

Article

Systems Engineering Methodology for Designing Digital Public–Private Partnership Platforms

Igor Nikolaevich Glukhikh ^{1,*} , Liudmila Anatolevna Tolstolesova ²  and Otabek Anzor ugli Arzikulov ³ 

¹ Center for Systems Engineering of Polytechnic School, Department of Information Systems, Institute of Mathematics and Computer Sciences, University of Tyumen, 625003 Tyumen, Russia

² Department of Economics and Finance, Institute of Finance and Economics, University of Tyumen, 625003 Tyumen, Russia; l.a.tolstolesova@utmn.ru

³ Department of Information Systems, Institute of Mathematics and Computer Sciences, University of Tyumen, 625003 Tyumen, Russia; Arzikulov.otabek@gmail.com

* Correspondence: igluhik@utmn.ru; Tel.: +7-904-492-2208

Abstract: The modern approach to realization of large, expensive projects with long payback periods in various sectors of infrastructure often involves combining the financial resources of public authorities and the private sector through a public–private partnership (PPP) mechanism. The PPP mechanism has a high potential for attracting investments and facilitating other conditions necessary for the project. At the same time, the project participants need a third-party coordination platform that is objective and able to organize their dialog on equal terms. The authors of this article, for these purposes, consider the capabilities of digital platforms (DP). Digital platforms are able to unite many project participants in a single information field and provide them with the necessary services. Given the potential multitude of participants in such a system, there arises the question of meeting their basic needs to create mutually beneficial conditions during the implementation of projects. Thus, there is a need for flexible DPs. Flexibility can be achieved by using systems engineering (SE) approaches during the design of the DP. The practice of interaction with stakeholders in the framework of systems engineering allows the determination of the basic needs and areas of activity of the participants. The results of this practice will form the basis for the functional and physical design of the future DPs.

Keywords: digital platform; public–private partnership; stakeholders; systems engineering



Citation: Glukhikh, I.N.; Tolstolesova, L.A.; Arzikulov, O.A.u. Systems Engineering Methodology for Designing Digital Public–Private Partnership Platforms. *Appl. Syst. Innov.* **2021**, *4*, 4. <https://doi.org/10.3390/asi4010004>

Received: 2 November 2020

Accepted: 22 December 2020

Published: 11 January 2021

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1. Introduction

The past decades have been marked by the implementation of a huge number of large-scale investment projects in the field of industrial and social infrastructure in the macro-regions of the world and individual countries. The population of many countries and regions is experiencing a serious lack of infrastructure objects, which are either nonexistent, worn out, or requiring urgent repairs and restoration, as well as the creation of new ones. The serious losses from the infrastructure deficit are also borne by society as a whole, for whom the problems of renewing existing infrastructure and finding sources for its financing have become very acute. The experience of many countries has demonstrated that tax revenues alone are unable to solve these problems in infrastructure provision.

The state, while acknowledging the importance of developing and implementing such policies, often has limited budgetary resources and a lack of professional staff for carrying out major infrastructure projects. Private business is also not ready to invest in infrastructure projects due to high risks and long payback period, and uncertainty of the result in the future. A solution could be to pool the resources and capabilities of the state and the private sector through the public–private partnership (PPP) mechanism.

At the same time, it is important to note the problems in the implementation of PPP projects. In particular, these include increases in the complexity and duration of the

project [1], the lack of risk-sharing, and conflicts of interest between participants, as well as the complex mechanism of tenders [2]. To simplify the interactions between the project participants, this article proposes to develop a digital platform uniting customers and suppliers of goods and services.

The development of such a platform also raises a number of questions: how to attract participants and thus increase the value of the platform [3,4], how, in the future, the platform will expand and what processes will be transferred to the external environment [5], which participants will form the core of the digital platform (DP) and its ecosystem [6]. The solution to these problems is directly dependent on the interests of stakeholders and future participants of the platform being designed.

The goal of this study is to form proposals on the development of a digital platform for PPP, taking into account the interests of the parties involved. The systems engineering (SE) methodology is used for the task as the basis for developing complex systems that meet the set of requirements of many interested parties [7]. Working with interested parties is especially important during the early stages of design. In systems engineering, there are a number of practices for working with stakeholders [7]. They allow us to form a detailed concept of a complicated system [8], which includes the DP.

To reach the set goal, the authors of this work identified the following tasks:

- Identify and analyze the current problems and shortcomings of PPP mechanisms;
- Provide an analysis of the concepts of the DP and form a definition of a DP for PPP;
- Develop a framework for implementing a DP for PPP based on the SE practices;
- Define a range of interested parties engaging in the implementation of joint projects using SE practices to revealing stakeholders and their needs;
- Reveal and present the key interests of stakeholders in a PPP on diagrams;
- Determine the challenges for further research work.

The results obtained will provide the basis for the subsequent development of functional–logical architecture and physical embodiment of the DP.

2. Definitions and Methods

2.1. Mechanism of Public–Private Partnerships: Opportunities to Use Digital Platform Solutions

The rationale for the content and substance of the public–private partnership mechanism has been reflected in the modern scientific literature. The complex approach of organization and financing PPP projects, including management methods of both the state and the private sector, has been considered in a number of works [9,10]. Much of the conceptual view is based on large-scale, capital-intensive projects of building quality public infrastructure or services [11–15]. The indicated reason for the emergence of PPPs is that the government does not possess the funds for public spending on the one hand and the great pressure of society to provide infrastructure on the other. The use of the PPP mechanism makes it possible to reduce the burden on short-term government spending and, to a certain extent, increase the efficiency and quality of public services [16]. At the same time, the need to create a favorable investment environment and to provide government support in developing a policy and management strategy in the future is noted as a condition for the implementation of PPP projects [17].

The PPP mechanism, which is a combination of the project's effects and the need to attract private investors who plan to get a positive financial result [18], has a high potential to attract investment and facilitate other conditions for the project. Government cooperation with the private sector in the form of PPP reduces initial capital expenditures on projects and makes efficient use of private capital, while private sector partners receive a return on their investment [19].

Researchers have identified some of the most important reasons for the use of PPP: reduced administrative costs of the public sector, general risk assumption, the reduction in the problem of public sector budget constraints, the best mobility for the private party, the ability to raise funds for the project from the private sector [20].

Despite the obvious advantages of this form of cooperation between the state and the private sector, there are difficulties, risks, and uncertainties arising during the implementation of projects, as the authors point out in their studies. It is noted that existing studies of the PPP mechanism are mainly focused on the significant economic and non-commercial benefits of the private party cooperating with the public sector. However, the organizational and managerial problems of such cooperation, as well as any potentially adverse effects on the private sector, have not been widely explored [21].

It has been established that PPP mechanisms are particularly vulnerable to uncertainties caused by several factors [22].

Risk as any event or impact in terms of cost, time, and quality can be described as the most important factor threatening the successful completion of the PPP project. PPP projects are characterized by a high level of long-term risk, as well as a multitude of participants involved in the partnership and risks associated with it [17].

The important component of the PPP is the nature of risk-sharing between the public and private sectors. If each of the risks can be taken on by partners who can cope well with risks, there will be no doubt that the costs can be minimized throughout the entire infrastructure project. In addition, in PPPs, the public sector and the private sector do not share profits but must control the likely high profits in the private sector. The private sector has no right to generate excess profits in the process of project implementation, as it is a public welfare project and is not aimed at maximizing profits [16].

Researchers have revealed that the most significant groups are financial, legal, and political risks, although design, changes in the value of the land provided, and termination of concessions also have a significant impact on the implementation of PPP projects [23].

Carpintero and Petersen demonstrated that the involvement of multiple government agencies at the local, regional, and national levels further increases the complexity of PPP projects and makes their time delays more likely [1].

In summary, the following complexities and uncertainties arising from the development and implementation of PPP projects can be noted [24]:

- Projects are characterized by large scale, long periods of implementation and payback, high capital intensity, and lack of guarantees to the private investor for the long term;
- Lack of a regulatory framework for PPP projects at the level of potential recipients of funding;
- Poor quality of the presented results of the technological audit, which does not allow the assessment of whether the presented set of technologies in the project is optimal;
- Lack of trained personnel for the preparation of project documentation, its justification, and further implementation of PPP projects;
- Complexity of the evaluation of the quality of the project itself, its real effectiveness, as well as the determination and separation of risks and responsibilities between the state and the private investor.

We should also define the problems associated with PPP projects [2]:

- Conflict between the project goals (financial and social ones);
- Higher cost of capital and initially significantly inflated cost of projects;
- Complexity of holding tenders and negotiating PPP contracts compared to the traditional procurement process;
- Weak “flexibility” of PPP contracts in general;
- Difficulty in implementing the optimal risk distribution between the PPP project participants in practice;
- Likely high corruption component in PPP.

As a result of these shortcomings, contradictions between the parties or conflicts of interest can arise, which leads to the need to introduce adjustments to projects, to an increase in their implementation periods, an increase in budgets, etc. In some cases, this leads to a halt or termination of the project, even at the stage of investment or operation. These contradictions are mainly associated with insufficient or incomplete consideration of

the needs of interested parties and poor organization of their interaction. Elimination of these shortcomings is possible if there is feedback throughout the entire period of project implementation.

Further development of the PPP mechanism requires not so much financial support as the formation of a specialized center, which would provide the necessary legal, educational, informational, analytical, and other supports for the activities of project participants. Within such a single information space, it becomes possible to ensure the interaction of subjects of the digital economy with each other, as well as with business and government bodies. In this regard, high expectations are placed on the management model based on platform solutions, which will allow the state and the private sector to solve various problems together by engaging in real-time (online) interactions. In essence, PPP parties involved in the project require a third-party coordination platform that is objective and fair and could facilitate their dialog on equal terms [16].

It is possible to organize the interaction of numerous stakeholders of projects with the help of a modern approach in the form of a single digital environment (platform). Platforms are usually created for large numbers of users. With the passage of time, as a rule, they develop. However, they present their value to the users only after the necessary number of such users is achieved [25]. Meanwhile, their main purpose is to manage a huge network of consumers and producers, which is achieved through complex negotiations between their participants [26]. The main capabilities of digital platforms lie in the reduction in transaction costs, the combination of the strengths of the participants, and the realization of economies of scale [27]. Digital platforms aim to harmonize stakeholder requirements with specifications at different levels [28].

We should note that such an important component of the PPP is the behavioral characteristics of users and their impact on the project. This aspect is not sufficiently researched and requires further study [16]. We believe that it is rational to use systems engineering as a methodology for constructing complex systems, which is precisely based on the idea of taking into account the needs of all interested parties.

2.2. Digital Platforms

According to the plan of the Russian National Program “Digital Economy”, more than 10 sectoral digital platforms for major areas of the economy are expected to be launched and successfully operational by 2024 [29].

In studies on platforms and their application, authors propose different approaches. Platforms can be considered, first, as focal points, where different participants interact in a single information environment. Second, as a social and technological system that enables the interaction of authorities, interested parties, and technologies by connecting on one platform, the interests of state structures, service providers, developers, and content providers. Third, as a sphere of technological mediation, uniting technologies, employees, consumers, altruistic participants, managers, and developers [26]. Fourth, as a system, which can support different types of generative mechanisms of social interaction: information sharing, cooperation, and collective action [30].

The concept of a “digital platform” is detailed in the paper “The Digital Platform: A Research Agenda” [31], which collects different definitions of the term according to the concept. The results are presented in Table 1.

This paper considers a platform that unites government structures and private businesses to implement large capital and infrastructure projects. Of the definitions outlined in Table 1, the most appropriate one is the definition of the concept of an ecosystem from an organizational point of view. Developing this view in the ongoing study, the authors identified the DP as an information environment with a pool of instruments and services that directly drive manufacturers, consumers, and partners to generate mutual value [32].

Table 1. Different definitions of the concept of the “digital platform” (DP) [31].

The Concept of the DP	Definition
Multilateral Platform	Mediation of various user groups, including buyers and sellers
Multilateral Markets	Uniting individual groups in one platform, where the value of a group grows as the number of participants in other groups increases
Direct Network External Factors	The value of the platform depends on the number of users in one group of users
Indirect Network External Factors	The value of the platform depends on the number of users in another group of users
Digital platform (technical point of view)	Expandable codebase where additional third-party modules can be added
Digital platform (sociotechnical point of view)	Technical elements (software and hardware) and related organizational processes and standards
Ecosystem (technical point of view)	A set of add-ons (apps) to the main technical platform, mostly provided by third-party organizations
Ecosystem (organizational point of view)	A set of enterprises interacting to achieve the goal
Applications	Executable pieces of software offered to end-users as applications, services, or systems

2.3. Methodology of Systems Engineering

The main purpose of this study is to conceive proposals to develop a digital platform for public–private partnership participants and other interested parties. Taking into account the fact that the system is becoming increasingly complicated [8] due to the potentially wide variety of its participants, the systems engineering approach was chosen as the methodological basis for the development of the platform.

As defined by the International Council on SE (INCOSE), systems engineering is a transdisciplinary and integrative approach facilitating the successful realization, use, and retirement of engineered systems, using systems principles and concepts, as well as scientific, technological, and management methods [33].

There are different schools and features in the application of systems engineering, but the following basic practices of SE can be principally singled out:

- Analysis of stakeholders and determination of their needs;
- Determining the target system;
- Requirements engineering;
- Architectural design;
- Verification and validation.

This paper focuses on the first practice of the ones presented above. The requirements of stakeholders play an important role in the development of systems, as they [7]:

- Form the foundation of the system requirements;
- Provide the basis for validation of the system and its acceptance by stakeholders;
- Serve as reference information within the integration and verification activities.

The practice of stakeholder analysis within the SE allows us to identify the range of interested parties involved in the successful implementation, operation, and decommissioning of the system, a digital platform in our example. This step in the design of the system is usually necessary to identify the needs of future members of the system. Based on the needs recognized, we can identify a pool of tools and services to incorporate into the digital platform, i.e., define the boundaries of the digital platform and the interfaces of interaction with external systems. This basis further determines the requirements for the

system, its functionality, architecture, and technological solutions that will meet all the identified needs of interested parties.

3. Results

Taking into account the basic principles of the SE methodology, the results of research on the cycles of the needs of stakeholders, and the decomposition approach in the development of architecture and design of the system [34], the framework of the implementation of the digital platform was formed Figure 1.

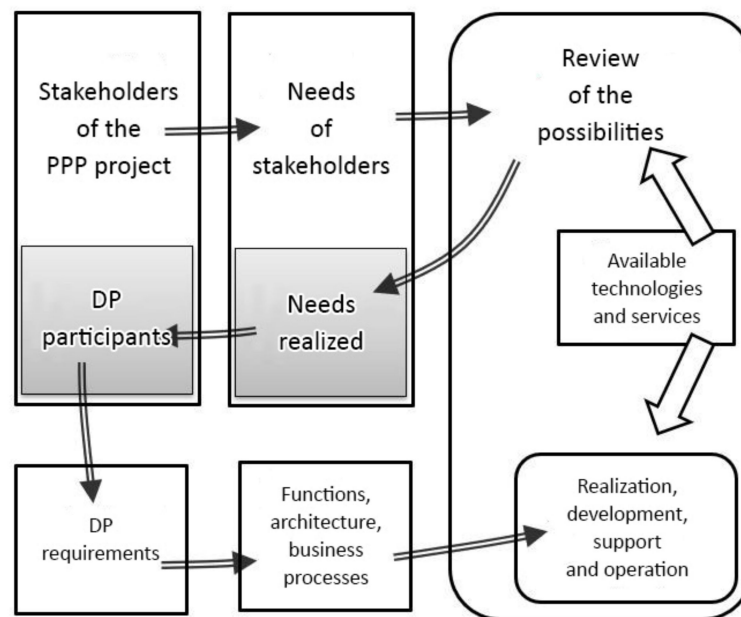


Figure 1. Digital platform development framework.

A previous work by the authors has included a list of PPP participants interested in the DP (Table 2) [32]. The stakeholders listed in the table are aggregated by their areas of activity.

Based on the identified needs (interests), the capabilities of existing technologies and services integrated into the designed DP are evaluated. If the needs of interested parties are met, DP requirements are formed on their basis. At this stage, requirements engineering techniques are used. Next, based on these DP requirements, the concept of a digital platform with internal functionality, interfaces of interaction, and other support systems is developed.

This approach allows us to keep all the needs of interested parties in a single field and take them into account when designing and implementing a digital platform.

Other authors' studies on similar topics utilized use case diagrams to illustrate and classify the needs of stakeholders [35]. This approach was used in this article to analyze the interests of the identified stakeholders. We offer five diagrams, each illustrating the corresponding group of needs:

- Partnership;
- Pre-project activities;
- Financing of operations;
- Performance control;
- Mass media and public relations.

Table 2. Subjects in the digital public–private partnership (PPP) platform [32].

Direction	Interested Parties
Suppliers, contractors	Manufacturers of industrial equipment Developers Contracting organizations Construction organizations
Financial intermediaries	National banks Securities issuers Central Bank International development banks World Bank structures in Russia Transnational banks Insurance and reinsurance companies Leasing companies
Design organizations	Design services Research and development institutions Architecture and urban planning authorities
Supervisory bodies	Environmental regulators State Fire Authority Monitoring services Federal Antitrust Service Federal Tax Service Accounts Chamber
The authorities that regulate import/export of participants of foreign economic activity	Federal Customs
Expert assessment services	Legal services Assessment services
Users, consumers	Recipients of services/goods Users, consumers Operating companies

The diagrams presented in this paper (Figures 2–6) allow the visualization of the subject of interaction between stakeholders in a public–private partnership, based on which it becomes possible to determine the tools of this interaction for their integration into the digital platform.

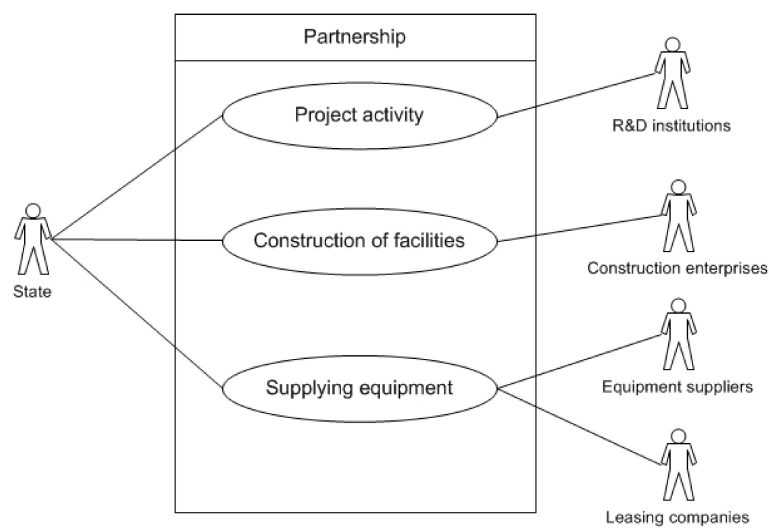


Figure 2. Partnership.

The partnership chart (Figure 2) shows the main parties involved in the direct implementation of a major PPP project, where government agencies are the initiator of the project, and private companies act as contractors and partners.

The digital platform we are considering should provide the tools for evaluation and pre-project activities so that the main PPP participant, the government, can assess the current need for a major project and its prospects and find potential partners to implement it. To this end, we have created a diagram of project preparation (Figure 3).

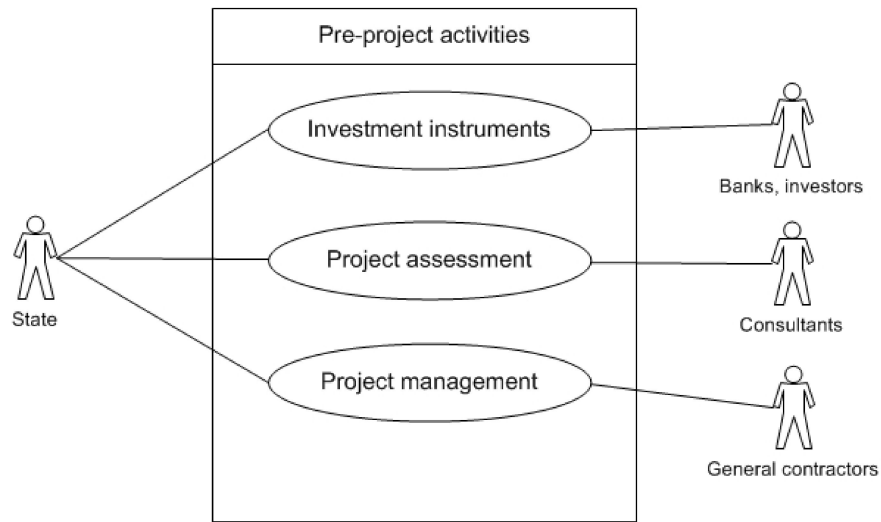


Figure 3. Pre-project activities.

The DP should provide for investment tools, including sources of investment financing, the procedure of financing of operations, investment directions, ability to insure risks of design and construction objects, etc.

In the diagram of needs (Figure 4) in investment instruments in the role of the customer, the initiator of the project is designated, who forms the requirements for the procedure and mechanism of financing. Banks, private investors, insurance companies, etc., can provide their financial resources to meet these needs, receiving in return income from their use.

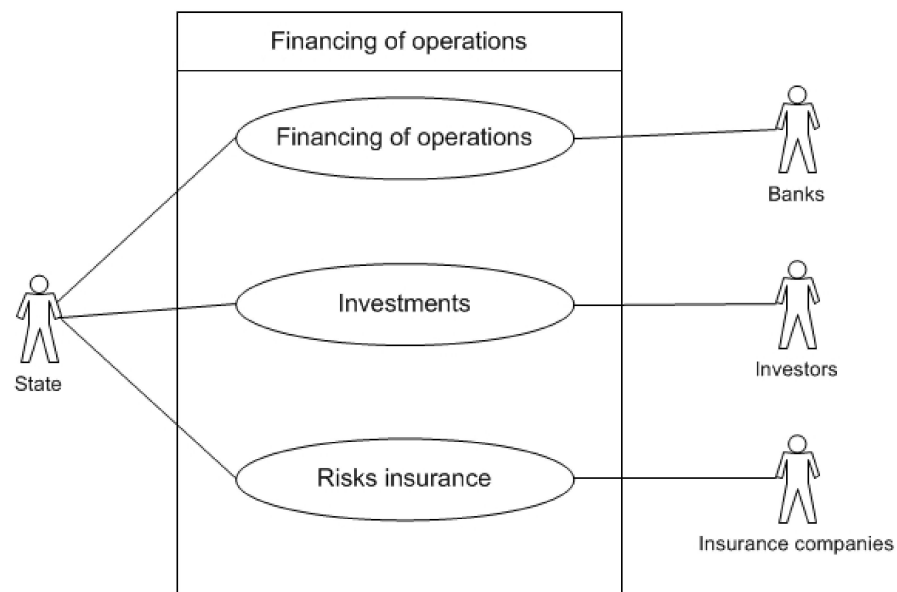


Figure 4. Financing of operations.

During the course of projects, the customer has a pool of tools for tracking the progress of the project. Such tools should be provided in the DP, and the requirements for their development can be formed by public services and supervisory bodies that monitor the orders being executed.

Figure 5 shows a performance control chart that considers tools, such as environmental and social monitoring, and controls budget expenditures during the project.

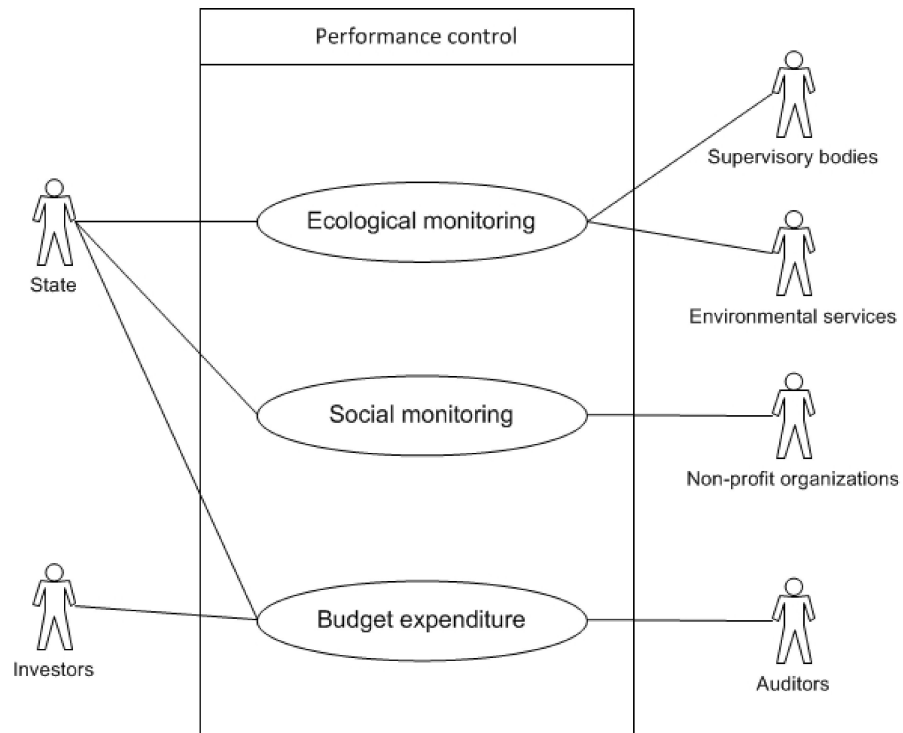


Figure 5. Performance control of operations.

An important factor influencing the success of the project is its PR. With the help of broad coverage of project activities, government structures can attract new partners to implement the projects planned (Figure 6). For these purposes, tools that facilitate interaction between PPP participants and those who own information resources must be integrated into the digital platform.

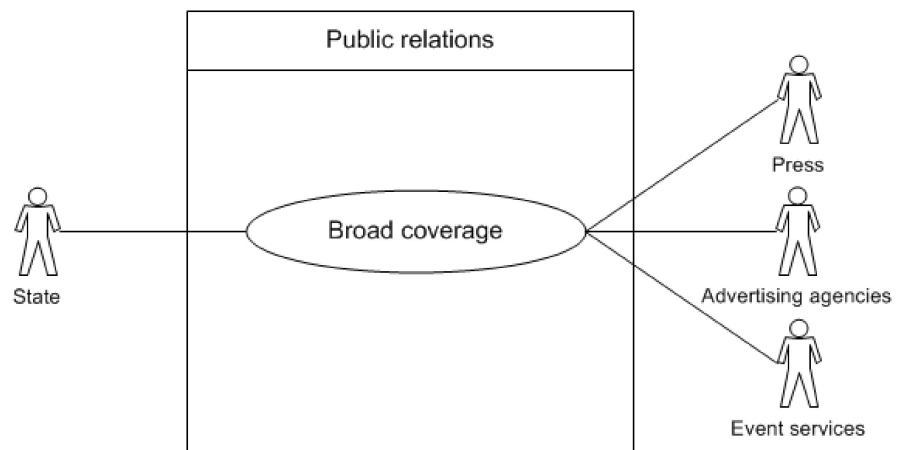


Figure 6. Media coverage of the project.

4. Discussion

The issues raised in Section 2.1 [2] can be addressed thanks to the close interaction between stakeholders through the digital platform we offer. In particular:

- Conflicts between the project goals can be avoided by identifying the needs of stakeholders and meeting them in the course of the implementation and operation of PPP projects;
- Problems of overvalued capital and the emergence of corruption schemes are solved through the involvement of regulatory and supervisory bodies in the platform;
- Complexity of tenders and PPP contract negotiation is simplified by the transparency of processes in digital platforms and their built-in mechanisms improving interactions between the parties.

The distribution of risks and benefits among the PPP platform participants is a topic of further research.

Earlier studies have examined the role of stakeholders in PPP infrastructure projects [36–38]. In them, the interested parties were evaluated from the point of view of project management in the context of the life cycle of PPP project realization. This work uses the systems engineering methodology, the tools of which facilitate the successful implementation of complex engineering solutions [39,40]. One of the criteria for the success of the implemented project according to the SE methodology is the satisfaction of the needs of stakeholders, and not only their participation and role in the project. At the same time, stakeholders are understood as users of the future infrastructure facility, as well as those who will be involved in the deconstruction of the facility at the end of its service life.

The interests of stakeholders interacting in the PPP format can vary from one project to another. However, their core needs will be within the line of business of the interested party. We propose to take these needs into account in the initial stages of the design of the digital platform (Figure 1) in which PPP projects will be carried out. It is important to note that stakeholders' needs may not always be realized in the form of functions and processes in the DP in the absence of technological capabilities. But by finding a compromise of interests between the parties at the initial stage of conceptual design, it will be possible to avoid additional complex research and development and expensive technological scouting with further detailed development of the DP.

Our proposed framework for PPP development is not limited to potential stakeholders (Table 2). Depending on the tasks of the designed PPP facility, the list of major stakeholders may change, as well as their lines of business, based on which their primary needs are revealed.

What may become a problem is the addition of a new key PPP participant to the current DP, which is unable to meet its needs. In this case, it is necessary to transform the digital platform with the introduction of new functions and processes or to look for new solutions to expand the DP ecosystem. The second problem is that the DP participants are not always able to disclose their true needs and objectives in PPP projects because of their concealment or lack of purpose. These problems need to be addressed in future studies.

5. Conclusions

The main goal set in the article, the formation of a framework for the development of a digital PPP platform taking into account the interests of the parties involved, has been achieved.

The paper presented the concept of developing a digital platform used in major projects through public–private partnerships. A framework for developing this platform using the practices and tools of systems engineering was proposed. According to the systems engineering methodology, a circle of interested parties (subjects) was determined based on which the types of needs were formed.

The selected groups (or types) of needs will subsequently make it possible to formulate requirements on the part of stakeholders for the designed digital platform for PPP, which will determine the future set of tools when shaping its architecture.

Such an approach in the development of the DP for PPP will allow the interests of those involved in the project activities to be taken into account and will create opportunities for the prompt and high-quality selection of contractors.

It is also important to note the contribution of this study to the development of the existing scientific context in the following two areas:

1. The paper contributes to the development of digital PPP tools through digital platforms. For this purpose, the concept of the DP has been proposed, for which important work has been done to identify a wide range of PPP stakeholders influencing the success of the project, as well as their needs. The aggregate needs (Figures 2–6) will allow the selection of the necessary set of tools for the DP. This approach will allow the design of the DP so that its participants benefit the most from satisfying their needs.
2. Moreover, the results of this study contribute further to the development of PPP as an approach to the organization and implementation of major projects. It lies in the application of system engineering practices to expand the understanding of PPP stakeholders in projects. The paper proposes identifying PPP parties to determine their needs and to create harmonized requirements for the project and its results. At all stages of the project's lifecycle, these requirements need to be taken into account, and the proposed solutions need to be checked for consistency with them. The digital platform is designed to support this work.

The results listed in the article can serve as a foundation for direct interaction with the identified stakeholders and detailed determination of their requirements for the DP. Further work with stakeholders will determine the functional architecture and physical implementation of the future DP.

Author Contributions: Conceptualization, I.N.G.; methodology, I.N.G., L.A.T., and O.A.u.A.; writing—original draft preparation, O.A.u.A.; writing—review and editing, I.N.G. and L.A.T.; visualization, O.A.u.A.; funding acquisition, L.A.T. All authors have read and agreed to the published version of the manuscript.

Funding: Preparation of this article was supported by the RFFI grant No. 19-010-00975.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: We are very grateful to anonymous reviewers for their insights and guidance.

Conflicts of Interest: The authors declare no conflict of interest.

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