PROJECT MANAGEMENT IN COMPLEX TECHNICAL INFRASTRUCTURE PROJECTS: CHALLENGES AND STRATEGIES

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Abstract: The paper delineates essential facets of hybrid management in the realm of infrastructure projects and programs, elucidating pivotal concepts, methodologies, and models integral to this approach. A comprehensive examination of the extant status of infrastructure project implementation at the regional level is undertaken, encompassing an inquiry into terminology, regulatory frameworks, and financial management standards specific to this domain. Noteworthy attention is devoted to global practices in program implementation at the regional level, as well as contemporary strategies for overseeing infrastructure projects and programs. The culmination of this investigation is the formulation of a refined scientific and applied framework for hybrid management at the regional level. This conceptual framework is rooted in the integration of project management knowledge systems and is delineated by its adaptation to the methodology of project program management. Within the parameters of this articulated concept, a convergent system for the utilization of project management methods and approaches in the context of efficient project program management has been devised.

Keywords: Project management, Technical project management cases, Infrastructure projects, Financial management.

1 Introduction

Technical infrastructure projects constitute a fundamental element of contemporary society, directed towards the advancement and fulfillment of requirements for facilities and services. Encompassing diverse domains such as the construction of bridges, tunnels, energy facilities, and other infrastructure structures, these projects are frequently characterized by considerable complexity and scale. The execution of substantial undertakings, such as the construction of expansive bridges or tunnels and the establishment of robust energy facilities, demands substantial resources and technical proficiency. Additionally, numerous technical infrastructure projects necessitate collaboration across multiple industries, including but not limited to construction, engineering, transportation, and energy. This necessitates the establishment of efficient communication and collaboration among diverse specialists. Infrastructure projects typically engage various stakeholders, including government agencies, businesses, communities, and others. Interaction with these entities constitutes a pivotal aspect of ensuring the success of project implementation. Given the substantial scale and significance of infrastructure projects, the establishment of elevated safety and quality standards is imperative. This pertains not only to the construction phase but also extends to the subsequent operation of the facility. In the contemporary context, an integral consideration is the assessment of the environmental impact of the project. Projects must adhere to requirements aimed at conserving natural resources and mitigating environmental impact. For the prosperous execution of technical infrastructure projects, proficient project management encompassing planning, controlling, and reporting is indispensable. The formulation of a fitting management strategy is paramount to realizing predetermined objectives.

The establishment of an effective management system for infrastructure projects and programs has emerged as a significant subject of inquiry in numerous scientific studies conducted in Ukraine and internationally in recent years. This matter has become an intrinsic component of the majority of investigations in the realm of project management. Several factors contribute to the inherent complexity of this study, encompassing the magnitude and breadth of infrastructure projects and programs at the regional level, coupled with the integration of hybrid project and program management technologies. A notable challenge arises from the diversity within project environments and the influence of various factors, including industrial, legislative, territorial, cognitive, market, and industry disparities. Within the domain of project management, endeavors are underway to devise and progressively align diverse models and mechanisms, aiming to facilitate the effective hybrid management of infrastructure projects and programs. It is imperative to recognize that successful hybrid management considers not only technical dimensions but also entails interaction with diverse stakeholders, thereby contributing to the intricacy of this issue. Specifically, it is essential to investigate and incorporate the experiences gleaned from successful infrastructure projects to formulate more effective management strategies. This subject retains its relevance and necessitates ongoing research efforts to refine approaches and attain optimal outcomes in the management of complex infrastructure projects and programs.

2 Literature Review

To leverage the increasing prevalence of infrastructure projects globally, an escalating number of construction companies possessing professional expertise are vying for construction contracts in foreign markets. Furthermore, companies exhibit a willingness to undertake projects in other countries as a means to broaden their business scope, driven by the swift internationalization context, a low threshold for entering the global market, and significant growth potential. Nonetheless, amid the expeditious construction of diverse infrastructure facilities, researchers are progressively acknowledging the environmental side effects associated with these endeavors, which are anticipated to yield adverse consequences for society (Ovetska et al., 2021). This will influence the appropriateness and efficacy of the ultimate products, consequently affecting the environment and society. Therefore, sustainable infrastructure development presently represents a crucial facet of the architecture, engineering, and construction industry. A method to guarantee infrastructure sustainability involves enhancing project management across all phases of the life cycle. Certain scholars propose the incorporation of sustainability aspects into project management practices, a measure that contributes to the success of a construction project (Khan, 2019). In the context of the increasing global significance of sustainability, it should be regarded as a novel criterion for project success.

Project management deemed a crucial instrument in attaining project success, is characterized as the methodical application of knowledge, skills, tools, and techniques to project activities with the objective of meeting project requirements (Bushuyeva et al., 2020). Notably, there is a critical need to establish transparency regarding the cost of risks and to pinpoint key factors and sources of risks. Achieving this at the organizational apex necessitates the effective implementation of a risk management system and the cultivation of risk culture, fostering awareness at all organizational levels. Prudent and transparent communication among diverse teams engaged in infrastructure projects stands as a vital prerequisite for the success of any project. Consequently, it is imperative to institute an enhanced communication system facilitating effective collaboration across various departments and ensuring alignment of goals and processes. Engagement with contractors, encompassing monitoring activities, holds significance for the prompt identification and evaluation of risks (Oguzie et al., 2021). Clear directives were established from the organizational apex to operational levels, facilitating the dissemination of risk management knowledge. This approach entailed enhancing transparency concerning on-the-ground operational risks and transitioning from a transient reactive strategy to a proactive anticipation of potential risks. To gauge the sustainability of infrastructure, scholars in the disciplines of architecture, engineering, and construction have explored the identification of assessment factors. For instance, researchers (Huang et al., 2021) devised indicator systems for evaluating infrastructure sustainability based on key indicators across three dimensions: economy, society, and the environment. They further categorized infrastructure sustainability into internal performance (encompassing construction, maintenance, and long-term adaptability) and external performance (encompassing public utility and environmental impacts) from the perspective of the project system. While the integration of sustainability into project management has emerged as a promising field (Stanitsas et al., 2021), certain gaps persist in the current advancement of sustainable infrastructure developments. These include a short-term perspective in the planning phase, insufficient consideration of demand fluctuations, and unfavorable conditions for maintenance during use.

The absence of formal and comprehensive frameworks addressing the factors intrinsic to infrastructure project management and infrastructure sustainability hinders this integration, impeding the capacity to manage projects and foster successful infrastructure development in practice. The investigator of the study (Beckers et al., 2013) undertakes an empirical examination of critical factors, offering insights into enhancing project management efficiency to attain infrastructure sustainability. While some risks may be inherently unavoidable, it is imperative to identify them effectively and promptly to formulate an appropriate mitigation plan (Gondia et al., 2022). Risk management exerts influence on diverse facets of an organization by heightening managerial awareness, enhancing the probability of success in goal attainment, and establishing a platform for the exchange of ideas within the organization. Moreover, proficient risk management serves to forestall unforeseen occurrences, bolster self-assurance in critical decision-making, ensure the delivery of high-quality services, and safeguard the organizational reputation. An infrastructure project is characterized as a multifaceted process encompassing technical, technological, economic, financial, and legal dimensions, necessitating coordinated and regulated activities for successful completion. Each project is assigned an estimated completion time, emphasizing the significance of establishing constraints for potential schedule deviations. While delays in infrastructure projects may be inevitable, it is crucial to delineate clear boundaries for the management of temporal shifts (Macura et al., 2022).

In the literature, risk is categorized as uncertainty that has the potential to impact project implementation both positively and negatively. Risk management enables the investor to foresee potential adverse consequences that may arise during project implementation. Delays in project implementation may be intrinsic, but a risk management plan is employed to predict them and enact effective measures for their management. The researchers (Macura et al., 2022) explored enduring trends during the development phase of substantial infrastructure projects to optimize processes and enhance management capabilities for more efficient project delivery. This investigation utilized a Type 2 fuzzy logic-based Failure Mode and Effect Analysis (FMEA) method for risk assessment in railroad infrastructure projects. Numerous organizations acknowledge the significance of implementing effective project and construction management, employing various frameworks and methodologies for this purpose. An essential component of every project is the project manager, tasked with choosing the appropriate methodology for a specific project and executing a consistent action plan (Khalfan, et al., 2022).

Instituting a project management structure represents a pivotal step, and the nuances of project management within the nuclear power industry shape the acquisition of experience, effective utilization of processes, and continuous adherence to authorizations (Kramskyi et al., 2023). The organization may encounter the necessity to incorporate diverse methodologies into the project management system contingent upon the type and scale of projects. Each method is amenable to adaptation and combination based on internal requirements and prevailing circumstances (Pinto et al., 2023). In infrastructure projects, employing multiple methodologies concurrently may be a judicious approach. The selection of a specific methodology is contingent upon the type and scale of the particular project (Rahat et al., 2023). The project management industry encompasses several distinct methodologies, illustrating the evolution and diversity of the field. These methodologies are hierarchically organized, with varying levels of general universality and specificity (Kramskyi, et al., 2023).

The objective of this article is to investigate and analyze the challenges inherent in project management within complex technical infrastructure projects, while also developing and identifying strategies aimed at mitigating these challenges. The study centers on the specificities and challenges encountered in the execution of complex infrastructure projects, encompassing technical dimensions, financial considerations, managerial aspects, and stakeholder engagement.

3 Research Methods

To assess the efficacy of project management in complex technical infrastructure projects, a multicriteria analysis was employed. This approach enables the evaluation of projects by considering various criteria and making decisions based on multiple parameters rather than a singular one (Lesik et al., 2020). The multicriteria analysis method encompasses a range of criteria, addressing both financial and non-financial aspects. The primary objective of the study is to identify the optimal alternative, rank potential options, or select several of the most effective solutions for further in-depth analysis. Multicriteria Analysis (MCA) holds particular relevance in diverse infrastructure projects and those involving both public and private sectors, especially when qualitative aspects play a pivotal role, such as in the allocation of risks between the two sectors. MCA proves highly valuable in scenarios where estimating the substantial impacts of an investment is challenging, thus serving as a substitute for a comprehensive cost-benefit analysis (CBA). This substitution may be imperative during the stage of selecting investment alternatives, as observed in transportation or urban regional development projects. In certain situations, MCA is integrated with CBA, particularly when assessing specific impacts of an investment is intricate, such as evaluating landscape impacts. In large-scale projects, MCA is employed to aid in the selection of options during the initial stages of development. In the context of evaluating infrastructure project performance, MCA offers a comprehensive approach to decision-making, considering various facets of the project. MCA facilitates a structured and objective assessment of diverse aspects of infrastructure projects, thereby fostering informed decision-making and enhancing project management.

The methodology for calculating the Net Present Value of a project (NPV) stands as a fundamental strategy for assessing investment opportunities. This approach finds widespread application in decision-making practices, providing a means to evaluate the project's effectiveness in terms of cost. The essence of the method lies in determining the Net Present Value, also referred to as NPV (Voitsekhovych et al., 2022). This metric signifies the increase in the company's value after the project's implementation. NPV considers the difference between the cash flows generated by the project and the discounted costs associated with its execution.

The multicriteria analysis method will be applied to evaluate the success and effectiveness of the project, focusing on various criteria, including:

Financial criteria:
NPV (Net Present Value): Assessing the financial profitability of the project over the defined time horizon.

Risk factors:
Risk profile: Analyzing potential risks and their impact on the project outcomes.

Public benefit:
Contribution to employment: Quantifying the number of jobs created or preserved by the project.

Strategic objectives:

Alignment with the strategic goals of the organization: Evaluating how well the project aligns with the company's development strategy.

Sustainability of technical solutions:
Technical sustainability: Gauging the effectiveness of the selected technical solutions in accommodating technological trends and future opportunities.

Customer satisfaction:
Product quality and customer satisfaction.
Multicriteria analysis facilitates the consideration of diverse aspects of the project and the determination of their significance in reaching a final decision. Throughout the analysis, the weighting of each criterion can be assigned based on the strategic goals and organizational needs.

The NPV was computed using the following formula:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+r)^t} - C_0, \quad (1)$$

Where: *NPV* - Net Present Value; *T* - Number of periods; *CFt* - Cash Flow in period t; *r* - Discount rate; C_0 - Initial Investment.

In adherence to the criterion established in the NPV calculation method, the project is deemed justified if the NPV surpasses zero. To conduct the requisite calculations as per the aforementioned formula (1), it is crucial to possess a clear expression for cash flows that incorporates the conditions specified in the problem statement. Formula (1) can be modified and expressed as follows (2):

$$NPV = -I_0 + PV(I_n) + \sum_{i=1}^{n} \frac{(P-VC)*FMS*MS*(1+MGR*(i-1))-FC}{(1+k)^i} \quad (2)$$

Where: $PV(I_n)$ is the discounted residual value of the investment, I_0 is the required amount of investment, I_n is the value of the residual asset, *P* is retail price, *VC* is operating cost, in turn, *FMS* - Fair market share, *MS* - Market size, *FC* - Fixed cost, *MGR* - Market growth rate.
The calculation of the discounted residual value of investments was conducted following formula (3):

$$PV(I_n) = I_n /(1+k)^n \quad (3)$$

The risk profile elucidates the alterations in outcomes corresponding to incremental changes in the model parameters. The procedure involves sequentially augmenting each variable within the model, such as by 10%, and subsequently calculating the new values of the Net Present Value (NPV). Utilizing the calculated values of the model parameters, a graph was constructed in the coordinates of $change\_in\_NPV = f(parameter\_deviation)$. This graph comprises a series of straight lines intersecting at the point (0;0).

Calculations according to formulas (2) and (3) were executed utilizing Microsoft Excel. This software enables efficient computation and visualization of risk profiles for the implementation of an infrastructure project.

4 Research Results

Infrastructure facilities encompass substantial industrial structures, including plants, power plants, transportation networks, water supplies, and other facilities pivotal to societal and economic functioning. Chemical plants, in particular, exemplify complex infrastructure facilities characterized by intricate technological processes, substantial production capacities, intricate security systems, and interconnections with other vital infrastructure components like transportation, energy, and water supply. Effectively managing projects aimed at expanding or modernizing a chemical plant demands a comprehensive approach, considering diverse technical, economic, and environmental aspects.

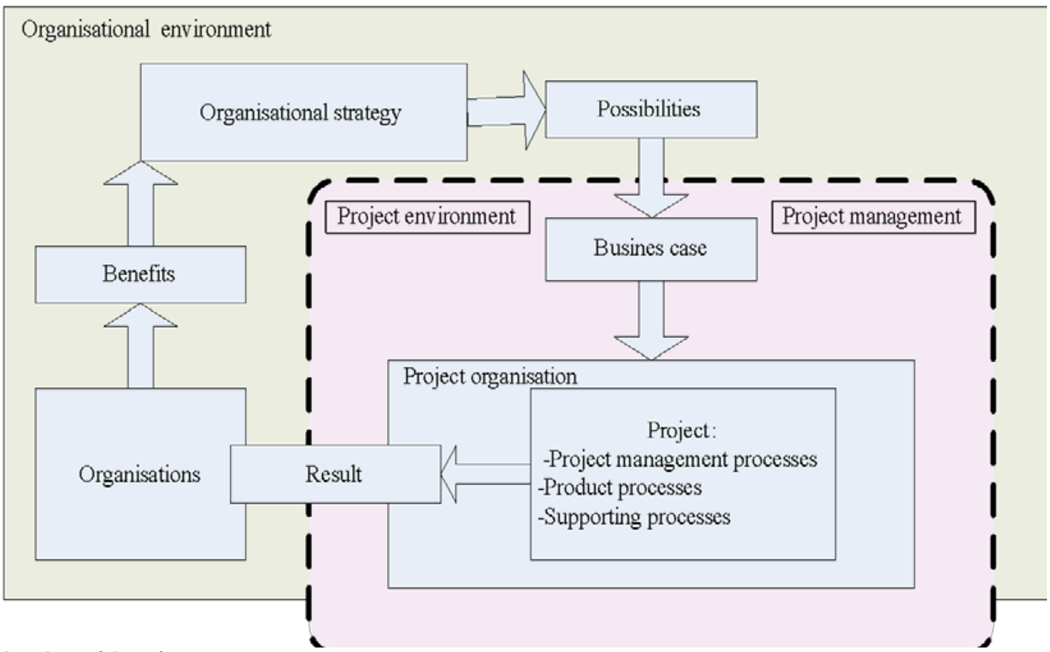

Figure 1. Flowchart of the infrastructure project management strategy

In the presented case study, a $10,000,000 investment project was examined, focusing on the expansion of capacity for a chemical manufacturing company. This company engages in the production of goods through the processing of raw materials valued at $435 per ton, which are subsequently sold on the market for $510 per ton. The objective involves conducting a thorough assessment of the risks associated with the investment project, employing the method of simulation modeling. Particular emphasis is placed on scrutinizing the challenges and strategies pertinent to project management within the realm of complex technical infrastructure projects. The project parameters encompassed a product market volume of 250,000 tons per year, coupled with a market growth rate of 3%. Commencing the project, the company's market share stood at -12%. Technical specifications stipulated a service life of 10 years for the equipment, with a residual investment value of $4,500,000 anticipated after this period. The plant incurred annual fixed costs of $300,000. A discount factor of 10% was employed in evaluating the project.

The diagram delineates the key stages and elements of the project management methodology as follows:

Organizational environment:
- Identifying the context in which the organization operates.
- Understanding the main aspects of the internal and external environment.

Organizational strategy:
- Defining the strategic goals and objectives of the organization.
- Developing strategic plans to achieve the goals.

Project environment:
- Analyzing the factors that impact a specific project.
- Identification of internal and external factors that may influence its implementation.

Opportunities:
- Identification of opportunities for improvement and development.
- Analyzing options and potential directions for the project.

Benefits:
- Identifying the benefits that the organization can gain from the successful implementation of the project.
- Analyzing the benefits that the project can bring to the organization.

Business case:
- Creating a rationale for project implementation.
- Analyzing the cost, risks, and benefits of the implementation.

Project management:
- Implementation of project management processes.
- Development of strategies, plans, and control points.

Project organization:
- Defining the project structure and roles of participants.
- Assignment of tasks and definition of responsibilities.

Results:
- Evaluation of the project's effectiveness against the goals and expected results.
- Reporting and analysis of the data obtained for future projects.

The diagram illustrates a systematic approach to project management, commencing with the organizational environment and culminating in the analysis of results and lessons applicable to future projects.

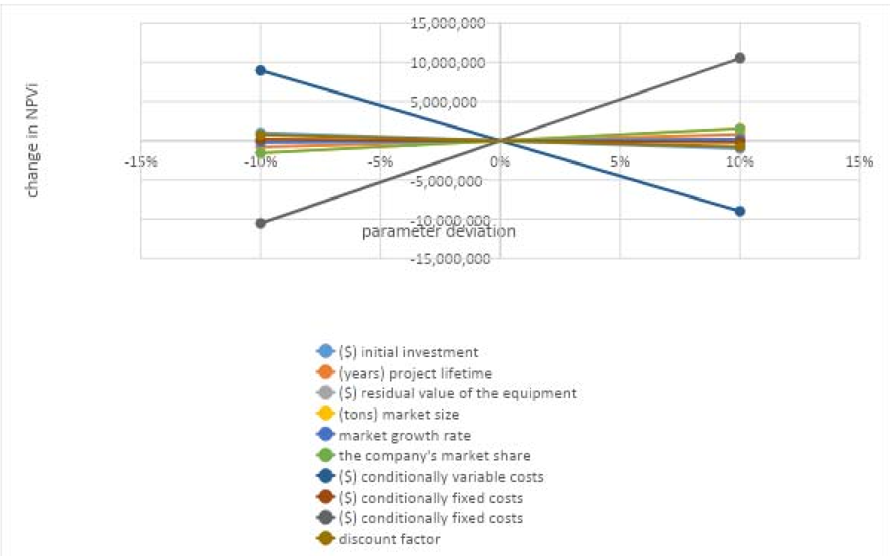

Figure 2. Risk profiles for an infrastructure project

Figure 2 depicts the impact of various changes on NPV when the respective variables are altered by ±10%. The graph indicates that a 10% reduction in the initial investment results in a corresponding $1,000,000 decrease in NPV, while a 10% increase in the initial investment leads to an equivalent $1,000,000 rise in NPV. Similar adjustments were applied to other project parameters, where $PV(I_n)$ represents the discounted residual value of the investment, I_0 is the required investment, I_n is the value of the residual asset, P is the retail price, VC is the operating cost, FMS is the fair market share, MS is the market size, FC is the fixed cost, and MGR is the market growth rate. These alterations have the potential to influence the Net Present Value (NPV) and other financial parameters of the project. The graph visually represents the impact of each variable on the project outcome. The slope of the lines in the graph signifies the extent of influence of a specific variable, facilitating the identification of variables with the most substantial leverage on the project's success. This information holds significance for the formulation of a risk management strategy, particularly when the identified changes in these factors can exert a considerable impact on the ultimate project outcome.

Base Case:

The calculation of Net Present Value (NPV) reveals a profit of $5,379,998 over the ten years.

The project demonstrates financial viability and the potential to generate substantial profits.

5 Discussion

Project management in complex technical infrastructure projects is a task demanding an advanced approach and strategies geared toward mitigating challenges and maximizing opportunities (Ivanenko, 2020). The execution of successful technical infrastructure projects is increasingly pivotal for the development of enterprises and society at large. The distinctive nature of complex technical infrastructure projects necessitates the efficient coordination of numerous factors, encompassing technical expertise to managerial aspects. Challenges, including technical uncertainties, time and budget risks, and interactions with diverse stakeholders, necessitate a systematic and flexible management approach. Project management strategies in this context should encompass anticipating potential risks, establishing mechanisms to respond promptly to changes, and underscoring the significance of communication and collaboration within the project team (Javed, et al., 2021). It is crucial to consider the principles of sustainable development and the integration of innovative technologies to enhance efficiency. Amidst rapid technological advancements and heightened customer expectations, project management in complex technical infrastructure projects is influenced not only by success in meeting objectives but also by the ability to adapt to unforeseen circumstances. This necessitates strategies that center on innovation and continuous improvement, along with the incorporation of change management practices.

The objective of project management in complex technical infrastructure projects is to establish optimal conditions for collaboration among all stakeholders, spanning from engineers and technicians to financial analysts and members of the public (Sabadash & Lysko, 2023). Only responsible and well-structured governance can guarantee successful project implementation and contribute to sustainable development. In the course of project management in complex technical infrastructure projects, several key aspects pertinent to the implementation and management of such projects should be highlighted (Bijańska & Wodarski, 2024). Our study sought not only to identify these challenges but also to propose strategies that can effectively address them. One key aspect that emerges in the management of complex projects is technical complexity. With the introduction of new technologies and innovations in construction, projects may encounter various technical challenges. Therefore, it is essential to discuss how to manage such challenges and explore strategies that can be applied to ensure project success. The financial aspect also assumes a crucial role in complex infrastructure projects. Many experts deem NPV, employed in our study, as the most informative indicator for most projects, as it accounts for the time value of money and expresses results in purely financial terms (Kryshtanovych, et al., 2021).

Effective methods of financing, budget optimization, and cost management should be contemplated to maximize the utilization of resources. Management aspects, including communication and interaction among project participants, should encompass strategies to enhance communication among project participants and efficient conflict resolution. A distinct aspect involves the strategy of interaction with stakeholders, such as communities, authorities, and other vested parties. Discussions should center on methods of public engagement and ensuring a sustainable social impact (Pasko, et al., 2021). It is crucial to underscore that success in complex technical infrastructure projects relies on integrated and strategic management, considering all facets of the project. References to best practices and instances of successfully implemented strategies can be pivotal in the discussion, reinforcing the thesis that approaches to managing such projects need continuous refinement. The assessment of investment project risks is frequently integral to the management of complex technical infrastructure projects. Risk assessment constitutes a crucial component of strategic project management, facilitating the identification, assessment, and management of potential threats and opportunities that may manifest during the project. The simulation modeling method enables the construction of a virtual model of the project, considering probable risks and their impact on various facets of the project, including timing, cost, and quality (Trach, et al., 2022). This method facilitates the analysis of different scenarios and the determination of likely consequences of risks, enabling more informed management decisions. Hence, risk assessment and simulation modeling techniques constitute crucial components for comprehending and managing risks in complex technical infrastructure projects. This stance reinforces the thesis that, for effective project management, the application of a variety of methods and strategies is imperative to ensure successful project delivery in highly technical and complex environments.

6 Conclusions

This article delves into crucial aspects of project management in complex technical infrastructure projects. It identifies the key challenges confronted by project managers in these domains and highlights strategies for addressing them. To illustrate risk assessment methods and management strategies for complex technical projects, a case study of a chemical plant expansion project is presented. A flowchart of the infrastructure project management strategy has been devised, outlining the key stages and elements of the project management methodology. Commencing with an examination of the organizational environment, encompassing the definition of context and strategic goals, the flowchart proceeds to scrutinize the project environment. It involves the identification of opportunities and benefits, the development of a business case, and the implementation of project management. The systematic approach concludes with project organization, performance measurement, and reporting, furnishing a comprehensive overview and the capability to leverage accumulated data in future projects.

The impact of various changes on the net present value (NPV) of the project was systematically analyzed by modifying relevant parameters by 10%. The findings reveal that a 10% reduction in the initial investment or other factors results in a decrease of NPV by $1,000,000, while an increase leads to a corresponding NPV increment. The study investigates the influence patterns of each variable on the project, determining their criticality. The overall NPV calculation for the baseline solution affirms the financial efficiency of the project, projecting a potential profit of $5,379,998 over ten years. Conclusions drawn from the economic perspective underscore the financial efficiency and significant profit potential resulting from the project implementation. The acquired data proves valuable for formulating risk management strategies, particularly in scenarios where parameter changes can significantly impact the project outcome.

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