics</li><li>- Account for staff schedules and constraints (shift patterns, night duty)</li></ul>        |
| Analytical                  | <ul style="list-style-type: none"><li>- Collection of statistics (average and maximum waiting time, staff utilization rate, number of patients leaving the department)</li><li>- Calculation of key KPIs for scenario comparison</li><li>- Ability to verify the model based on historical data</li></ul> |
| Scenario                    | <ul style="list-style-type: none"><li>- Support for “what-if” analyses (epidemics, flow growth, change in number of employees)</li><li>- Flexibility to customize flow and resource settings</li><li>- Scalability for different healthcare facilities</li></ul>                                          |
| Interface                   | <ul style="list-style-type: none"><li>- Integration with medical information systems (MIS, EGISZ)</li><li>- Visualisation of emergency room dynamics (queues, resource utilisation)</li><li>- Export of results to standard formats (Excel, PDF)</li></ul>                                                |

Source: developed by N.V. Trifonova, A.I. Levina.

In this study, such a role is assigned to motivational modelling based on an extension of the ArchiMate language according to the TOGAF methodology. Motivational modelling allows:

- Structure the interests and priorities of key actors (hospital administration, medical staff, patients, health authorities).
- Reflect the relationship between drivers, constraints and objectives.
- Formalise a framework for building simulation modelling scenarios.

Thus, the motivational model acts as a link between the identified requirements and the instrumental implementation of the simulation model in the AnyLogic environment. It ensures the logical integrity of the study and also makes it possible to consider the conflicting interests of various participants in the admission process.

*3. Economic efficiency*

The economic impact of congestion in the emergency room is expressed in terms of direct and indirect costs. Direct costs include increased staff time, increased costs

of medication and hospitalization, and the need for additional resources. Indirect costs are associated with deterioration in the quality of care, increased complications, repeated hospitalizations and decreased patient satisfaction.

For quantitative assessment, it is advisable to use the following indicators:

- Average cost of one hour of waiting time for a patient ( $C_w$ ) — calculated as the ratio of total costs of the institution for processing the flow to the number of patients, taking into account the time spent in the queue.
- Average resource cost ( $C_r$ ) — defined as the ratio of labour remuneration fund and operating costs to the number of working hours of personnel.
- Economic losses from patients leaving without care ( $C_l$ ) — estimated as the product of the number of patients leaving by the average cost per treatment.
- Economic effect of optimization ( $E_o$ ) — the difference between the costs in the baseline scenario and in the optimization scenario.

$$E_o = (C_{w_{base}} + C_{r_{base}} + C_{l_{base}}) - (C_{w_{opt}} + C_{r_{opt}} + C_{l_{opt}}). \quad (1)$$

The application of the simulation model allows testing various scenarios. For example, the introduction of an additional doctor's shift can reduce the average waiting time by 30%, which is equivalent to a saving of up to  $X$  thousand rubles per month. The introduction of a digital triage system reduces the number of patients leaving the reception department without being seen, which further reduces indirect losses.

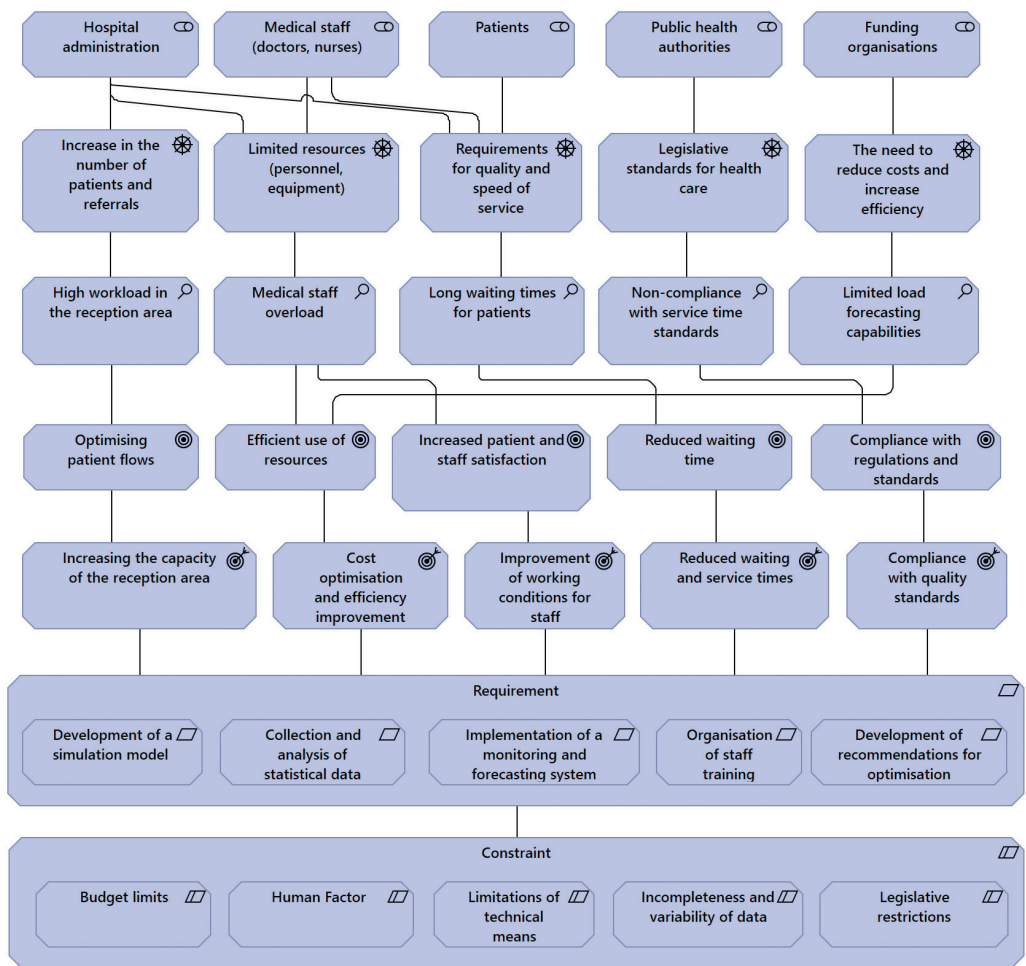
Thus, the economic evaluation confirms that optimization of organizational processes in the emergency room not only improves the quality of medical care but also provides a direct economic effect by reducing costs and increasing the efficiency of resource use.

#### 4. Building a motivational model

The application of simulation modelling in healthcare, especially in the analysis of the functioning of the emergency room, requires a systematic approach to problem formulation and requirements definition. As the process involves different stakeholders with often conflicting expectations, it is important not only to technically model the processes, but also to conceptualize the goals, constraints and motivations underlying the designed system.

To this end, the study adopts an approach based on a motivational extension of the ArchiMate architectural modelling language, consistent with the TOGAF methodology. This approach allows the formation of a structured view of the system's goals, constraints and requirements, taking into account the interests of key stakeholders. The motivational model becomes a link between the identified problems and the formation of requirements for the AnyLogic-based toolkit.

Thus, in order to comprehensively understand the problem and develop an effective solution, a motivational model (Figure 2) was constructed within the framework of this study, depicting the key needs and goals of reception center administration. This model allows us to systematise the requirements and identify areas of process optimization.



**Figure 2.** Systematization of requirements to the patient flow management system in the emergency room of a medical organization  
*Source:* developed by N.V. Trifonova, A.I. Levina.

Stakeholders include hospital administration, medical staff, patients, public health authorities and funding organisations (Chupin, Ragas, Chupina, 2024; Ilin et al., 2024; Levina, Ilin, et al., 2024; Levina, Rylova, Odainic, 2024; Levina, Trifonova, et al., 2024; Volgina, 2022). For each stakeholder, drivers, constraints and goals were identified, which formed the basis of the presented motivational model.

The factors requiring the attention of the hospital administration were identified as increasing numbers of patients and referrals, resource constraints, and demands for quality and speed of care. Medical staff and patients, respectively, also consider the latter two drivers worthy of attention. All these factors initiate high waiting room congestion, overburdened medical staff and long waiting times for patients. Public health authorities and funding organizations are interested in compliance with legislative standards, the need to reduce costs and improve the efficiency of health care organizations.

Optimizing patient flows, efficient use of resources, increasing patient and staff satisfaction, reducing waiting times and meeting regulations and standards are the goals of each stakeholder. If each objective is successfully achieved, the following

results are expected: increased waiting room capacity, cost optimization and efficiency gains, improved working conditions for staff, reduced waiting times and service, and compliance with quality standards.

The development of a simulation model makes it possible to reproduce and analyze the behavior of the emergency room under different workloads, identify bottlenecks in the patient care process and test organizational solutions without risking real work. This makes it possible to reasonably reallocate resources, adjust staff schedules, change the order of admission and routing, which ultimately leads to shorter waiting and service times, higher throughput and more efficient use of available resources, reducing costs.

## Discussion

The conducted study demonstrates the effectiveness of a methodological approach that combines discrete-event simulation modeling with enterprise architecture tools for analyzing and optimizing the operations of an emergency room. The obtained results confirm that the formalization of requirements through a motivational model is a critical step that ensures the relevance and practical applicability of the simulation model. This allows not only for the replication of technical processes but also for accounting for the often-conflicting interests of all stakeholders — from medical staff and patients to administration and regulatory bodies.

The economic efficiency of the proposed approach, identified in the study and expressed in the reduction of direct and indirect costs, has significance that extends beyond a single medical institution. In the context of shaping new vectors of trade and investment within BRICS+, the presented results reveal significant prospects. The developed methodological complex and toolset can be considered as a replicable product — a “high-tech medical service” in the field of management consulting and digital transformation.

Within the framework of deepening cooperation among BRICS+ countries, several potential directions can be identified:

Trade in software solutions and services. The simulation models and software complexes developed based on the proposed methodology (e.g., on the AnyLogic platform) can become an export product to partner countries interested in improving the efficiency of their healthcare systems without significant capital investment in physical infrastructure.

Investment in digital healthcare infrastructure. BRICS+ countries can initiate joint investment projects aimed at creating and implementing standardized platforms for managing hospital patient flows. The universality of the proposed approach, ensured by its architectural flexibility and scenario analysis, makes it an ideal candidate for cross-national adaptation.

Reduction of operational risks for investors. The use of simulation modeling to justify management decisions and forecast economic effects helps minimize risks in the implementation of large-scale infrastructure projects in the healthcare sector

within BRICS territories. An investor receives not just a concept, but a quantitatively justified optimization plan, which increases the attractiveness of such projects.

Development of human capital. The methodology presented in the study can form the basis for joint educational programs and the exchange of best practices in the field of management engineering in healthcare, contributing to the strengthening of professional ties between member countries.

Thus, the discussion of the results of this study allows it to be considered not only as a contribution to the theory and practice of managing medical organizations but also as an element in forming a new, knowledge-intensive, and digital agenda for cooperation within BRICS+. Optimizing the work of such critical nodes as emergency rooms directly impacts the economic sustainability of national healthcare systems, which, in turn, creates a favorable climate for foreign investment and technological partnership. Further research should be directed toward adapting the proposed approach to the specifics of the regulatory frameworks and epidemiological profiles of different BRICS+ countries.

## Conclusion

The economic evaluation confirmed that the functioning of the emergency room is directly related not only to the medical but also to the financial performance of the hospital. Excessive workload leads to significant costs, which can be classified as direct and indirect. Direct costs include increased labour costs due to forced overwork of staff, increased consumption of medicines and diagnostic materials, as well as increased cost per patient visit due to lengthened time spent in the department. Indirect costs are expressed in the deterioration of the quality of medical care, reduced patient satisfaction, increased re-hospitalizations and, as a consequence, in additional costs of the health care system for the treatment of complications.

The use of a simulation model allows us to move from a qualitative description of these consequences to a quantitative assessment. The calculation of indicators such as the average cost per patient hour ( $C_w$ ), the average cost of a resource ( $C_r$ ) and the economic loss from patients leaving without care ( $CI$ ) makes it possible to express the burden on the system in monetary terms. This makes the relationship between current costs and potential savings in changing organizational scenarios visible.

The results show that even small organizational adjustments aimed at reducing waiting times or reallocating resources can lead to tangible financial benefits. For example, reducing waiting times by 20–30% can free up resources, increase the number of cases processed and at the same time reduce labor costs through more efficient use of working time. Similarly, reducing the number of patients who leave the emergency room without being seen reduces the facility's losses and increases its financial sustainability.

Thus, simulation modelling acts not only as a tool for analyzing operational processes, but also as a means of economic justification of management decisions. It allows us to justify the need to invest in organizational changes, demonstrate their payback and forecast the long-term economic effect. This makes the developed approach

particularly valuable for managers of medical organizations and health authorities interested in improving the efficiency and sustainability of the emergency room system.

The methodologies and tools proposed in the study can serve as a basis for joint BRICS+ projects in the field of healthcare digitalization, contributing to the development of new trade and investment vectors in the high-tech healthcare services and management solutions sector.

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