

SELECTIVE MANAGEMENT OF INFRASTRUCTURE SYSTEMS BASED ON RISK MONITORING AND SCENARIO MODELING

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Summary. Infrastructure systems operate in increasingly unstable environments characterized by technological, economic, operational, and security-related risks. This study develops a selective management mechanism for infrastructure systems aimed at concentrating managerial attention and resources on critical elements while maintaining their overall sustainability. The research adopts a system-oriented conceptual approach and draws on scientific literature, regulatory materials, practical cases, and established risk-management practices. System analysis, SWOT analysis, Failure Mode and Effects Analysis (FMEA), and scenario modeling are incorporated into the proposed framework. The study distinguishes selective management from general infrastructure management and identifies the principal conditions and organizational mechanisms required for its implementation. The proposed mechanism comprises continuous risk monitoring, identification and ranking of critical infrastructure elements, risk identification and assessment, development of targeted management measures, decision-support information systems, and coordination and personnel training. Particular attention is given to automation, modularity and scalability, security, fault tolerance, continuous monitoring, and standardization as principles supporting selective infrastructure management. The framework also integrates adaptive management, resource redistribution, redundancy, recovery mechanisms, and scenario-based decision support. The proposed approach provides a structured basis for prioritizing vulnerable infrastructure components and allocating management resources according to their significance, condition, criticality, and exposure to risk. It can support more focused and adaptive infrastructure management under conditions of uncertainty.

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1. Introduction

Infrastructure constitutes a fundamental component of modern economic systems, supporting economic activity and the provision of essential services to society. Increasing environmental instability, technological change, and exposure to multiple risks have strengthened the need for management approaches capable of

maintaining the reliability and sustainability of infrastructure systems. Recent research emphasizes that infrastructure resilience requires the capacity to withstand disruptions, adapt to changing conditions, and restore essential functions following adverse events (Curt & Tacnet, 2018; Guo et al., 2021).

The concept of infrastructure has been interpreted from different theoretical perspectives. Bell (2004) and Schumpeter (2007) associated infrastructure with the conditions supporting economic activity and societal development, while Mallaev and Avramchikova (2017) emphasized its institutional dimension and its role in creating organizational and economic conditions for market functioning. Previous studies have also addressed specific aspects of infrastructure-related risk management, including energy-service systems (Guskova & Ul'yankin, 2016), entrepreneurial risks within economic security systems (Barikaev, 2018), and IT infrastructure risks (Maslova, 2022). These studies demonstrate the importance of risk-oriented management but primarily address particular sectors or categories of risk.

Under conditions of uncertainty, managing individual infrastructure components in isolation may be insufficient because failures or imbalances in one element can affect the functioning of interconnected components. Risk-oriented and adaptive approaches are therefore increasingly important for maintaining system sustainability under changing operating conditions (Gridneva & Vasilevsky, 2025).

Accordingly, this study aims to develop a mechanism for selective management of infrastructure systems under risk conditions. The proposed approach integrates risk monitoring, prioritization of infrastructure elements, targeted managerial interventions, and scenario-based decision support to improve the adaptability and sustainability of infrastructure systems.

2. Materials and methods

The study adopts a system-oriented conceptual approach to the management of infrastructure systems under risk conditions. The analysis draws on scientific publications, regulatory and legal documents, research reports, practical cases, and other materials describing infrastructure management and risk-management practices.

The methodological framework combines system analysis with induction and deduction, analysis and synthesis, SWOT analysis, Failure Mode and Effects Analysis (FMEA), and scenario modeling. System analysis was used to examine infrastructure as an interconnected set of components, while SWOT analysis and FMEA provide tools for identifying vulnerabilities, assessing critical elements, and prioritizing risks. Scenario modeling was incorporated to support the evaluation of alternative management responses under changing conditions (Nevskaya et al., 2024).

Based on this framework, existing infrastructure-management practices were synthesized to develop a selective management mechanism comprising risk monitoring, prioritization of infrastructure elements, risk assessment, targeted management measures, and decision-support procedures.

3. Results and discussion

Infrastructure systems comprise interconnected technical, organizational, and managerial components whose reliable operation is essential for the functioning of the broader economic system. Their management therefore requires a combination of general and selective approaches. General management covers the system as a whole through common planning, organization, coordination, and control procedures, whereas selective management introduces targeted interventions for individual elements or groups of elements that require additional managerial attention.

In this study, selective management is understood as a complementary mechanism rather than a replacement for general infrastructure management. Its purpose is to identify problematic or vulnerable elements and concentrate managerial actions and resources on preventing failures, mitigating negative consequences, and supporting critical activities. Selective interventions can be incorporated at different stages of the management cycle, including goal setting, planning, organization, implementation, coordination, and control.

The proposed approach is particularly relevant under risk conditions because infrastructure components differ in their criticality, vulnerability, technical condition, and contribution to overall system performance. Selective management therefore allows management resources to be directed toward those elements where intervention is expected to have the greatest importance for system stability.

The expected benefits of selective management include reduced potential losses and operating costs, improved resource efficiency and management quality, and a better balance among the interests of infrastructure-system participants.

The proposed framework is based on six interrelated principles: automation, modularity and scalability, security and risk prevention, availability and fault tolerance, continuous monitoring and analysis, and documentation and standardization. Automation can reduce manual intervention and operational errors, while modularity supports adaptation to changing system requirements. Security and fault tolerance protect critical components and maintain service continuity, whereas continuous monitoring enables the early identification of anomalies and emerging risks. Documentation and standardization provide transparency and facilitate the integration and management of infrastructure components. These principles should be periodically reviewed as technological conditions, risks, and organizational requirements evolve. The principal types of selective infrastructure management are summarized in Figure 1.

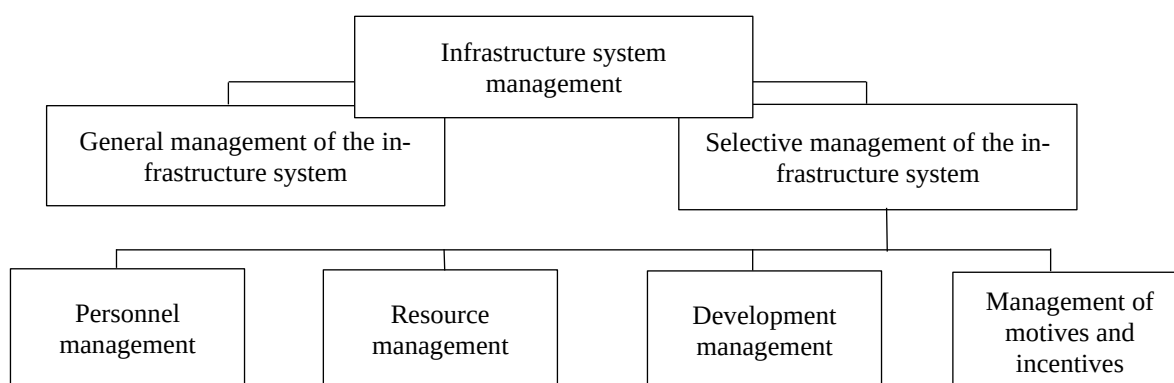


Fig. 1. Types of selective management of the infrastructure (compiled by the author)

Selective infrastructure management can be implemented through four main areas: personnel management, resource management, development management, and management of motives and incentives. Personnel management may employ role-, attribute-, behavior-, and rule-based approaches to regulate responsibilities, permissions, and access to infrastructure resources. Resource management focuses on targeted interventions that improve resource utilization and reduce the likelihood of operational problems, while development management directs goals, resources, and projects toward long-term system sustainability. Management of motives and incentives aims to align the interests of personnel and service users with infrastructure-management objectives. The appropriate combination of these approaches depends on organizational characteristics, security requirements, and the scale and complexity of the infrastructure system.

To implement selective management, it is advisable to have an appropriate mechanism in the management system of the infrastructure system.

The mechanism of selective management of the infrastructure system under risks is a comprehensive approach aimed at selectively influencing key elements of the infrastructure to minimize risks and increase the sustainability of its functioning.

The selective management mechanism uses a sample, selective approach to concentrate management actions and resources on the most critical infrastructure elements in order to minimize the negative consequences of risk impact.

It includes the following components.

1. Functional organization (or units) for the implementation of continuous monitoring of the state of the infrastructure system and risks (risk monitoring, timely response to threats, assessment of the effectiveness of risk identification, etc.). Risk management methods (SWOT analysis, FMEA, scenario modeling) can be used as tools.

2. Studying the condition and ranking of infrastructure elements. The main function is to determine the priority of infrastructure components and their condition (e.g., power supply systems, traffic centers, IT platforms) according to the criteria of significance (socio-economic, technical, etc.), condition and criticality for the functioning of the infrastructure, vulnerability to risks.

3. Implementation of systematization and determination of risks (identification, recognition and classification of risks).

4. Conducting risk analysis and assessment (determining possible damage from risk occurrence, clarifying the probability of risk occurrence).

5. Development of measures for selective risk management (definition of objects and elements subject to selective impact, development and planning of measures, programs, projects for selective impact, appointment of a responsible officer, determination of the results of selective impact).

6. Information system for decision support. This system should ensure the integration of current data from different sources (e.g., geographic information systems, Big Data, etc.) for scenario modeling and optimization of management decisions.

7. Interaction and personnel training. They are used for the purposes of personnel training to act in crisis situations, as well as for the coordination between departments (for example, the Ministry of Emergency Management, energy, logistics).

The following methods and tools can be used in the mechanism of selective management of the infrastructure system under risk conditions:

- adaptive management strategies; flexible plans of action for key elements in the form of redundancy (duplication of critical nodes), dynamic redistribution of resources (e.g., energy, personnel) in case of threats; localization of impact (isolation of damaged segments to prevent cascading failures), etc.

- implementation of a monitoring and feedback system that ensures continuous monitoring of the infrastructure state using sensors, IoT devices, analytical platforms, etc., which allow to forecast wearing of equipment and track anomalies in real time;

- mechanisms for redundancy and restoration to create “buffer zones” (in the form of reserve capacities, backup communications);

- plans for the fallback recovery, etc.

Selective management of the infrastructure system under risk conditions allows concentrating resources, focusing actions on key critical elements of the infrastructure, ensuring a sufficient level of stability of its functioning even in conditions of uncertainty. This approach should combine proactivity (risk prevention) and reactivity (quick response), which allows for an efficient and comprehensive solution to the problem of effective management of the infrastructure system.

Selective management of the infrastructure system under risk conditions is an innovative approach aimed at increasing the sustainability and efficiency of the key elements functioning. The main focus is on selective effect on the most vulnerable components, such as traffic centers, power supply systems and IT platforms, which allows minimizing risks and reducing costs. The use of SWOT analysis, FMEA and scenario modeling techniques ensures accuracy in assessing threats and developing adaptive strategies.

An important aspect is the implementation of special devices and analytical platforms for continuous monitoring of the infrastructure condition. This allows for prompt detection of anomalies and prevention of cascading failures. The principles of modularity, scalability and security ensure the flexibility of the system in a changing external environment.

Selective management also involves the creation of “buffer zones” and reserve capacities, which increases fault-tolerance. However, successful implementation of the approach requires regular updating of the methodology and adaptation to new challenges. Thus, the proposed mechanism contributes not only to reducing risks, but also to increasing the competitiveness of infrastructure systems.

4. Conclusion

This study proposes a selective management mechanism for infrastructure systems operating under risk and uncertainty. Unlike general management, selective management focuses managerial attention and resources on infrastructure elements according to their criticality, vulnerability, and current condition. The proposed mechanism integrates continuous risk monitoring, prioritization of infrastructure elements, risk identification and assessment, targeted management measures, decision-support tools, and personnel coordination and training.

The framework combines proactive risk prevention with responsive measures and incorporates adaptive management, monitoring and feedback systems, redundancy, and recovery mechanisms. Its application can support more focused allocation of management resources and strengthen the ability of infrastructure systems to respond to disruptions and changing operating conditions. The proposed mechanism provides a conceptual basis for further development and practical testing of selective infrastructure management approaches in different infrastructure contexts.

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ДИФФЕРЕНЦИРОВАННОЕ УПРАВЛЕНИЕ ИНФРАСТРУКТУРНЫМИ СИСТЕМАМИ НА ОСНОВЕ МОНИТОРИНГА РИСКОВ И СЦЕНАРНОГО МОДЕЛИРОВАНИЯ

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Резюме. Инфраструктурные системы функционируют во всё более нестабильной среде, характеризующейся технологическими, экономическими, операционными рисками и рисками, связанными с безопасностью. В исследовании разрабатывается механизм селективного управления инфраструктурными системами, направленный на концентрацию управленческого внимания и ресурсов на критически важных элементах при сохранении общей устойчивости систем. Исследование основывается на системно-ориентированном концептуальном подходе с использованием научной литературы, нормативных материалов, практических примеров и сложившихся методов управления рисками. В предлагаемую концептуальную модель включены системный анализ, SWOT-анализ, анализ видов и последствий отказов (FMEA), а также сценарное моделирование. В исследовании проводится разграничение селективного и общего управления инфраструктурой, определяются основные условия и организационные механизмы, необходимые для его реализации. Предлагаемый механизм включает непрерывный мониторинг рисков, выявление и ранжирование критически важных элементов инфраструктуры, идентификацию и оценку рисков, разработку целевых управленческих мероприятий, информационные системы поддержки принятия решений, а также координацию и подготовку персонала. Особое внимание уделяется автоматизации, модульности и масштабируемости, безопасности, отказоустойчивости, непрерывному мониторингу и стандартизации как принципам, обеспечивающим селективное управление инфраструктурой. Предлагаемая модель также объединяет адаптивное управление, перераспределение ресурсов, резервирование, механизмы восстановления и поддержку принятия решений на основе сценариев. Предложенный подход формирует структурированную основу для определения приоритетности уязвимых компонентов инфраструктуры и распределения управленческих ресурсов в соответствии с их значимостью, состоянием, критичностью и подверженностью рискам. Данный подход может способствовать более целенаправленному и адаптивному управлению инфраструктурой в условиях неопределённости.

Ключевые слова: инфраструктурные системы, селективное управление, мониторинг рисков, сценарное моделирование, оценка рисков, поддержка принятия решений

RİSKLƏRİN MONİTORİNGİ VƏ SSENARİ MODELLEŞDİRİLMƏSİ ƏSASINDA İNFRASİSTEMLƏRİNİN SELEKTİV İDARƏ EDİLMƏSİ

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Xülasə. İnfrastruktur sistemləri texnoloji, iqtisadi, əməliyyat və təhlükəsizliklə bağlı risklərlə səciyyələnən, getdikcə daha qeyri-sabit mühitdə fəaliyyət göstərir. Tədqiqatda infrastruktur sistemlərinin ümumi dayanıqlığını qorumaqla yanaşı, idarəetmə diqqətinin və resurslarının kritik elementlər üzərində cəmləşdirilməsinə yönəlmiş selektiv idarəetmə mexanizmi işlənib hazırlanmışdır. Tədqiqat sistem yönümlü konseptual yanaşmaya əsaslanır və elmi ədəbiyyata, normativ materiallara, praktiki nümunələrə və formalaşmış risklərin idarə edilməsi təcrübələrinə istinad edir. Təklif olunan çərçivəyə sistem təhlili, SWOT təhlili, nasazlıq növlərinin və təsirlərinin təhlili (FMEA), həmçinin ssenari modelləşdirilməsi daxil edilmişdir. Tədqiqatda selektiv idarəetmə infrastrukturun ümumi idarə edilməsindən fərqləndirilmiş, onun həyata keçirilməsi üçün tələb olunan əsas şərtlər və təşkilati mexanizmlər müəyyən edilmişdir. Təklif olunan mexanizm risklərin davamlı monitorinqini, kritik infrastruktur elementlərinin müəyyənləşdirilməsini və rəqləşdirilməsini, risklərin müəyyən edilməsi və qiymətləndirilməsini, məqsədyönlü idarəetmə tədbirlərinin hazırlanmasını, qərarların qəbuluna dəstək verən informasiya sistemlərini, eləcə də koordinasiya və kadr hazırlığını əhatə edir. Selektiv infrastruktur idarəetməsini dəstəkləyən prinsiplər kimi avtomatlaşdırmaya, modulluğa və miqyaslı bilməyə, təhlükəsizliyə, nasazlıqlara davamlılığa, fasiləsiz monitorinqə və standartlaşdırmaya xüsusi diqqət yetirilmişdir. Təklif olunan çərçivə adaptiv idarəetməni, resursların yenidən bölüşdürülməsini, ehtiyatlılığı təmin edən mexanizmləri, bərpa mexanizmlərini və ssenarilər əsasında qərarların qəbuluna dəstəyi də özündə birləşdirir. Təklif olunan yanaşma həssas infrastruktur komponentlərinin prioritetləşdirilməsi və idarəetmə resurslarının onların əhəmiyyətinə, vəziyyətinə, kritikliyinə və risklərə məruz qalma səviyyəsinə uyğun bölüşdürülməsi üçün strukturlaşdırılmış əsas yara-dır. Bu yanaşma qeyri-müəyyənlik şəraitində infrastrukturun daha məqsədyönlü və adaptiv idarə edilməsini dəstəkləyə bilər.

Açar sözlər: infrastruktur sistemləri, selektiv idarəetmə, risklərin monitorinqi, ssenari modelləşdirilməsi, risklərin qiymətləndirilməsi, qərar qəbuluna dəstək