Management Theory and Studies for Rural Business and Infrastructure Development
eISSN 2345-0355. 2025. Vol. 47. No. 4: 537-548
Article DOI: https://doi.org/10.15544/mts.2025.42

SAFETY-ORIENTED MANAGEMENT OF PROTECTION PROJECTS OF CRITICAL INFRASTRUCTURE OBJECTS

Dmytro Kobylkin[1], Andrii Havrys[2], Andrii Rogulia[3], Ruslana Sodoma[4], Ihor Pavuk[5], Khrystyna Avdieyeva[6], Viktoriia Filippova[7]

[1] *Assoc. Prof., Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: dmytrokobylkin@gmail.com*

[2] *Assoc. Prof., Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: havrys.and@gmail.com*

[3] *Assoc. Prof., Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: jetandy@ukr.net*

[4] *Assoc. Prof., Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: sodomaruslana@gmail.com*

[5] *PhD student, Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: Pavuk82@ukr.net*

[6] *PhD student, State Emergency Service of Ukraine in Lviv region, St. Pidvalna 6, Lviv, Ukraine, E-mail address: kristina_avdeeva@ukr.net*

[7] *PhD student, Lviv State University of Life Safety, Kleparivska 35, Lviv, Ukraine, E-mail address: filippova99@ukr.net*

Received 09 03 2025; Accepted 13 05 2025

Abstract

The article discusses approaches to ensuring the state of protection of infrastructure projects, programs and portfolios of projects, in particular critical infrastructure objects, under the conditions of risks and exposure to hazards. The study is based on the analysis of potentially dangerous objects of critical infrastructure (hydraulic structures) in the western region of Ukraine. Their mapping, simulation and modelling of the consequences of possible accidents were carried out using the ArcGIS software environment. The modelling results made it possible to determine the regions with the highest level of flooding risk as a result of accidents at hydrotechnical structures and to assess the potential impact of these emergency situations on other critical infrastructure objects, population and territories. A model of a protective mechanism has been developed to ensure the safety of infrastructure projects, programs, and portfolios. The model accounts for the adaptation of standardized protection project templates to external and internal environmental factors, deviations, and risks. A model of a safety-oriented environment for the functioning of the protective mechanism of infrastructure projects has been formed. It identifies the levels of project protection due to their individual characteristics and network connections. The need for a comprehensive approach to risk management and monitoring of the safety status of infrastructure projects at different phases of the life cycle is summarized and further directions of research are formed.

Keywords: *Civil Protection, Critical Infrastructure, Flood Modelling, Infrastructure Project, Project Management, Safety-Oriented Management.*

JEL Codes: *H54; O22; R15.*

Introduction

Today, in Ukraine and around the world, the management of projects, programs and project portfolios is an integral part of the functioning mechanism of the state and regions. However, in the conditions of constant growth of threats, risks, turbulent project environment, military operations, such mechanisms cannot always adequately respond and adapt to new threats that directly or indirectly affect the state of safety of life activities of the population and territories and are provided with the appropriate infrastructure. The infrastructure of the state is, first of all, objects of critical life support: energy, transport, information technologies and telecommunications, water supply, etc.

The theoretical component of the research lies in the definition of key vectors in the direction of the development of the processes of managing projects, programs and portfolios of infrastructure projects: integration of new technologies, adaptive management, development of competences, maintenance of stability of infrastructure objects and safety-oriented risk management. The integration of new technologies includes the application of risk prediction algorithms to optimize the resource pool, which in turn will significantly increase the efficiency of the management process, and simulation modelling of processes and researched objects (Sodoma, 2021, Sodoma, 2023). The development of competencies of project managers, in the conditions of the global impact of the turbulent environment and risks on infrastructure projects, includes constant training and self-improvement, as well as the exchange of experience for the implementation of the best international approaches (Pakeltienė et al., 2024); (Miceikienė et al., 2024). Maintaining the stability of infrastructure objects by increasing protection and creating backup systems for uninterrupted operation by applying safety-oriented risk management, in particular processes of forecasting and analysis of event development scenarios (Ustymenko, 2021).

On the basis of the above key vectors of the development of research project management processes, domestic and foreign researchers can also be grouped by thematic blocks. They relate to both the general theory of project and program management and flexible Agile practices. In particular, the concept of “clip” thinking in the framework of flexible project management in AI-driven environments was investigated (Bushuyeva, 2024); defined complex project management frameworks in various fields that meet the international standard (PMBOK® Guide, 2021); transformational processes of managing the configuration of a multi-project environment using modelling tools (Dotsenko, 2023). The second block is the management of the environment and natural disasters: in particular, the use of computer modelling to analyze and identify dangerous zones during floods and strategies for creating a safe environment in territorial communities (Havrys, 2024a, Havrys, 2024b); formation of the state emergency risk management mechanism in Ukraine and assessment of its features (Fedorchak, 2018); modern challenges and threats that arise during the implementation of civil defense tasks (Kuleshov, 2022) and the functioning of united territorial communities under martial law (Zahidna, 2022). The third block is the planning and management of infrastructure projects: the formulation of reliable target costs for the implementation of transport infrastructure projects (Walker, 2024); collective learning processes in project-oriented organizations involved in infrastructure planning (de Groot, 2024); performance of public infrastructure projects outsourced and external contractors using a grounded theory approach (Awuzie, 2024); modelling of tactical risk management processes in infrastructure projects and portfolios (Kobylkin, 2023); presentation of a visual model of managing the evacuation of people from sports infrastructure objects (Ivanusa, 2023); error control in transport megaprojects (Love, 2024); development of a simulation model of safety management in projects with a mass gathering of people (Zachko, 2017). The fourth block is critical infrastructure protection and safety projects. To date, the process of development and application of a reconfigurable digital twin for the protection of critical infrastructure objects has been investigated (Mathur, 2023); a conceptual model of face recognition systems for the secure identification of personnel at critical infrastructure objects was formed (Bushuyev 2024); complex machine learning algorithms designed to detect dangerous objects online at critical infrastructure objects (Azarov, 2023); described the application of federated learning models in decentralized critical infrastructure objects (Siniosoglou, 2023) and the features of ensuring safety, efficiency and stability in nuclear infrastructure objects (Piliuhina, 2024).

However, a thorough analysis of literary sources and key areas of development of project management processes, programs and project portfolios indicated the incompleteness of existing research in the direction of the application of safety-oriented approaches, crisis risk management, the use of adaptive

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monotemplates for effective management of infrastructure projects, their protection in the face of threats, risks and hazards during all phases of the life cycle.

This state of affairs requires the adaptation of existing and the implementation of new approaches to the management of projects, programs and project portfolios, which include, in particular, adaptive methods and innovative tools for effective response to changes and risks to the infrastructure and make it possible to optimize project management processes, in particular, to increase the ability to respond more quickly to threats and risks and adapt to them.

Materials and methods

Protection of infrastructure projects, programs and project portfolios, in particular critical infrastructure objects, in conditions of risk and danger is a complex organizational and technical task. For this you need: conduct an analysis of potentially dangerous objects of critical infrastructure; perform software processing of data on critical infrastructure objects and map them; conduct computer modelling of the consequences of possible accidents or dangerous events at critical infrastructure objects, in particular hydraulic structures; carry out the distribution of regions according to the level of potential damage to infrastructure objects; to develop a model for the formation of a protective mechanism for infrastructure projects, programs and project portfolios; to formalize the model of the safety-oriented environment of the functioning of the protective mechanism of infrastructure projects, programs and portfolios of projects.

Critical infrastructure objects include a number of potentially dangerous objects (energy, transport, banks and finance, chemical industry, information technologies and telecommunications, health care, food, utilities, etc.). Power engineering objects are one of the largest among all, both in terms of size and potential consequences of impact on the population and territories. Therefore, the objects of hydrotechnical structures of the Western region of Ukraine were chosen for the study, due to their significant localization within the region.

For this, statistical methods and methods of expert evaluations are used, the probable impact of possible consequences of exposure to risks (technical, financial, time, etc.) on the implementation of infrastructure projects, programs and project portfolios is determined, risks are ranked by priority due to the probability of occurrence, critical risks are determined, which require the creation and application of approaches for their minimization, constant reassessment of risks and monitoring of their condition.

Results and discussions

The threat to the safe functioning of state infrastructure objects, in particular critical ones, in conditions of constant risks, creates turbulent conditions and significant risks for the implementation of various stages of the life cycles of projects, programs and project portfolios at the object, local, regional and state levels. So, for example, only as of January 1, 2024, in Ukraine, as a result of military operations, damage to the state's infrastructure in the amount of more than 156 billion US dollars was caused (Ukrinform, 2024) (table 1).

Table 1. Total assessment of infrastructure damage by industry in monetary terms, as of January 1, 2024

Property type	Estimated direct losses, billions of US dollars	Percentage, %
Residential infrastructure	58.9	37.63
Infrastructure (complex)	36.8	23.51
Infrastructure of enterprises, industry	13.1	8.37
Energy infrastructure	9	5.75
Agricultural industry and land resources	8.7	5.56
Educational infrastructure	8.6	5.49
Housing and communal services	4.5	2.87
Forest fund	4.5	2.87
Vehicles	3.1	1.98
Health care	3.1	1.98
Trade	2.6	1.66
Culture, tourism, sports	2.4	1.53
Administrative buildings	0.5	0.32
Digital infrastructure	0.5	0.32
Social sphere	0.2	0.13
Financial sphere	0.04	0.03
Together	156.54	100.00
Ecology*	16.4	

**Environmental damage is calculated as damage from air emissions and is not a direct loss of Ukraine's infrastructure.*
***Source: calculated by the authors.*

Mapping and visualization of the location placement of identified objects is carried out in the ArcGIS software environment, by creating GIS layers from base maps, conducting spatial analysis to determine the zones of influence of objects, assessing relationships. The results of the mapping of critical infrastructure objects on the example of hydrotechnical structures of the Western region of Ukraine are shown in figure 1.

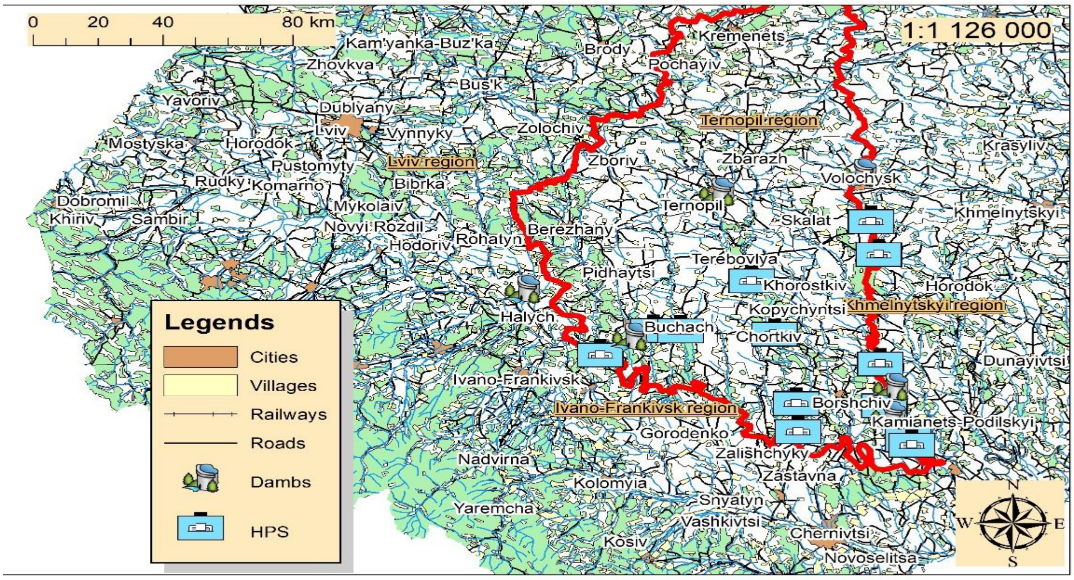

Figure 1. Mapping of critical infrastructure objects (using the example of hydrotechnical structures) of Ternopil region

**Source: suggested by the authors.*

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According to the results of computer mapping, the region - Ternopil Oblast - has been determined as the region with the largest number of hydraulic structures that have a direct or indirect impact on the state of life safety in the region.

Mapping of the region with the location of critical infrastructure objects (hydraulic objects) made it possible to identify and visualize their zonal location. Further research into the consequences of the potential negative impact of dangerous factors, threats and risks on the state of safety, integrity and functioning of infrastructure objects makes it possible to determine the potential threat to the population and territories. For this, a script written by the authors in the Python programming language in the ArcGIS software environment was used.

The block diagram of the script for creating catchment basins of the studied territory in the ArcGIS software complex in Python is shown in figure 2.

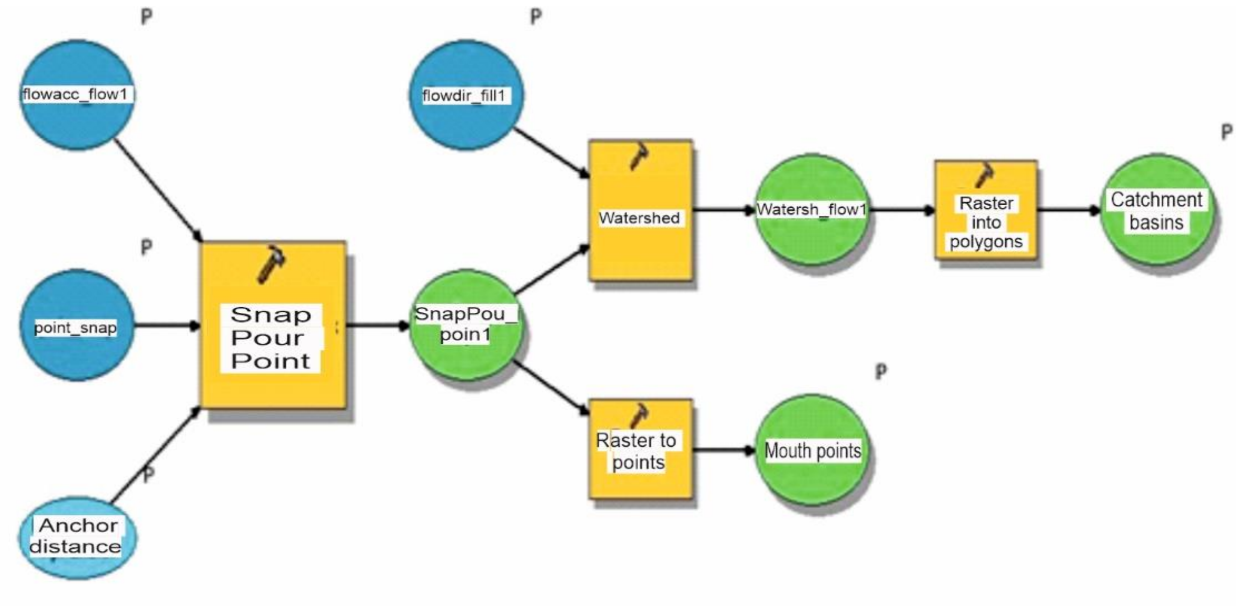

Figure 2. Block diagram of the script for creating catchment basins of the studied territory in the ArcGIS software complex in Python

**Source: suggested by the authors (Leendertse, 2024).*

In the process of programming and computer modelling, data on relief and height difference are taken into account, the direction of water flow and accumulation is calculated, the points of water catchment sources and the creation of water catchment basins are determined.

Taking into account the received data, computer modelling of the consequences of possible accidents or dangerous events on critical infrastructure objects (hydrotechnical structures) was carried out, flood zones of territories were determined, simulation results were visualized, which allows to evaluate the impact of the consequences on other infrastructure objects, the population and the territory , if necessary, to form logistical and safety routes for the evacuation of the population and to ensure prompt response to an emergency event.

The results of modelling the consequences of accidents on critical infrastructure objects (hydraulic structures) of the Ternopil region using ArcGIS are shown in Figure 3.

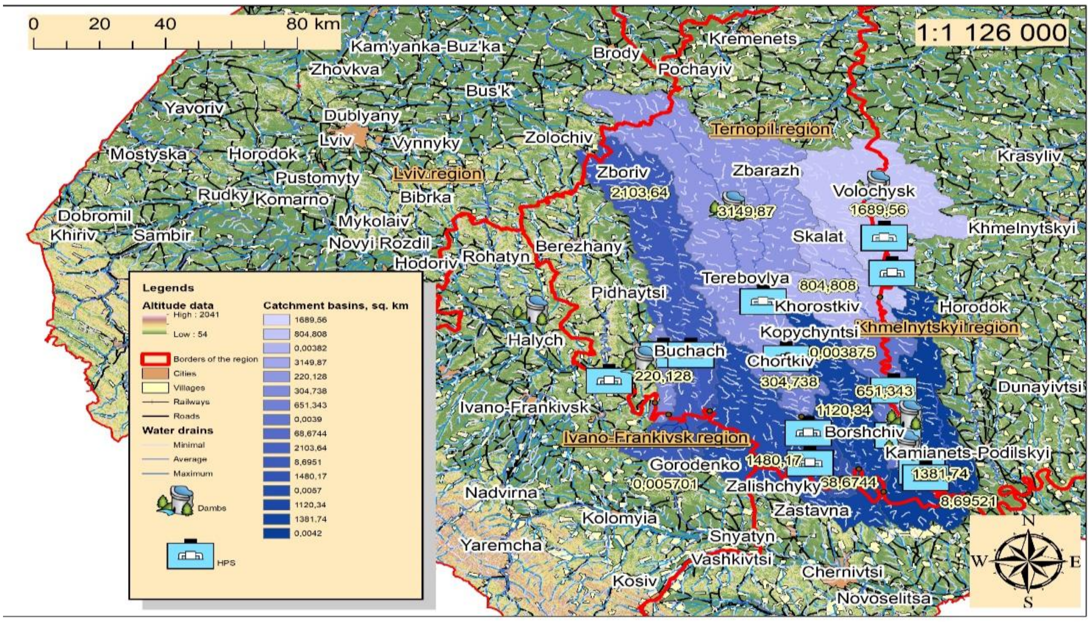

Figure 3. Results of modelling the consequences of accidents at critical infrastructure objects (hydraulic structures) of the Ternopil region using ArcGIS

**Source: suggested by the authors.*

According to the simulation results, potential territories that are negatively affected by the consequences of violating the integrity or functional purpose of critical infrastructure objects are visualized.

As a result, the impact of negative factors will affect 5 different regions, in particular cities, towns and objects of critical infrastructure, including transport and logistics routes (of both national and European importance (highways and railways)), power plants (in addition to hydrostations and hydraulic structures – wind, biogas, solar), schools, hospitals, a significant number of dangerous objects and, most importantly, the local population.

Processing of the affected areas made it possible to carry out a regional distribution of data (see Table 2) and to group quantitative data by types of critical infrastructure objects, which will serve as a database for further planning of their protection projects at the local, regional and state levels: where TPPs are thermal power plants, CHP – thermal power plants, NPP – nuclear power plants, HPP – hydroelectric power plants, SPP – solar power plants.

Table 2. Distribution of regions according to the level of potential damage to infrastructure objects

	Ternopil Oblast	***Lviv Oblast***	***Ivano-Frankivsk Oblast***	***Chernivtsi Oblast***	***Khmelnytsky Oblast***
Objects	**Quantity**				
Population centers:	**1057**	**277**	**190**	**220**	**336**
Cities	18	3	3	6	2
Villages	17	4	5	5	6
Sela	1022	270	182	209	328
Number of population	1 039 750	163 300	278 200	648 600	312 400
Motorways:	**597**	**151**	**105**	**155**	**197**
Of state importance:	**29**	**5**	**6**	**20**	**12**
European	2 (E50, E85)	1(E40)	0	1(E85)	0

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International	3 (M09, M19, M30)	2(M09, M06)	0	1(M19)	0
National	2 (H02, H18)	1(H02)	1(H10)	2(H03, H10)	1(H03)
Regional	4(P26, P39, P41, P43)	1(P39)	2(P20, P24)	1(P62)	2(P24, P48)
Territorial	18	2	3(T0904, T0905, T0909)	15	9
Of local importance:	**568**	**146**	**99**	**135**	**185**
Regional	16	6	9	15	87
District	552	140	90	120	98
Railway	**41**	**8**	**10**	**20**	**6**
Power plants:	**39**	**2**	**15**	**10**	**35**
TPP and CHP	0	0	0	0	0
NPP	0	0	0	0	0
HPP	14 (just 3 large)	0	1	0	15
Windy	3	0	0	0	0
Biogas	2	0	0	0	1
SES	20	2	14	10	29
Schools	**739**	**48**	**154**	**284**	**145**
Hospitals	**90**	**3**	**6**	**11**	**10**
Potentially dangerous objects	**674**	**37**	**124**	**169**	**161**
Chemically dangerous objects	16	3	1	4	2
Landfills	**31 officials (700+ unauthorized)**	**73**	**36**	**134**	**148**

**Source: calculated by the authors (Ukrinform, 2025).*

Such a possible negative scenario of the development of events requires the development and implementation of a set of measures that, with the use of project tools, risk management and proactive safety-oriented management, allows to form a model of the protective mechanism of infrastructure projects, programs and portfolios of projects to ensure the state of safety of infrastructure objects at various levels (Figure 4).

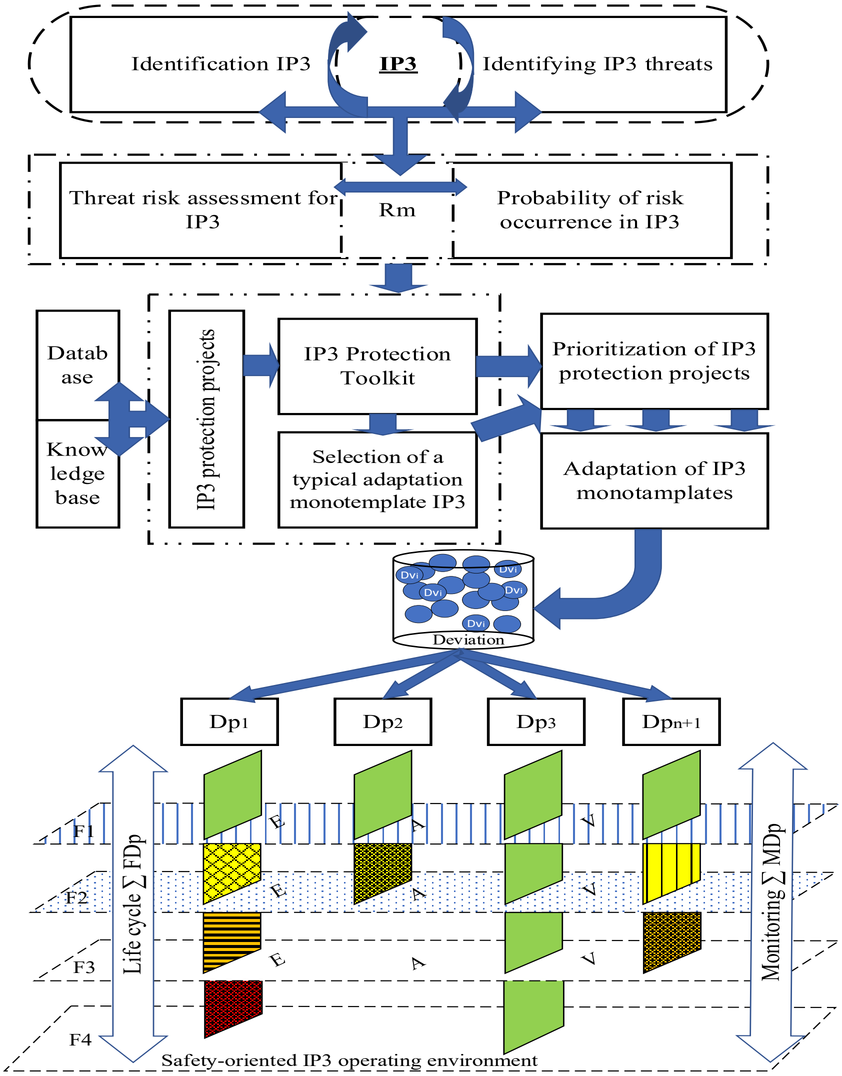

Figure 4. Model-scheme of the formation of the protective mechanism of infrastructure projects, programs and portfolios of projects

**Source: suggested by the authors.*

The basis of the model for the formation of the protective mechanism of infrastructure projects, programs and project portfolios, which is a multi-complex system, is the multi-level identification of risks and the determination of threats, both strategic and tactical, and the probability of cascading effects on infrastructure projects. We formalize the dependence with expression (1):

$$IP3 = \langle Ir; It \rangle \Rightarrow Rm \quad (1)$$

where Ir – identification of risks of infrastructure projects, programs and project portfolios; It – definition of threats.

Risk management Rm, as a derivative of the function of identifying risks Ir and identifying threats It, in the process of managing infrastructure projects, programs and project portfolios includes the components of risk assessments of the occurrence of a threat to IP3 and the probability of the occurrence of the risk itself. We formalize the dependence with expression (2).

$$Rm = \langle Re; Rp \rangle \quad (2)$$

where Re – is the risk assessment of threats to infrastructure projects, programs and project portfolios; Rp – is the probability of occurrence of risk forIP3.

where IP3 – infrastructure projects, programs and portfolios of projects; Rm –

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project risk management; Dvi – deviations affecting the adaptive monotemplate of infrastructure projects; E – evaluation; A – analysis; V – verification; ∑ MPp – adaptive monotemplates of infrastructure projects.

The next block of the model is the block for initiating the formation of a protective mechanism for infrastructure projects, programs and project portfolios. It includes the accumulated database and knowledge base about IP3 monotemplates, risks and threats, their potential impact on various stages of functioning of IP3 monotemplates, probability of occurrence and countermeasures, and is an information resource for the formation of an element of the mechanism - protection projects (3).

$$\begin{matrix} Db \\ \Updownarrow \\ Dk \end{matrix} \Rightarrow Dd \tag{3}$$

де Dd – проєкти захисту IP3; Db – база даних; Dk – база знань.

IP3 protection projects using the theoretical and practical tools of project and program management, according to the given parameters, carry out the selection of a typical IP3 adaptation monotemplate. Formally, let's write the expression (4).

$$Dd = \begin{matrix} Di \\ \Downarrow \\ Dc \end{matrix} \Rightarrow Dp \longrightarrow Da \tag{4}$$

where Di – is the IP3 protection toolkit; Dc – selection of a typical adaptive monotemplate; Dp – prioritization of IP3 protection projects; Da – is an adaptation of IP3 monotamplates.

The adaptive monotemplate of IP3 protection projects is a flexible, but standardized structure capable of adapting to individual and collective requirements of projects and programs. However, for each individual protection project, this process will occur with different levels of consequences for the successful implementation of the project during different phases of the life cycle. Let's formally write the process by expression (5).

$$Da = \begin{matrix} Dvi \\ \Downarrow \\ IP3 \end{matrix} \Rightarrow \begin{cases} Pp_1 \\ Pp_2 \\ Pp_3 \\ Pp_{n+1} \end{cases} \tag{4}$$

where Dvi – is the deviation of the IP3 protection project; Dp1; Dp2; Dp3; Dpn+1; – adaptive monotemplates of IP3 protection projects under different influence of deviations on the structure and content of IP3 projects.

Project deviations Dvi have different effects on different phases of the project life cycle ∑FDp. The life cycle of IP3 protection projects is described by expression (6).

$$\sum \text{FDp} \in [F1; F2; F3; F4] \tag{6}$$

where F1 – is the initiation phase of IP3 protection projects; F2 – planning phase; F3 – phase of practical implementation; F4 – phase of putting into operation and operation of the project – the state of ensuring a safety-oriented operating environment IP3.

At each phase of the project life cycle ∑MDp projects are monitored and 3 main control processes take place: Dvi impact assessment; Dvi impact analysis and verification of Dvi impact consequences. According to the results of ∑MDp monitoring and control processes, not all adaptive monotemplates of IP3 protection projects meet the requirements and relevant parameters that allow reaching the F4 phase and ensuring the functioning of the IP3 safety-oriented environment. Monotamplates screened out at different phases can be refined, changed, and re-implemented. In this case, resource costs for their implementation increase significantly, and the main drawback remains the state of safety, which will not be achieved in time.

The formation of a protective mechanism to ensure the state of safety of IP3 at the 4th phase of the project life cycle requires the development of an additional model of the safety-oriented environment of its functioning (Fig. 5).

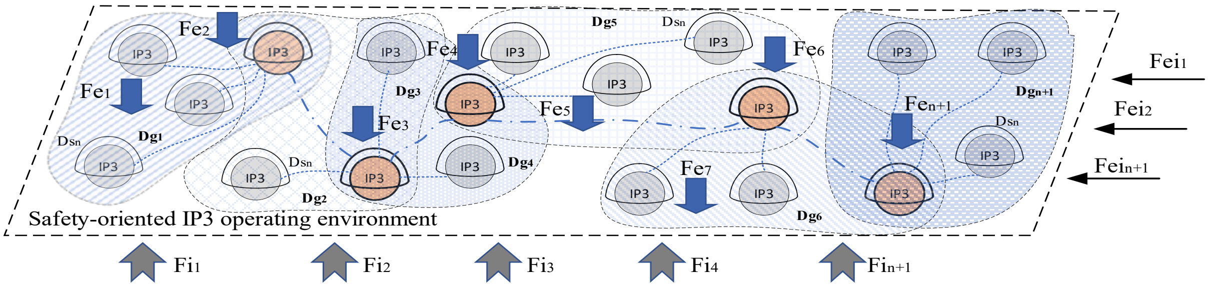

Figure 5. Model scheme of the safety-oriented environment of the functioning of the protective mechanism of infrastructure projects, programs and project portfolios

**Source: suggested by the authors.*

The model scheme of the safety-oriented environment of the functioning of the protective mechanism of infrastructure projects, programs and portfolios of projects is an environment that is implemented to ensure protection and achieve a state of safety and effective management of IP3.

The components of the model scheme include IP3 protective mechanisms that reflect various types of infrastructure projects, programs and portfolios of projects (with different types of danger, scale, impact) with specific functioning and individual safety-oriented approaches to protection. All IP3s are connected by network connections at different levels (local and general), which connect IP3s into a common system. At each local level, IP3 are segregated according to the level of importance and danger. The formation of a safety-oriented environment includes various levels of protection and measures to achieve the goal of ensuring a state of protection and safety (safety protocols, risk management, technological solutions, etc.). A system with different levels of hierarchy and control forms a complex structure of a safety-oriented environment IP3.

The result of the implementation of the IP3 protection mechanism provides for the functioning of the system of individual Dsn and group-type Dgn protection of IP3, which form a safety-oriented environment. Local Dsn – protection of an individual IP3, group Dgn – protection that provides for the creation of safety conditions for a group of IP3s that are networked in a regional aspect. For particularly important IP3, protection is provided by an additional coating of 2 or more Dgn. The safety-oriented environment of IP3, protection systems Dsn and Dgn are constantly affected by external and internal factors of influence (Fei1, Fei2, ... Fei(n). External factors of influence (Fe1, Fe2, ... Fe(n) include external threats and risks, military actions, economic, political, etc. The internal influencing factors (Fi1, Fi2, ... Fi(n) include technological processes, resources, thermistor component, turbulent environment, human factor, etc.

Thus, the model-scheme of the safety-oriented environment of the functioning of the protective mechanism IP3 reflects a comprehensive approach to ensuring the state of safety, which is focused on the integration of a set of control and protection elements into a single system capable of responding to the challenges of the influence of external factors and the internal environment of the project.

Conclusions

The conducted study of safety-oriented management of projects for the protection of critical infrastructure objects indicated that the protection of infrastructure projects, in particular, critical infrastructure objects, is a complex organizational and technical task. To ensure the protection of critical infrastructure objects, an analysis of critical infrastructure objects was carried out (potentially dangerous objects were identified). Computer modelling and mapping of critical infrastructure objects was carried out. The ArcGIS software

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environment was used to process data and create a cartographic representation of the region. Conducted computer modelling and simulation of the effects of hazardous factors on the functioning of critical infrastructure objects (hydraulic structures) and the impact of the consequences on the infrastructure of regions and the population. This made it possible to visualize areas of flooding and suggest evacuation routes. The analysis of zones of potential damage showed that the impact of negative factors can affect five different regions, in particular Ternopil, Lviv, Ivano-Frankivsk, Chernivtsi and Khmelnytskyi regions. Regions were divided according to the level of damage and classified according to the level of potential danger. To solve the problems of the research and on the basis of the obtained data, a model of the formation of the protective mechanism of infrastructure projects, programs and project portfolios was formed, and the features of its functioning were described. Also presented is a model scheme of a safety-oriented environment for the functioning of the protective mechanism of infrastructure projects, programs and project portfolios.

Prospective directions for further research into the process of safety-oriented management of projects for the protection of critical infrastructure objects are the further integration of risk and safety-oriented approaches to the management of infrastructure projects, programs and project portfolios and the improvement of existing risk management methodologies of critical infrastructure objects under the influence of external threats from using the software environment and elements of artificial intelligence.

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