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DOCTORAL THESIS

SUMMARY

Cost management of construction projects

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Content

I. INTRODUCTION

The construction industry has always played an important role in economic and social development, influencing the way people live and interact with the built environment. In a global context marked by rapid changes, the construction industry occupies a central position in the economic development and infrastructure of society. However, project management within this complex industry requires strong strategic and tactical approaches, given the dynamic context characterized by the complexity of structures, variability of resources and interdependence of disciplines. The study of construction project management aids in infrastructure and urban ecosystem development, focusing on resource optimization, risk minimization, and enhancing the quality of final products. The construction sector is vital to a country's economy, generating jobs and beeing closely linked to productive infrastructure development. Economic development and the construction industry are interdependent, mutually influencing the entire economy of the country. Highly complex, the construction industry involves numerous actors such as investors, contractors, consultants, stakeholders and suppliers, representing a dynamic and complex industrial environment.

The evolution of constructions over time

The subchapter explores the evolution of the construction industry throughout history, highlighting the transition from ancient times' rudimentary structures to the advanced technologies and innovative materials used today. In the early stages, the constructions were simple, made of stones and mud, with thatched roofs. Over time, techniques, materials and philosophies have evolved, with constructions becoming representative of economic progress and transformations in the evolution of society. Traditional materials such as stone and brick were complemented by modern blends and metal components.

Natural factors influenced the evolution of constructions, and the ingenuity of engineering facilitated their effective approach. Currently, construction adopts innovative methods and eco-friendly materials, with an emphasis on durability and efficiency, reflecting technological progress and increased attention to ecological aspects. Recent changes in construction reflect adaptation to contemporary needs, including the use of advanced technologies to create more comfortable and eco-friendly living spaces.

The evolution of roads and other means of communication

Since the dawn of human civilization, roads have been fundamental to civilizational progress, serving as essential means of communication and resource transport. The emergence of road networks responded to the needs of communication, exchange of information and goods, marking a decisive step in the evolution of human society.

In parallel with the evolution of construction, innovative technologies such as modern concrete have transformed road infrastructure from ancient paths to modern highways. Road evolution reflects a complex process, in which technology, social needs and urban development have shaped human connections and influenced the stage of societies development.

Diversity and evolution of professions in the construction sector

Since the dawn of civilization, construction has spawned specialized professions, from ancient home builders to architects and energy efficiency specialists. Technological advances have significantly changed cost management in construction, introducing cost assessment specialists and diversifying professions. The future of this field will be influenced by smart technologies, machine learning and sustainability, this becoming an essential factor for long-term cost calculations. Skills related to accurate cost estimation and budget planning are considered essential for everyone involved in construction, from engineers and architects to project managers and contract administrators.

Socioeconomic impact and predicted future

The construction industry is currently facing significant challenges and opportunities in a context of rapid technological change and diversifying societal needs, representing a key pillar of the global economy. The construction sector has a major impact on economic growth, generating jobs in various sectors, but also faces challenges related to sustainability, energy efficiency and environmental impact.

Recent data highlights significant changes in the industry, with an increasing focus on green building projects and eco-friendly materials, in line with global concerns about climate change and sustainability. In a constantly changing environment, increased interest in construction and infrastructure is seen as a strategic necessity and an investment in a sustainable future.

The construction industry, the foundation of the global economy, is adapting to rapid technological change and sustainability concerns. Increasing focus on green building projects and eco-friendly materials, reflecting climate change concerns. Infrastructure is considered vital for an advanced society, and the development of the construction sector is seen as an investment in a sustainable future. The development of the industry has a significant social and economic impact, helping to stimulate the local economy and generate jobs. Challenges include waste management and the balance between development and heritage conservation.

The future of the construction industry seems closely linked to advanced technologies and sustainable solutions. With innovations in renewable energy, green materials and state-of-the-art construction technologies, the industry has the potential to become an example of smart and responsible development.

The aim and main objectives of the work

The purpose of this paper is to make construction investment projects more cost-effective by exploiting in depth the fundamental principles and practices of project management in the context of the construction industry and cost management.

The main objective of the paper is to analyze the strategies, techniques and tools essential for the successful planning, implementation and completion of construction projects, with an emphasis on understanding key concepts and exploring effective methods. Through case studies, it illustrates the need to apply project management principles in construction, highlighting specific solutions. **The central aim** is to improve project performance by providing readers with knowledge and skills for effective planning and management. The paper promotes sustainable development, identifying practices to reduce environmental impact. **The ultimate goal** is to stimulate research and continuous learning, providing a solid foundation for future construction project management professionals.

Overall, the aim of this paper is to provide a comprehensive and detailed look at construction project management, providing the necessary tools to address the complex challenges and maximize the opportunities presented by this vital industry.

One of the key reasons behind the relevance of this work lies in the complex nature of construction projects and the challenges they face. The construction industry is characterized by the diversity and interconnectedness of processes, variable factors and significant environmental and community impacts. In this context, a deep understanding of how project management influences the development and effective management of construction projects becomes essential to ensure their success and sustainability.

Secondary objectives of the work

The work aims to achieve the following secondary objectives:

- **Understanding the importance of cost and time control**: The paper aims to provide a clear and deep insight into the crucial role that effective cost and time management plays in the context of construction projects. It will explore the theoretical and practical aspects that support the need for and benefits of rigorous control in these areas.

- **Identifying critical factors**: The study will analyze and identify internal and external factors that may affect cost and time control in construction projects. From design changes to political instability, it will explore the factors that can generate risks and deviations in the management of these critical factors.

- **Analysis of management methods and practices**: The paper will analyze the available methods, tools and practices for cost and time control in construction projects. It will explore planning, monitoring and adjustment techniques that can help minimise risks and ensure project progress in the desired direction.

- **Impact on project performance**: Through this study, it will be analyzed how effective cost and time management can influence the final results of construction projects. It will explore how avoiding deviations and delays can contribute to the achievement of set objectives and client satisfaction.

- **Impact on the construction industry**: A significant focus will be placed on the construction industry, where the complexity of projects and the interaction with the environment requires a careful life cycle approach. The paper will focus on how the concept is applied in this industry and how it influences the final results of construction projects.

- **Contribution to knowledge**: To make a significant contribution to the deep understanding of the field of cost and time management in construction projects, developing a critical and complex perspective on the subject.

- **Benefits and challenges of implementation**: The paper aims to identify and analyze the benefits offered by project management, but also to reveal the challenges faced by organizations in implementing and adapting this concept in their management practices.

II. DEFINING INVESTMENT PROJECTS IN CONSTRUCTION

The first step in starting a construction investment is to develop a complex construction project, which involves coordinating multiple entities with different expertise and managing human and non-human resources within a well-defined time, cost and performance framework.

A project is a temporary effort to produce a unique result, with clear objectives for completion within the established time, within budget and with quality requirements. To ensure the success of a construction project, it is important to approach cost management effectively, involving a deep understanding of the concept of project management. It is defined as a complex process of planning, organizing, coordinating and controlling resources to achieve project objectives with a focus on meeting time, cost and performance parameters. A graphical representation associated with these definitions highlights that effective project management aims to meet client requirements and maintain positive relationships, and project success is measured in meeting these predefined parameters.

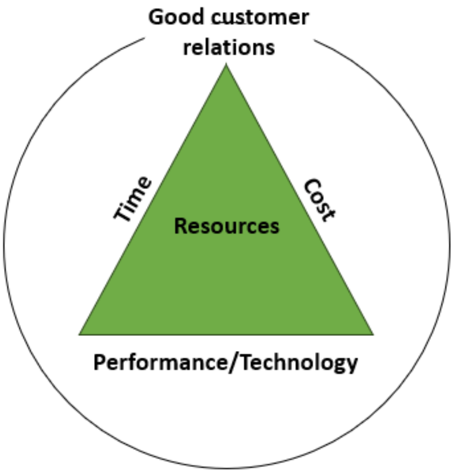

Figure no. 72. Overview of project management [2] , [3], [40].

Selection process of construction investment projects

The selection process of construction investment projects is an essential aspect of strategic business decisions, involving the detailed evaluation and selection of projects with the potential for financial returns and significant organizational benefits. This process consists of carefully analyzing and comparing investment options, taking into account criteria such as profitability, technical feasibility, environmental impact, risks and other relevant factors.

There are five important steps in developing a model for evaluating and prioritizing project proposals, as follows:

- establishing evaluation criteria,
- establishing the scale score for each of the criteria,
- establishing the scoring method for each of the criteria,
- establishing the calculation of the final score,
- establishing the list of projects based on the calculated score [44].

Life cycle of construction investment projects

The development process of a construction project goes through a life cycle, starting with the identification of the investor's need. This cycle, often linear, involves the development of a conceptual design and the analysis of technical, economic and social feasibility. Structured in successive phases, the linear cycle simplifies the distribution of tasks and allows accurate forecasting of execution periods in the field of construction. The illustration of the project cycle is presented in Figure no. 77 [34].

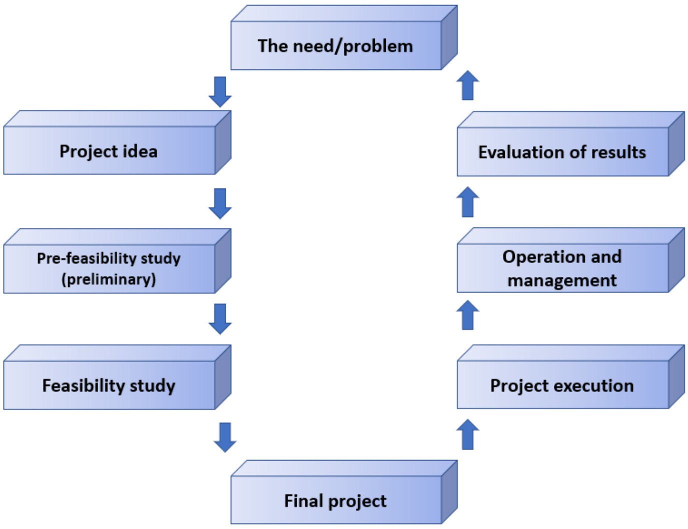

Figure no. 77. Phases of a project cycle of construction [34].

Stages within a construction investment project

The need for the project

In construction projects, initiation begins with identifying the need, evolving from idea to project formulation and reaching maturity in the execution and operation phases. The process of identifying the need is a creative approach, focused on recognizing a problem that can be addressed through the project, providing a solid basis for coherent and effective development of the initiative. It is a process that involves a meticulous evaluation, confirming the relevance and significance of the proposed initiative.

Pre-feasibility study

The pre-feasibility stage is a detailed analysis of the viable alternatives identified in the previous stage, with the aim of narrowing down the options. Allocation of resources for studies is essential at this stage, and a favorable pre-feasibility study provides early warning of the financial resources required for the future project implementation. The process determines the effectiveness or ineffectiveness of the proposal and influences the decision to proceed, postpone or abandon the project, taking into account technical, economic, social and environmental aspects. The final decision is based on a careful evaluation of the advantages and disadvantages.

Feasibility study

In the feasibility stage, the aspects studied in pre-feasibility are investigated in detail to reduce uncertainty and quantify risk factors more precisely. The objective is to eliminate uncertainties and minimize the variation in costs and benefits of the construction project. The study seeks optimal solutions, helping to identify and solve problems, based on a clear problem formulation. This is essential for initiating the study and justifying the significant costs, confirmed by the prior pre-feasibility study.

Development of the final project

Once the viability of the project has been confirmed, the final study or the detailed technical file is prepared, including technical, financial, socioeconomic, environmental and organizational documents. This file ensures that the selected alternative can be implemented with maximum guarantees, ending with the preparation of a technical file that includes a descriptive memorandum, a detailed memorandum, technical plans, a specification, detailed technical specifications and a financial evaluation, each having an impact on the quality of the project and construction processes.

Project execution

This stage represents the concrete implementation of the project, marked by the start of the physical execution of the investments through the bidding process for the works associated with the whole project or a part of it. The phase adapts to the technical specifics of each project, involving the mobilization and efficient management of resources in order to develop the project.

Project operation and management

In the project operation and management phase, the focus is on monitoring progress against initial planning and implementing corrective measures. The active leadership role involves guiding the team and subcontractors to efficiently and promptly complete their tasks. The importance of ensuring compliance with the original plan, legal compliance and environmental protection are priorities. Well-defined procedures for risk management and contingency planning are essential. Constant cost monitoring and effective communication between all involved are necessary to prevent problems and keep progress aligned with original plans.

III. THEORETICAL ASPECTS OF COST MANAGEMENT IN CONSTRUCTION INVESTMENT PROJECTS

The role of cost management in construction projects

The cost management system is a key factor in the decision-making process. Cost management consists of three distinct components:

- **Cost analysis and calculation**: Preparation of essential information for planning, control and evaluation, covering production/construction costs and service delivery costs.
- **Cost planning and control**: Fundamentals for providing the necessary information for decision-making on the future prospects of the project.
- **Decision-making and performance estimation**: Involves defining objectives, analyzing alternatives, evaluating them and selecting the best option.

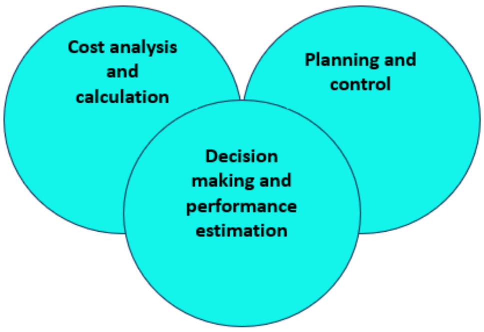

Figure no. 88. The three elements that characterize the cost management system [55].

Construction cost management is essential at all stages of the investment cycle, with the objective of maintaining or reducing construction costs compared to tender phase estimates.

The project manager's role as quantity surveyor for the investor involves planning construction costs with attention to detail, efficiency and objectivity. The economic performance of the construction is optimized by reducing the total cost during the entire life cycle of the project.

Construction life cycle cost

The term "life cycle cost" is defined according to the ISO 15686:2008 standard as a technique that allows understanding comparative costs, taking into account all relevant economic factors over an extended period of time, including initial capital costs and future operational costs [70], [34]. According to the ISO/DIS 15686:2008 standard, life cycle costs have the following structure (Figure no. 89):

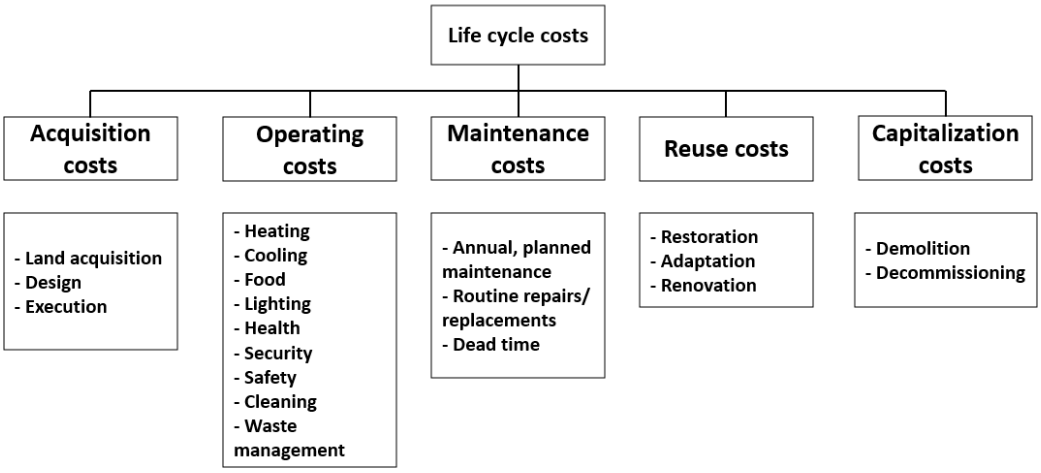

Figure no. 89. Life cycle costs [34].

Construction life cycle costs (CCVC) are calculated according to the following formula:

$$CCVC = C_A + C_E + C_Î + C_R + C_V$$

where:

C_A = Acquisition costs

C_E = Operating costs

$C_Î$ = Maintenance costs

C_R = Replacement/reuse costs

C_V = Costs regarding the demolition, decommissioning of the construction [34].

Cost estimation and control are fundamental in construction projects, representing an essential starting point. The project requires accurate cost estimates and the establishment of execution budgets before the actual start. During execution, it is important to calculate and monitor all expenses related to human resources, materials, machinery and equipment, thus avoiding exceeding the established budgets. Over the construction's lifetime, operation and maintenance costs can significantly exceed the initial construction costs, reaching up to 85% of the total costs [34].

Types of costs and their classification

In the construction industry, the first step to a profitable project involves understanding and evaluating the various cost categories associated with the work. Accurate estimates are essential for both investors and executors, having a significant impact on the decision to proceed with the project or not. Cost evaluation, an important tool in decision-making, involves careful analysis of the impact of each decision and the possible implications for the involved entity [71], [2].

Total cost

Total cost in construction investment projects represents the sum of all expenses involved from conception to operations and long-term maintenance. It includes direct costs (materials, equipment, labor) and indirect costs (feasibility studies, expertise, authorizations, administration). Both direct costs, related to specific components, and indirect costs, essential for the overall evaluation of the project's efficiency, also cover post-implementation aspects such as maintenance, repairs and subsequent improvements.

$$CT = CD + CI$$

where:

CT = total cost of construction project
CD = direct cost
CI = indirect cost

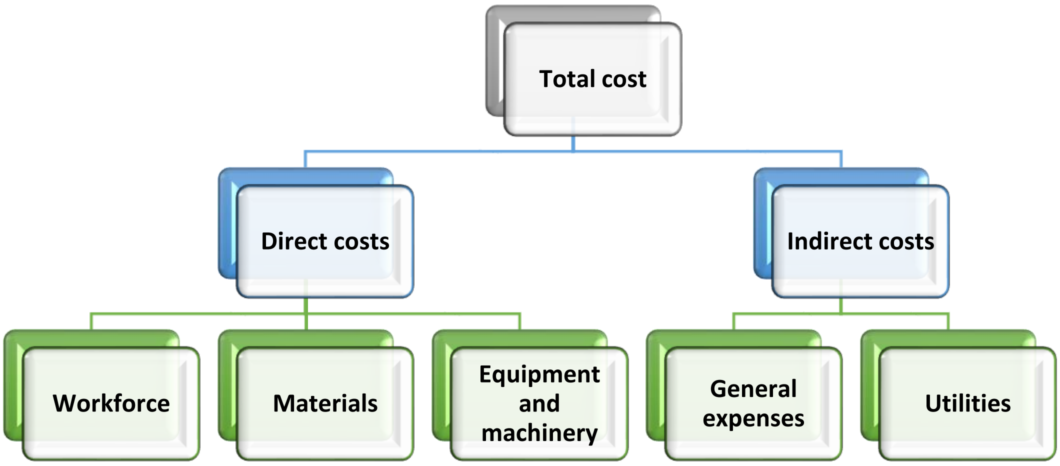

Figure no. 91. Classification of costs according to the mode of distribution [34].

Direct cost

The direct cost in the construction of a project represents the amount directly related to its development and implementation, covering materials, labour, equipment and tools required. These expenses, considered variable, fluctuate depending on the quality and quantity of the materials. Analysis of these costs for each element of the project can have varying levels of approximation, and their refinement does not always guarantee a significant improvement in accuracy. Direct costs derive from the geometric analysis of plans and are essential for budgetary control, covering the execution of construction work and aspects such as the acquisition of lands and utilities.

Indirect cost

Indirect cost in the construction of a project is the extension of expenses beyond the immediate, covering utilities, office equipment, rent, mobile devices and consumables. These costs can be variable or fixed and persist after the direct costs have been calculated. They include overheads such as administration, organization, technical direction, supervision, machine transport, contingency resources and construction equipment. In budgeting, indirect costs are often expressed as percentages of direct costs and also include operating costs such as fuel, technical and administrative expenses, land charges, taxes and financing expenses. The importance of controlling these costs increases in case of delays in project completion.

The relationship between the duration of a project and it's cost

The total costs of a project can vary if the duration of the project increases or decreases, resulting in different costs for different durations of a project [79] and for this reason it is possible to generate models that correlate the duration with the project costs [34].

Relationship between project duration and direct cost

The relationship between the duration and direct cost of a construction activity can be simplistically represented by a linear function with a negative slope, suggesting that an increase in duration brings a decrease in direct costs. However, in reality this relationship may be more complex, with influences such as additional labour and associated costs. Theoretical modeling suggests that cost–duration relationships are generally convex functions, and cost increases may be driven by factors such as reduced productivity due to overtime and the increased size of work teams [80], [34] .

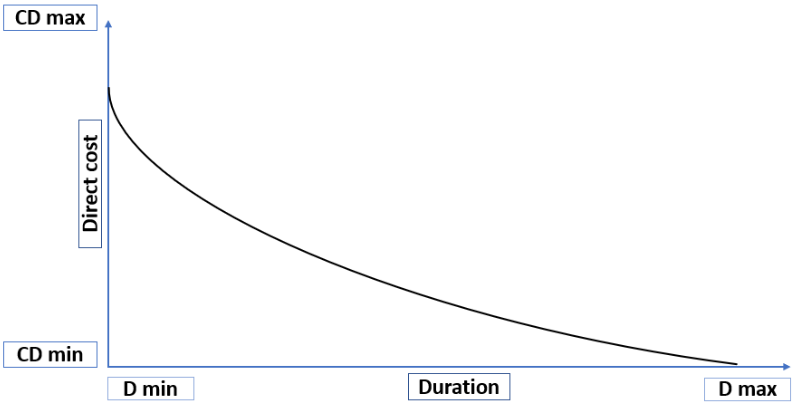

Figure no. 93. Duration - direct cost relationship [80], [34].

Relationship between project duration and indirect cost

The indirect costs of a project can be modeled as a linear function, increasing and decreasing in direct proportion to the duration of the project. Thus, indirect costs increase as the duration of activities increases, generating higher costs for administrative staff and other associated aspects [34].

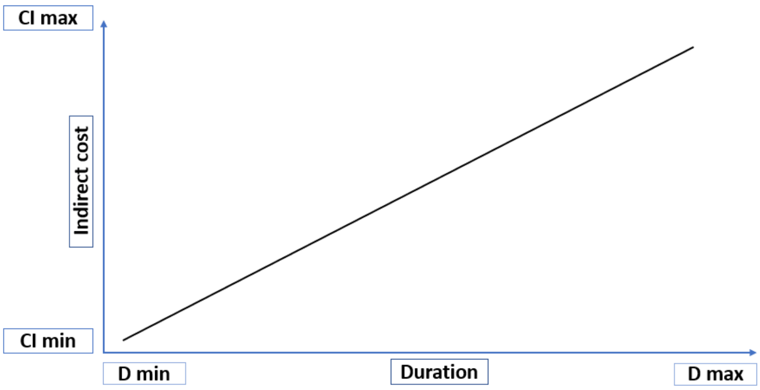

Figure no. 94. Duration relationship - indirect cost [80] , [34].

Relationship between project duration and total cost

By summing direct and indirect costs, a curve is obtained from which it is possible to determine an optimal duration that minimizes the total costs (coordinate (D opt, CT min)). And, starting from the sum of the costs associated with all activities, the total cost of the project can be determined [34].

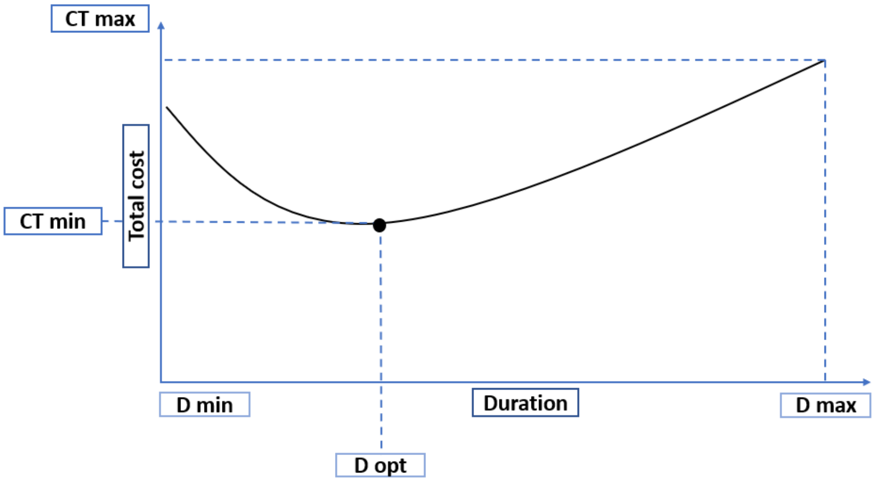

Figure no. 95. Duration - total cost relationship [80], [34].

Reducing the duration of a project can be achieved by speeding up critical activities, involving increased resources, introducing overtime or different construction methods. However, these changes bring with them an increase in direct costs, while indirect costs will decrease accordingly, regardless of the strategy adopted [79], [34].

IV. PLANNING, ESTIMATING AND COST CONTROL

Cost planning of a construction project

Cost planning in a project contributes to its effectiveness and progress. Accurate cost anticipation helps to minimize the risks associated with budget overruns, wasted resources and inadequate financial management. The developed budget must cover all phases of project development, including expenses such as preliminary investigations and design plans.

Cost optimization involves understanding external influences, such as material delivery delays or workforce health issues. Planning must integrate contingency and alternative strategies to manage these issues. Land acquisition and obtaining approvals are important issues, considering the potential impact on neighboring facilities and population. Transparency in cost planning is vital for effective collaboration between parties ensuring common understanding of project management.

Estimating the costs of a construction project

Estimating construction costs involves the total assessment of direct and indirect costs within the project. Purposes include determining the economic magnitude of the project and justifying the appropriate planning. Adapting the analysis to the specifics of each project is essential, taking into account variables such as material, labor and equipment costs, spatial and temporal coordinates. Factors such as construction method, complexity of the work and regulations have a significant influence on cost estimation.

Cost estimation and economic analysis interconnect throughout the project lifecycle, providing support from conception to completion. The estimate provides a detailed insight into the costs, but the actual cost is revealed when the project is completed. In construction, cost estimating identifies and evaluates the costs and time likely to be required, and is essential in planning for financial evaluation and effective budgetary control. An effective estimating system involves the development of initial estimates, the generation of costing options, and the implementation of control measures to ensure compliance with the budget.

Uncertainty in cost estimation is greatest at the beginning of the process when information is limited in quantity and quality. As information improves, uncertainty is reduced until all costs are known with certainty. Cost estimation is a trade-off between information and uncertainty.

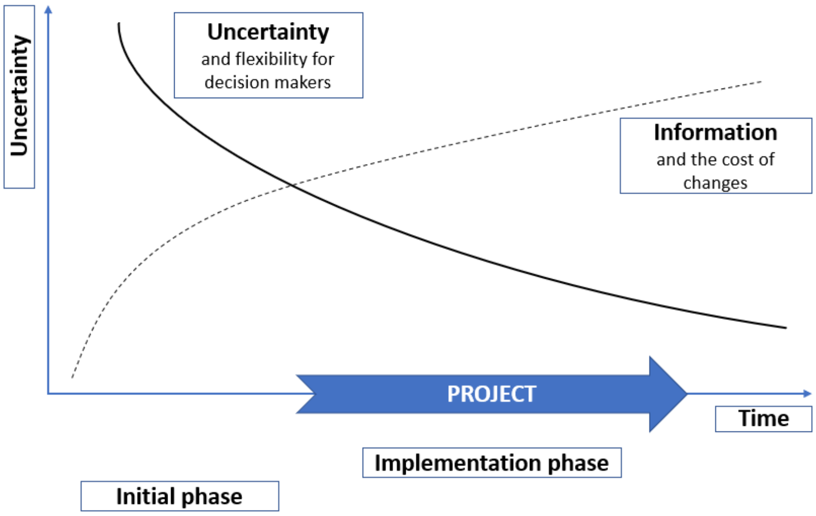

Figure no. 101. The relationship between information and cost estimation uncertainty [54].

Construction project cost estimating tools and techniques

Cost estimation in construction projects is influenced by the level of detail of the project. Parametric estimation can be used for budgets with limited information, while unit cost estimation is applicable for detailed budgets. Estimating techniques vary, with some relying on experience and reasoning and others taking a more mathematical approach.

Analog estimation:

- It is based on the actual costs of previous similar projects to estimate the current cost.
- It is less accurate, but less expensive and less time consuming.

Parametric estimation:

- Uses variables taken from other similar projects and applies them to the current project.
- Can provide a higher degree of accuracy than analog estimation.

Three values estimation:

- Reduces biases and uncertainties by evaluating three variables: the optimistic, pessimistic and most likely estimate.
- Calculates an estimated (expected) cost of the activity based on these three values.

Bottom-up estimation:

- This is the most accurate method.

- Calculate the cost of each activity and component subunits, adding maximum detail.
- Requires considerable time and financial resources, but reduces the associated risk.

Expert opinion:

- Provides information on labor rates, material costs, inflation, risk factors etc.
- It can help reduce risks and give the project credibility.

Each method has advantages and disadvantages, and the choice depends on the level of detail available and the specifics of the project. Cost estimation remains an essential process in construction project management, helping to establish a solid foundation for budget planning and control.

Cost control of a construction project

Cost control in construction aims to identify and reduce costs in order to optimize profit and reduce overall costs. The process involves monitoring actual progress against initial planning, tracking team tasks and detailed evaluation of schedules and costs, and is essential in a competitive environment.

The purpose of time control in construction projects is to strictly adhere to the established schedule, which is essential to avoid delays and budget overruns. Despite careful planning, projects may experience delays for various reasons such as scope changes, weather conditions or material resource limitations and variations in labor availability [2], [3], [117] . Effective cost management involves a well-defined methodological approach and a firm commitment to monitoring and intervention to ensure budget and time compliance of projects.

V. COST ANALYSIS IN ROAD INFRASTRUCTURE INVESTMENT PROJECTS

Defining road infrastructure investment projects and the involved participants

Infrastructure projects, such as the construction of roads and highways, are fundamental to the functioning of society and have a significant impact on the quality of life and the local economy. These long-term investments support economic and social development by facilitating mobility, reducing logistics costs and promoting trade exchanges. Road infrastructure construction projects are complex, involving various stakeholders, and careful coordination and cost estimation are useful for minimizing risks and ensuring project success. Effective communication and collaboration between participants are the key to achieving functional, safe and sustainable road infrastructures.

Cost analysis in road infrastructure investment projects

Assessing costs in road infrastructure projects is a complex process influenced by variables such as project complexity, construction type, market conditions, geographical constraints, meteorological factors and the financial position of the beneficiary. The project's feasibility and construction methods are also essential factors in cost evaluation. Infrastructure projects are characterized by high customization, and cost estimation involves careful assessment of the project's opportunity and feasibility, taking into account aspects such as additional fees, construction permits, and stakeholder perspectives, which can influence the final cost.

When discussing about infrastructure projects, cost evaluation is performed by means of the following mathematical expression:

$$Project\ cost = Construction\ cost + Financial\ cost + Maintenance\ cost$$

Project costs are closely tied to the investment required for the construction of the works and the amounts allocated for maintenance over the project's useful life. The main aspects covered include initial costs, maintenance, environmental costs and incident management costs that arise during the project's execution.

During the life cycle of a project, the accuracy of estimated costs evolves with its progress and the degree of uncertainty associated with costs decreases. The distinct stages of costing include:

- **Conceptual cost**: The initial cost estimate provided by the designer, based on known factors or indices.
- **Pre-construction cost**: Calculated on the basis of the conceptual cost, it includes costs associated with technical preparation, work execution and project supervision.
- **Cost of additional work**: Additional cost incurred during construction due to unforeseen factors that may affect the project schedule.
- **Cost of completion of the works**: The total investment cost at the end of construction, including the estimated cost before construction, plus variations that occurred during the project.

Initial construction and rehabilitation costs

Initial construction and rehabilitation costs cover the expenses required for the planning, design and execution of new road infrastructure or the restoration of the existing one. These costs are influenced by factors such as project complexity, geographic location and type of road surface. The initial assessment focuses on achieving a favorable balance between costs and benefits, taking into account the proportionality between construction and rehabilitation costs.

Maintenance and operation costs

Road infrastructure maintenance works and services cover the activities required throughout the year to counteract wear and tear or degradation under normal operating conditions. The aim is to ensure the technical conditions for safe traffic, complying with technical standards and keeping public assets clean and presentable [131].

Maintenance costs include the expenses required to maintain the system at established levels to meet the demand defined in the project . Regarding maintenance costs, the following categories of activities are taken into account:

- Routine maintenance;
- Periodic maintenance;
- Scheduled maintenance;
- Regulatory maintenance;
- Resilient activities;
- Reactive interventions;
- Rehabilitation (reconstruction);

Calculation formulas for determining maintenance and operation costs [133]:

The determination of operating costs can be done according to the following two formulas. The first variant distinguishes between capital and current repairs:

$$C_e = \sum_{t=1}^{n} (C_{rc} + C_{rk} + C_{ce} + C_u + C_a + C_m + A_c) \frac{1}{(1+a)^t}$$

where:

C_{rc} – current repair costs;
C_{rk} – capital repair costs;
C_{ce} – costs related to energy consumption;
C_u – utility costs;
C_a – administrative costs generated by the use or ownership of the construction;
C_m – environmental costs considered as negative externalities or costs for environmental protection in the form of reductions;
A_c – other costs that appear previously (determined according to the specifics of the construction);
a – discount rate;
t – the year of the exploitation period.

The second option does not distinguish between current and capital repairs. These appear in the form of maintenance, repair and rehabilitation costs.

$$C_e = \sum_{t=1}^{n} (C_{mrr} + C_{ce} + C_u + C_a + C_m + A_c) \frac{1}{(1+a)^t}$$

where:

C_{mrr} – maintenance, repair and rehabilitation costs;
C_{ce} – costs related to energy consumption;
C_u – utility costs;
C_a – administrative costs generated by the use or ownership of the construction;
C_m – environmental costs considered as negative externalities or costs for environmental protection in the form of reductions;
A_c – other costs that appear previously (determined according to the specifics of the construction);
a – discount rate;
t – the year of the exploitation period

The maintenance, repairs and rehabilitation cost during the lifetime of the construction can be expressed as follows:

$$C_{mrr} = \sum_{i=0}^{t} \sum_{j=1}^{n_i} C_{j;i} \frac{1}{(1+a)^t}$$

where:

C_{mrr} = the cost of maintenance, repairs and rehabilitation works during the lifetime of the construction;
$C_{j;i}$ = the cost of maintenance works "j" in year "i";
n_i = number of maintenance works in year "i";

t = the number of years in the time sequence considered (the exploitation period in its entirety or only a part of it);

a = discount rate.

The cost of maintenance, repairs and rehabilitation works can also be determined statically:

$$C_{mrr} = \sum_{i=0}^{t} \sum_{j=1}^{n_i} C_{j;i}$$

Maintenance costs are calculated in accordance with the technical procedures specific to each mentioned concept. Each maintenance concept is exclusive, meaning that in the years when routine maintenance is performed, periodic conservation will not occur, and in the years when rehabilitation occurs, none of the other concepts will be implemented.

In order to determine the necessary conservation works for roads, a modeling of the deterioration process of their superstructure is proposed. The aim is to estimate the degree of damage that the road can suffer, given the technical specifications of the project. Costs are then distributed for each section of the project and aggregated to obtain an annual cost estimate.

The mode of damage to the road superstructure

The road surface deteriorates due to a complex set of factors, including heavy traffic, extreme weather conditions and natural events. Deterioration analysis not only facilitates the anticipation of priorities and the efficient allocation of resources, but also the identification of overloaded areas, as well as the introduction of control measures to reduce negative events in road infrastructure. It is important to emphasize that a severely damaged superstructure requires constant maintenance and can eventually lead to significant traffic delays and congestion in traffic [137].

The behavior of the road superstructure, illustrated in Figure no. 108, highlights its deterioration over time as a result of loads and climatic conditions. Initially, road infrastructure provides a "very good" quality, but as it is exposed to adverse demands and conditions, its condition deteriorates. There are two main levels of condition: "very good" and "unacceptable", influenced by user requirements.

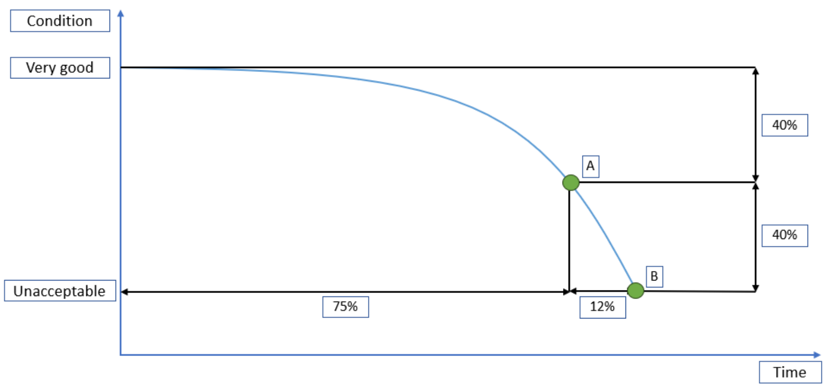

Figure no. 108. Behavior of the road superstructure [138].

For a well-designed, constructed and maintained road, the road surface undergoes gradual deterioration from the time it is put into use, significantly accelerating at a later stage marked in Figure no. 108 as point A. About 40% of the deterioration occurs from commissioning to point A, and another 40% happens from point A to point B. The road reaches point A in about 75% of its service life, from where it rapidly degrades towards point B.

The cost associated with the rehabilitation of a road, representing all the techniques and activities necessary to restore it to its original state, varies considerably depending on its state of deterioration, according to Figure no. 109. The discrepancy is so significant that determining the right timing and the right type of maintenance and rehabilitation becomes of particular economic importance.

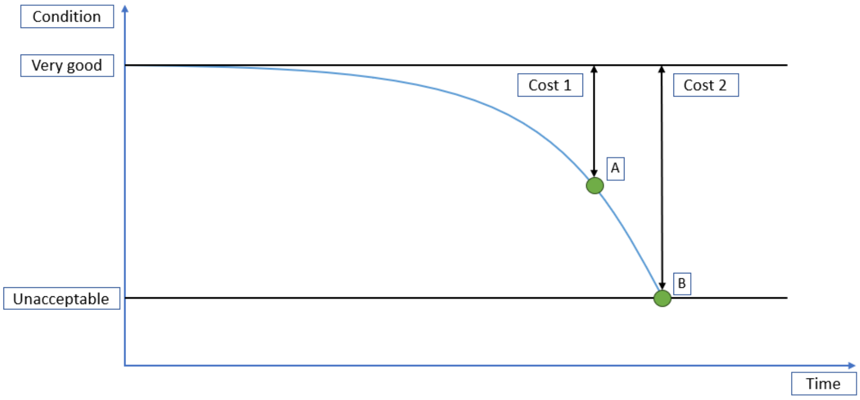

Figure no. 109. The economic implications of postponing rehabilitation investments [138].

Additionally, the chosen strategy for the maintenance and/or rehabilitation of the road has a direct impact on the level of service it will provide to users during its useful life, as illustrated in Figure no. 110.

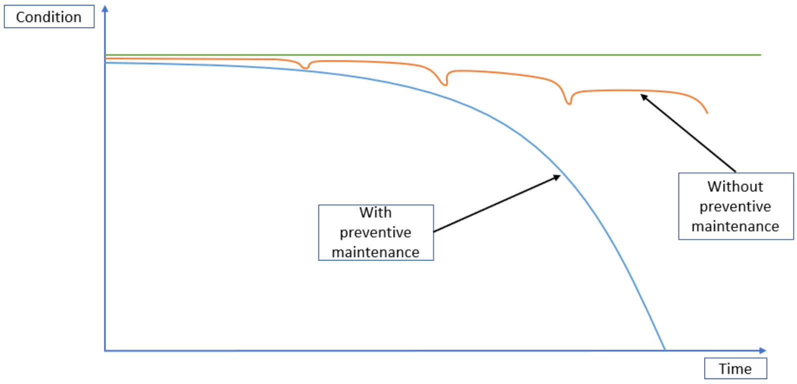

Figure no. 110. Implications of different strategies on road condition [138].

Finally, it is important to note that the condition of the road over time, which depends on the selected maintenance and rehabilitation strategies, will also influence the costs borne by road users. Figure no. 111 illustrates the impact of road condition on both maintenance costs and operating costs.

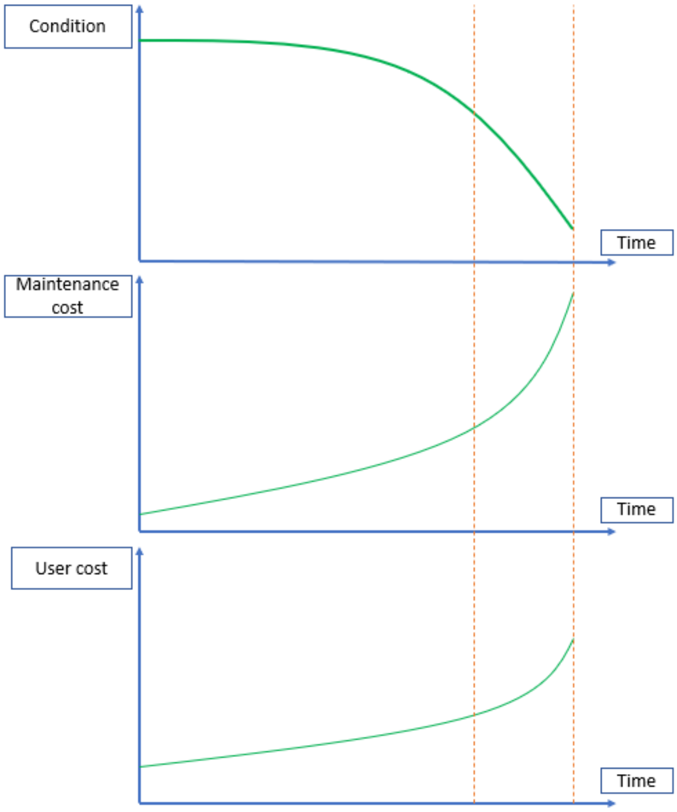

Figure no. 111. Relationships between road condition, maintenance costs and usage costs [138].

An inadequate road maintenance strategy can lead to deterioration, generating significant increases in maintenance and rehabilitation costs. This situation also affects user costs, including vehicle operating costs and travel time, resulting in higher overall costs for passenger and freight transport. These implications have a significant impact on the socio-economic profitability of the road and underline the importance of maintenance decisions and their consequences.

The benefits of investment projects in road infrastructure construction

The benefits associated with the project focus on the annual cost savings at the national level and for the users of the respective infrastructure, with an emphasis on the positive impact in the region where it is implemented. Benefits related to the entry into operation of the project include savings in generalized travel costs for vehicles traveling on the relevant road network. Improvements in road conditions lead to less wear and tear and lower fuel consumption for vehicles. The poor state of road infrastructure not only creates barriers in transportation, but also contributes to pollution, increased road accidents and insecurity.

In areas where road infrastructure improvement projects are implemented, the reduction of transportation costs is the main benefit, having a positive impact on all activities related to the transport market in the project area.

Evaluation methodologies for investment projects in road infrastructures construction

Road infrastructure project evaluation starts by defining the "no project" situation and optimizing it, followed by comparison with the "with project" situation. The analysis focuses on the relationships between demand and supply of infrastructure, paying particular attention to the technical characteristics of the road. Demand is influenced by road users and the costs and benefits of travel vary according to the purpose and socioeconomic characteristics.

Alternatively, each road project has its own deterioration pattern, highlighted by the International Roughness Index (IRI), varying according to types of projects and materials used [34].

The International Roughness Index (IRI) directly reflects the condition of the road surface, ranging from 0 for a perfectly flat surface with no imperfections to higher values for roads with irregularities and roughness.

Profitability indicators

Profitability refers to the rate of return on investment from the income generated by an activity and project evaluation analyzes and compares alternatives to provide essential information for decisions. Profitability indicators, whether quantitative, qualitative or descriptive, reflect the impact on economic, social or environmental aspects and contribute to the analysis of results [154]. A road project is considered beneficial for social welfare when the benefits exceed the intervention costs, aiming to solve existing problems in the market and bring significant and sustainable improvements to society [155].

Net present value (NPV), internal rate of return (IRR) and cost-benefit ratio (C/B)

Choosing an infrastructure construction project proposal requires an economic evaluation to determine profitability. There are specific indicators that can help in identifying the most advantageous proposal, minimizing the associated risks. These indicators help determine the value of road infrastructure construction, resulting in the evaluation of the financial performance of the project in order to make informed decisions [34].

Net present value (NPV)

The net present value (NPV) expresses the difference between the project's revenues and expenses in current currency. A positive NPV indicates the project's acceptability. In cost-benefit analysis, expressing costs and benefits in present value provides a true perspective of profitability, and a project is considered acceptable when it achieves an NPV greater than zero, reflecting a favorable balance between benefits and costs.

$$VAN = \sum_{t=0}^{T} \frac{CF_t}{(1+r)^t} = CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_T}{(1+r)^T}$$

where:

CF_t = net value of cash flow in year t (difference between actual income and expenses)
CF_0 = initial investment
r = discount rate (cost of capital)
t = number of years
T = project lifetime

Internal rate of return (IRR)

The internal rate of return (IRR) is an important criterion in project evaluation, representing the rate at which the net present value (NPV) becomes zero. It is used to avoid selecting an initial rate of return, being compared to the market interest rate. However, calculating the IRR can be complex and susceptible to errors.

$$IRR = \frac{D_1 + NPV_1(D_2 - D_1)}{(NPV_1 - NPV_2)}$$

where:

D_1 = reduction standard, corresponding to NPV_1
D_2 = discount rate corresponding to NPV_2
NPV_1 = positive value of net income
NPV_2 = negative value of net income

To be profitable, a project must have an internal rate of return greater than the opportunity cost. This indicator is essential for comparisons between alternatives when choosing between projects, especially in the context of limited resources in the public sector.

Cost/Benefit Ratio (C/B)

The cost-benefit ratio (C/B) is calculated by relating the costs to the benefits of a project, and if the result is greater than 1, the project is considered advantageous or feasible [34] .

$$B/C = \frac{\sum_{t=1}^{D} \frac{V_t}{(1+a)^t}}{\sum_{t=1}^{D} \frac{(I_t + C_t)}{(1+a)^t}}$$

where:

V_t = the incremental income obtained in year t as a result of making the investment (u.m./year)
I_t = investment made in year t (u.m./year)
C_t = the incremental cost in year t obtained as a result of the investment (u.m./year)
a = discount rate (%/year)
D - the period of analysis that includes the execution time and the economic life time (years)
For the acceptance of an investment in infrastructure projects, the essential condition is that B/C >1. This parameter is widely used in the analysis of highway projects globally, providing a simple measure for assessing the value of public assets. B/C analysis allows the observation and comparison of alternatives within road projects, including variants related to maintenance periods and the use of different technologies. From a technical perspective, the results are similar, but financial aspects can influence the choice of one alternative over another.

CASE STUDY I. INVESTMENTS IN MAINTENANCE WORKS AND SERVICES FOR THE NATIONAL ROAD AND HIGHWAY NETWORK

During the period 2019-2022, the National Company for Road Infrastructure Administration (CNAIR) managed the increasing challenges in the field of road infrastructure, carrying out extensive maintenance, repairs and inspections to maintain the proper condition of national highways and roads. Investments in infrastructure registered a significant increase, reaching a record amount of approximately 2 billion lei in 2022. The financial allocation targeted summer and winter maintenance, as well as periodic maintenance works and current repairs. The ongoing priority is to ensure the quality and sustainability of the road infrastructure to support the economic development of the country. The investments were substantial, with total amounts of approximately:

Year 2019: 1.768.347.971 lei, including VAT, of which:

- works and services regarding current maintenance during summer: 306.222.417 lei, including VAT;
- investments made for current maintenance in the winter season: 390.786.057 lei, including VAT;
- periodic maintenance works and current repairs: 398.969.972 lei, VAT included.

Year 2020: 1.413.991,525 lei, including VAT, of which:

- works and services regarding current maintenance during summer: 159.356.536 lei, including VAT;
- investments made for current maintenance in the winter season: 241.937.520 lei, including VAT;
- periodic maintenance works and current repairs: 478.257.567 lei, VAT included.

Year 2021: 1.699.219.784 lei, including VAT, of which:

- works and services regarding current maintenance during summer: 335.942.220 lei, including VAT;
- investments made for current maintenance in the winter season: 400.120.853 lei, including VAT;
- periodic maintenance works and current repairs: 405.119.433 lei, VAT included.

Year 2022: 1.954.496.083 lei, including VAT, of which:

- works and services regarding current maintenance during summer: 323.699.136 lei, including VAT;
- investments made for current maintenance in the winter season: 400.719.680 lei, including VAT;
- periodic maintenance works and current repairs: 581.871.602 lei, including VAT.

During the period 2019-2022, CNAIR demonstrated an increased commitment to improving road infrastructure, reflected in a global increase in investment of 10.53%. Current maintenance work increased by 5.71% in the summer season, highlighting the concern to keep the infrastructure in proper condition. In the cold season, investments for current maintenance increased by 2.54%, highlighting the preparation for difficult weather conditions. Significant investments in periodic maintenance and current repairs saw a 45.84% increase, indicating increased attention to improving existing infrastructure. Investments were made to improve road safety, contributing to the reduction of accidents:

- Year 2019: 151.749.447 lei including VAT;
- Year 2020: 101.459.653 lei including VAT;
- Year 2021: 95.847.096 lei including VAT;

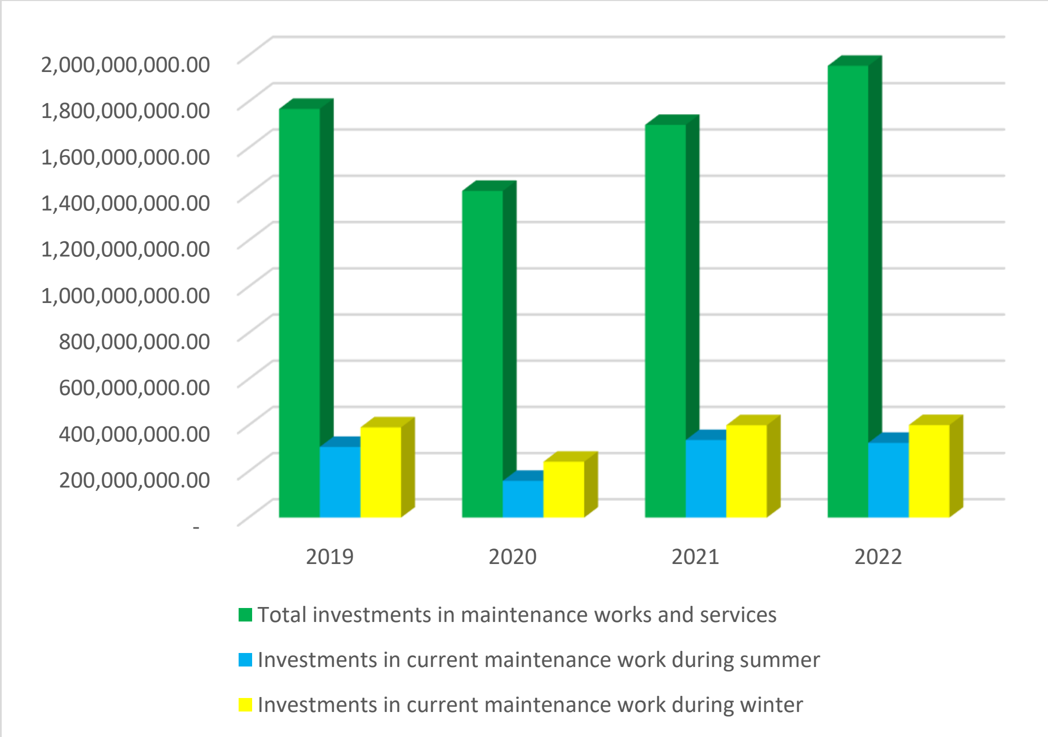

Figure no. 122. Investments associated with maintenance works and services 2019-2022 [221], [131], [222], [223].

Significant investments in road infrastructure during the period 2019-2022 reflect the commitment to the economic and social development of Romania. The significant financial allocation highlights the priority given to the maintenance and conservation of the national road and highway network. Periodic and current maintenance work were planned, contributing to maintain safe traffic conditions and preventing road damage. Investments covered the entire road system, including highways, reflecting a global approach to infrastructure improvement. Ongoing road safety efforts have included significant improvements, justifying the continued importance of these investments for long-term economic and social benefits.

CASE STUDY II. COST ANALYSIS FOR A HIGHWAY IN FOUR CONSTRUCTION OPTIONS

1. Development

The construction of the Ploiești-Buzău Highway, part of Corridor 3, represents a national priority for improving the road infrastructure. The objective of the study is to identify the most viable solution for the section, analyzing four types of road structures. Structural aspects and associated costs were evaluated for the following options: flexible, semi-rigid, rigid and rigid with cement concrete base layer and bituminous coating according to Romanian technical design norms.

2. Current situation analysis

The General Transport Master Plan reveals that less than 3% of the national road infrastructure in Romania corresponds to highway standards. The existing network, predominantly roads with a 1x1 profile, generates an average speed of 66 km/h for interurban travel. In the Ploiești-Buzău project area, the average speed on DN1B is approximately 71 km/h, with a 1x1 road profile. Major road safety issues are related to the fact that approximately 90% of national roads are one-way, limiting safe overtaking and affecting traffic capacity.

3. Cost benefit analysis

The cost-benefit analysis is structured in three stages: economic analysis, financial analysis and risk analysis. Economic analysis explores the long-term impact of the project on the economy and society, while financial analysis focuses on specific aspects of cash flows and profitability. Risk analysis is important for identifying and managing potential obstacles and uncertainties in project implementation, ensuring a comprehensive assessment of feasibility and sustainability.

Financial analysis

The analysis for the Ploiești-Buzău highway project focuses on criteria related to structural performance and costs associated with the construction, maintenance and reinforcement of road structures. The criteria include total construction cost for a 30-year lifetime and maintenance costs for different types of road structures over various periods. The evaluation of these criteria aims to identify the optimal road structure option, balancing initial costs, maintenance costs and long-term performance.

Additional criteria, such as conditions and duration of execution, behavior over time and the state of the structures at the end of the perspective period, complement the financial and structural analysis to determine the most suitable solution. The selection process involves assigning scores to economic criteria such as cost of execution (construction cost + reinforcement cost) and maintenance work cost + intervention/reconstruction cost, and in case of a tie, criteria related to structural performance are taken into account for a comprehensive and sustainable final decision.

Economic analysis of the project

Execution cost of the proposed road structures

Calculations for pricing in the Ploiești-Buzău highway project are based on experience from similar projects and unit cost data, using unit prices and layer thicknesses for each type of road structure. These elements form the basis for calculating the costs per kilometer for the execution works. In addition, the construction of a 22-meter platform according to the Typical Cross-Section Profile for high-speed roads with a highway profile is considered.

Table no. 46. Execution cost (construction cost + reinforcement cost) for road structures under analysis [230].

Structure type	Construction cost Lei	Reinforcement cost Lei	Execution cost Lei
Flexible	7.951.220,20	1.948.809,5	9.900.029,70
Semirigid	6.894.713,10	1.948.809,5	8.843.522,60
Rigid with cement concrete coating	7.105.472	-	7.105.472
Rigid with cement concrete base layer and bituminous coating	9.847.803,90	-	9.847.803,90

Maintenance work cost

The analysis for selecting the road structure in the Ploiești-Buzău highway project focuses on the total investment cost, excluding maintenance works that go beyond the road parts and current maintenance during winter. Estimates for maintenance and repair work for bituminous pavements are based on the physical parameters of the transverse and longitudinal profile for each kilometer of the highway, and for cement concrete layers, a total area of 22.000 m^2 for each kilometer is considered, taking into account cement concrete slabs of 4x5 meters each.

4. Alternative selection

The costs analysis for the Ploiești-Buzău highway section includes the final costs and scores awarded for maintenance and repair works during the perspective period of the evaluated road structures. Costs, expressed as present values with a discount rate of 4%, are essential for evaluating the economic viability of the project. The score for the economic return of each option is determined using the Net Present Value (NPV) as an indicator of the net benefits over the life of the project. Results were calculated by multiplying the quantities of work for each solution by the unit rates per work.

Table no. 58. Final costs [230].

No. crt.	Type of road structure/ Road coating	Total NPV cost (lei)	Score
1	Flexible/Bituminous	**13.591.140**	**93**
2	Semi-rigid/Bituminous	**12.585.710**	**100**
3	Rigid/Rigid (cement concrete tiles)	**17.399.370**	**72**
4	Rigid/Bituminous	**12.718.579**	**99**

The score related to this criterion was calculated as the ratio between the minimum cost and the cost of each option. According to the analysis, the semi-rigid road structure recorded the lowest costs, namely 12.585.710 lei, and was selected as the proposed solution for the Ploiești-Buzău highway section.

5. Estimated execution time

This criterion focuses on evaluating the execution duration of the proposed road structures and analyzing their behavior within the project context.

Flexible road structures, with extensive execution experience, are used in approximately 95% of the national road network. Their notable advantage consists in the possibility of construction without waiting times, except for the waterproofing of foundation layers in the cold season. Semi-rigid road structures, which include a top layer of stabilized ballast, involve a stiffening process, extending the execution duration. In the case of rigid road structures, with cement-bonded material, the execution time is longer, affecting the project schedule. Table no. 63 provides relevant details to guide decisions regarding the type of road structure.

Table no. 63. Behavior of road structures in terms of execution duration and behavior within the project [230].

<table>
<tr><th>No. crt.</th><th>Type of road structure/coating</th><th>Execution duration</th><th>Structure behavior</th></tr>
<tr><td>1</td><td>Flexible/Bituminous</td><td>No waiting times</td><td>Reduced demands on the roadbed</td></tr>
<tr><td>2</td><td>Semi-rigid/Bituminous</td><td>Stiffening over time of the stabilized layer</td><td>Cracking over time of the stabilized layer</td></tr>
<tr><td>3</td><td>Rigid/Rigid (cement concrete tiles)</td><td rowspan="2">Stiffening over time of the cement-bound material</td><td>Rigorous execution; Concrete cracking from thermal variations</td></tr>
<tr><td>4</td><td>Rigid/Bituminous</td><td>Transmission to the bituminous coating surface of joints, cracks and fissures from the cement concrete layer</td></tr>
</table>

6. Behavior over time and the condition of structures at the end of the perspective period

In this sub-chapter we have analyzed the following key aspects in road infrastructure: the cost of planned interventions at the end of the perspective period and the impact of the type of road surface on the quality of vehicle traffic, including the discomfort generated during maintenance work.

Cost of interventions at the end of the perspective period. For rigid road structures, such as those with cement concrete slabs and bituminous coating, a constructive treatment is provided with the addition of at least 18 cm of asphalt layers to delay the appearance of cracks and fissures. In the case of flexible and semi-rigid road structures, which have increased their bearing capacity through periodic maintenance works, the thickness of the reinforcement layers will be adapted to the existing bearing capacity.

Vehicle traffic quality. Flexible and semi-rigid road structures offer a high level of comfort, characterized by flatness, roughness and continuity of the running surfaces. These structures have a reduced International Roughness Index (IRI) and Mean Profile Depth (MPD), contributing to the reduction of CO2 emissions. In contrast, rigid road structures, either with cement concrete slabs or with bituminous coating, show less flatness due to transverse joints, generating discomfort in traffic and affecting the driving experience.

Traffic inconvenience during maintenance work can affect both drivers and residents of the surrounding areas. Noise, dust and traffic disruptions can cause discomfort and disruption. In the case of flexible and semi-rigid road structures, periodic maintenance work, such as laying an asphalt carpet at regular intervals, can create significant obstacles to traffic. These works require the temporary closure of some traffic lanes, generating discomfort and traffic disruptions.

7. CO_2 footprint assessment

The carbon footprint of road infrastructure refers to the emissions of CO_2 and greenhouse gases generated by the construction, maintenance and operation of roads. Influencing factors include materials, technologies, maintenance methods and traffic volume. Road condition affects vehicle fuel consumption through rolling losses related to uneven surface conditions. Reducing the carbon footprint can involve using less emissive materials, optimizing construction and maintenance processes, implementing energy-efficient technologies for street lighting and promoting maintenance practices to extend the life of the infrastructure.

8. Results analysis

Following this analysis, it was recommended to choose a semi-rigid road structure for the Ploiești-Buzău highway section, considering the criteria of resistance, durability and costs. This recommendation is based on careful evaluation of the specific characteristics and needs of the project, providing a balance between efficiency and long-term safety. Semi-rigid structures offer advantages such as reduced thicknesses of bituminous layer, convenient ballast supply, load bearing capacity and rich execution experience, but involve a longer execution and a risk of cracking of the stabilized ballast layer. The choice between semi-rigid, flexible or rigid structures should adapted to the specifics of the project and its requirements.

Environmental impact analysis

Pollution is an important problem during construction and operation of roads. Possible sources of pollution, at different stages of the project, can include:

Negative impact during the execution period:

During the execution of road infrastructure construction projects, the negative impact is significant. Handling of earthworks and construction materials leads to the transport of fine particles in surface waters, generating their pollution. The use of transport vehicles contributes to exhaust gas emissions, affecting air quality. Site organization and construction activities generate specific emissions and noise pollution. Cutting or milling concrete releases dust and particles into the air, impacting human health and the environment. The use of hazardous materials and the excavation of waste can lead to soil and groundwater pollution, affecting local ecosystems.

Negative impact during the operational period:

The environmental impact of road infrastructure during the operational period includes exhaust gas emissions, tire wear, corrosion of vehicles and galvanized parapets, road wear and temporary economic impact. These aspects generate air and soil pollution as well as noise pollution. Sustainable management of road infrastructure involves an efficient maintenance strategy, focused on reducing CO_2 emissions. Roads in good condition contribute to mitigate climate change, stimulate the economy and reduce vehicle maintenance costs.

Impact on population and human health

Negative impact during the construction of road infrastructure include noise, dust and emissions from machinery, disrupting community life and creating environmental and health risks. Soil and groundwater pollution, road accidents and exposure to noxious gases are major concerns.

Throughout the operational period, road traffic becomes the main source of noise, vibrations and emissions affecting the quality of life of the inhabitants.

Impact on the water environmental factor

During highway construction, the impact on water resources is generated by construction work, site traffic and specific activities related to site organization and production bases.

The impact during the execution period is limited in scope and manifests locally and temporarily.

During the operational period, the discharge of contaminated rainwater, the use of polluting maintenance materials and road accidents contribute to the pollution of surface and groundwater. Soil erosion and effects on aquatic ecosystems require careful management of impacts to conserve water quality and ecosystems.

Impact on the soil/land use environmental factor

The most significant impact on the soil during the construction and operation of the highway derives from the permanent occupation of the areas required for the road construction.

During construction, excavation can lead to soil degradation and erosion, and roads can fragment land, affecting biodiversity.

During the exploitation period, heavy traffic can cause soil compaction, affecting its quality and ability to support vegetation. Uncontrolled waste disposal, discharges of contaminated water and accidents involving toxic materials are potential sources of soil pollution. Concerns regarding air quality also involve the deposition of polluting substances on the soil.

Impact on air quality and climate

Air quality impact during highway construction come primarily from dust emissions and the burning of fossil fuels in the engines of machinery, equipment and vehicles used in the work.

During the operational period, road traffic, brake wear, tire and road wear, as well as the handling of anti-skid materials are the main sources of impact on air quality. However, the construction of the highway can also have positive effects on air quality in the areas adjacent to national and county roads by facilitating traffic flow and reducing frequent stops, which can contribute to a decrease of air pollutant emissions in these areas, where traffic generally operates with frequent brakes and stops.

VI. RISK MANAGEMENT IN ROAD INFRASTRUCTURE PROJECTS

In project evaluation, it has so far operated under the assumption that the future values of the relevant variables are known with certainty. However, in reality, at the time of evaluation, there is often uncertainty or a lack of knowledge regarding various aspects related to the project, which can significantly influence the benefits, costs and, consequently, the values of the profitability indicators. Therefore, it is important to consider the risk factor in the project evaluation process.

Defining risk management

Risk management in road construction and road infrastructure projects is a complex process that includes identifying, analyzing and managing risks to maximize positive events and minimize the impact of adverse events on project objectives. Considered both art and science, this process integrates scientific principles and guidelines based on logical reasoning. In major projects, risk management becomes essential to avoid cost overruns and ensure delivery quality. Proper risk allocation in construction contracts is a major aspect and risk management often relies on well-defined contractual provisions.

To adopt an appropriate approach to risk, investors must go through two essential steps: identifying and evaluating risks. Precise identification in an early stage is decisive, avoiding exposure to significant consequences in later stages. Ignoring significant risks can severely affect the profitability of the construction project, emphasizing the importance of careful management and the use of suitable methods in this initial stage.

In cost evaluation, cost risk analysis focuses on evaluating, managing and communicating the risks associated with the budget and expenses required for a project or activity. The aim is to consider financial risks and implement measures to manage and minimize their impact on costs.

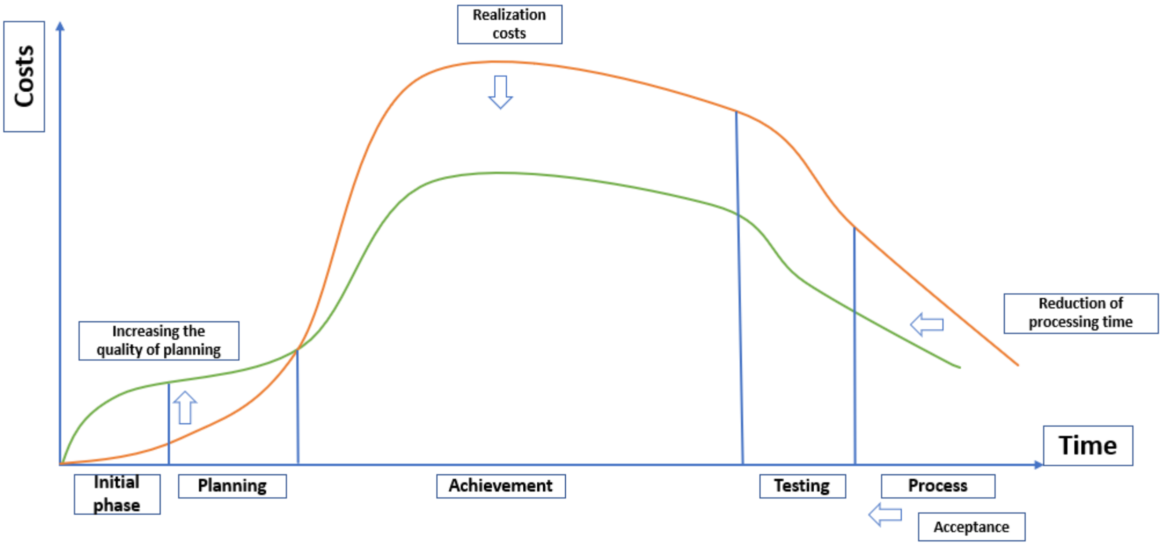

Figure no. 132. The potential through the use of risk management in construction projects [170].

Implementing risk management may initially involve additional costs, but the subsequent benefits justify these expenses. The purpose of risk management is to anticipate and manage potential problems before they occur or, in the case of positive risks and opportunities, to influence them. In the context of modern organizations, exposed to complex risks generated by globalization, pandemic events or digital technology, the importance of risk management has increased significantly, helping to determine the risks that match the organization's risk appetite and to identify those that require additional controls and actions before to become acceptable [171].

Risk definition

The risk associated with a project is an event or condition characterized by uncertainty, with a potentially positive or negative impact on the project's objectives. Companies adopt a dual perspective on risks, perceiving them either as threats to project success or as opportunities to improve the chances of achieving objectives.

Risks considered threats can be evaluated and, depending on the analysis, can be accepted, provided that the benefit from effective management outweighs the potential negative impact. These risks may involve proactive measures to minimize adverse effects or can be integrated into the planning process to anticipate and manage their consequences. On the other hand, risks considered opportunities are favorable circumstances that can improve the project. Opportunities must be monitored and managed to ensure that the project maximizes their benefits and efficiently achieves its objectives.

The degree of effort and initial investment in the planning phase directly influences the project's execution, as shown in Figure no. 133. Careful planning and adequate initial investment can significantly impact the success and efficiency of a project.

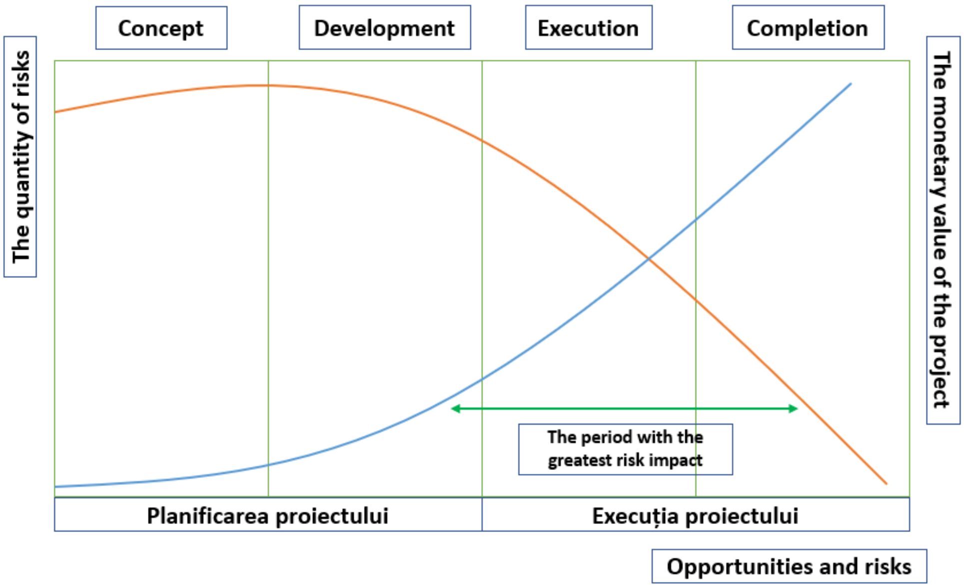

Figure no. 133. Cost-risk relationship [33].

Symbolically, risk can be expressed as:

$$Risk = f\,(uncertainty\ of\ an\ event,\ potential\ gain/loss\ of\ the\ event)\ [160].$$

Risk can be expressed in the form of a mathematical equation, as follows:

$$Risk = the\ probability\ or\ frequency\ of\ the\ occurrence\ of\ a\ defined\ event\ *\ the\ consequences\ of\ producing\ that\ event;$$

or

$$R = P \times C\,[181].$$

Probability refers to the chance or frequency of an event occurring, while impact refers to the extent to which the event may affect the project's objectives or outcomes. This formula reflects the common approach to risk assessment and management, where risks with higher probability and impact are considered significant and require increased attention in the risk management process.

Inherent risks of investment projects in road infrastructure construction

Risk exposure is common in infrastructure projects, being particularly important in the construction industry for all involved parties. Identifying and describing risks at different levels can vary significantly between projects and organizations, and general or high-level approaches to risks may encounter difficulties in developing appropriate responses, while detailed descriptions may involve increased effort. In the construction industry, risk is generally perceived as a negative element, associated with losses or damages on site, requiring a careful definition that takes into account all parties involved.

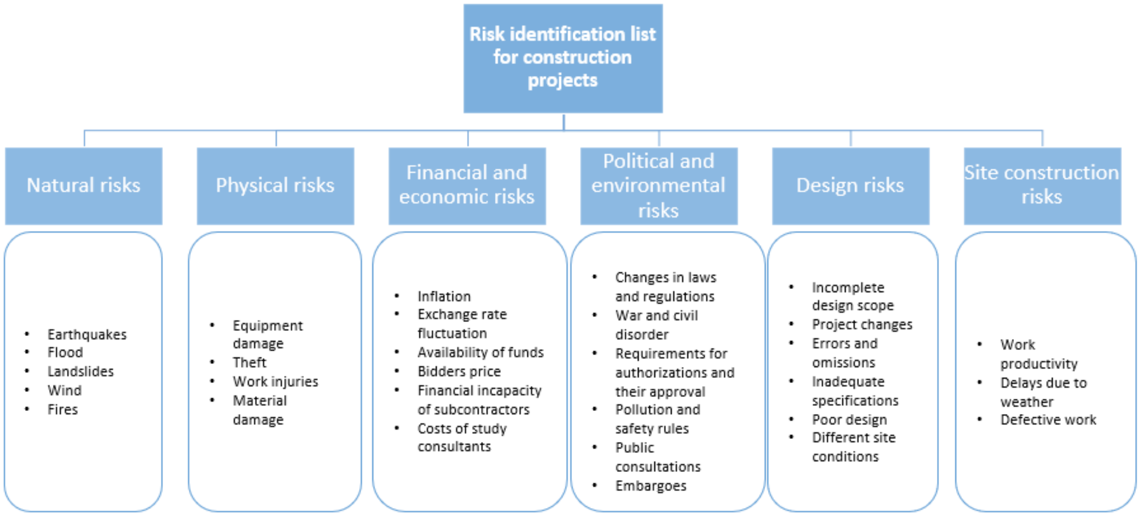

Figure no. 135. Risk classification list [183].

The various sources of risk associated with a typical road construction project require careful planning, for example: the risk of reduced funds or delayed release of funds can be managed through appropriate contract negotiation, especially when it comes to subcontractor requirements regarding the delivery of tools, materials, services or human labor; the risk of not meeting project deadlines, this can be addressed by negotiating the possibility of extending the duration of the project, especially if obstacles related to the supply of materials may arise or in case of unforeseen natural events, such as rainy or cold seasons, which may affect the construction process, such as concrete placement or drying.

Risk analysis

Risk analysis in road construction projects focuses on assessing adverse events over the entire project life cycle. The purpose of this analysis is to support the decision-making process at all stages, ensuring the project is completed on time and within the established budget, while maintaining functionality and safety of the project. Proactive identification and management of potential risks help to minimize impact and ensure project success. The analysis provides a deeper understanding of risks, facilitating comparisons between different options and highlighting the impact of identified risk management measures.

Risk assessment

Risk assessment in road infrastructure projects is carried out in three distinct stages: threat identification, vulnerability assessment and risk analysis. The first stage involves identifying the severity and frequency of significant natural hazards and estimating the anticipated impact. The next step is to determine the road corridor's exposure to these threats and assess possible losses. Finally, overall risk levels are assessed, taking into account both identified threats and identified vulnerabilities. This essential framework contributes to the development of a risk management plan to ensure the safety and sustainability of road infrastructure in the face of potential natural threats.

Dealing with risks

Addressing and reducing the negative impact of risks in construction projects involves adopting risk response practices and strategies. These strategies include avoiding risk, accepting it in low-level situations, transferring responsibility to a third party through insurance, or mitigating risk through measures to reduce the likelihood or impact.

Implementation of these strategies requires careful management given the potential impact on project cost, schedule, and quality, but appropriate use can improve overall project performance.

Avoidance as a risk response strategy aims to completely eliminate the possibility that the risk will cause loss, but it can be considered unwise because the steps required for elimination can affect the ability to achieve plans and objectives. When avoidance is not possible, risk mitigation is often used, which involves reducing the probability or negative impact of the risk.

Mitigation, essential in risk management, involves careful planning of negative events or factors to minimize their impact, being particularly important in road construction projects given the severity of potential threats. The major difference between avoidance and mitigation lies in the focus on eliminating the possibility of the risk versus managing the negative effects when the risk materializes.

Risk transfer, another essential strategy, requires attention to contractual details and the qualities of the parties involved to ensure project success and protection against risk.

Accepting the risk may be a valid option, particularly when the costs of other risk management options might exceed the costs associated with the risk itself. This can be considered the "do nothing" option, taking into account potential consequences and alternatives to make a well-informed decision.

Risk control and monitoring

Risk control in construction projects involves the use of a set of methods and techniques to neutralize or reduce the impact of potential risks. Even when a risk is known and controlled, it can still be a threat, which is why assessing and addressing the risk are essential steps. The fundamental purpose of the risk monitoring and control process in construction investment projects is to identify, mitigate and eliminate risks that may affect the project. This process is useful for implementing appropriate responses to risks and for verifying the validity of the initial assumptions made in the planning phase. Risk monitoring and control help ensure project success and maintain operational stability. During the implementation of a project, unexpected costs, known as cost overruns, may occur. To prevent these additional costs, detailed planning from the outset is essential, including evaluation of possible scenarios with the help of historical data and previous experience in similar projects.

VII. SUSTAINABLE ROAD INFRASTRUCTURES: APPROACHES FOR ECONOMIC EFFICIENCY AND ENVIRONMENTAL PROTECTION

Chapter VII explores strategies for achieving two major objectives in the construction and operation of road infrastructures: economic efficiency and environmental protection. Highways and roads, essential for mobility and economic development, can have a significant impact on the environment and involve substantial costs. To ensure long-term sustainability and viability, approaches that minimize environmental impact and optimize resource use are examined.

This chapter analyzes the use of eco-friendly materials, streamlining operations, effective planning and design to reduce costs, strengthening existing infrastructure, investments in renewable energy and the impact of digital technology in sustainable development of road infrastructures. It aims to reconcile economic needs with those of environmental protection to achieve a sustainable and efficient road infrastructure.

Cost optimization in road infrastructure construction investment projects through the use of ecological materials and technologies

This segment explores strategies in road infrastructure projects to optimize the use of financial resources by adopting eco-friendly materials and technologies that support sustainable development in the road infrastructure sector, bringing significant ecological and economic benefits. Given the considerable financial requirements of road infrastructure construction, cost reduction is sought to ensure the economic viability of projects and expand access to transportation infrastructure. In this context, numerous strategies aimed at reducing the costs involved can be identified, including:

The use of eco-friendly and renewable materials in construction projects, such as recycled concrete, wood from sustainable sources, self-repairing concrete, ecological asphalt and lignin-based biopolymers, is a key strategy for reducing the impact on the environment. These materials contribute to reducing the consumption of natural resources and carbon emissions, having lower carbon footprints compared to traditional materials. The benefits include not only environmental aspects, but also economic advantages, offering competitive costs and generating long-term savings through efficient management of resources and costs in construction. The adoption of these materials represents a significant step towards the sustainable development of the sector [216].

Optimizing operations through modern technologies represents a key strategy for reducing costs in road infrastructure construction, related to the use of eco-friendly materials and technologies. This approach materializes in the automation of procedures, the optimization of work flows and the elimination of redundant processes.

The adoption of advanced technologies, such as automation and artificial intelligence, aims to improve process efficiency and reduce expenses. Implementing automation in various stages of construction, including the use of autonomous equipment, can decrease human labor costs and optimize construction schedules, thereby reducing project duration and associated costs. Also, the adoption of new technologies and innovative methods, such as precast and modular construction, can reduce material costs and construction time, contributing to the overall goal of creating an eco-friendly, sustainable and energy-efficient road infrastructure.

Effective planning and design play a major role in the cost reduction strategy in road infrastructure construction. Through rigorous planning and detailed design, significant savings can be achieved in the development and operation phases of these infrastructures. The design process enables the identification of innovative and economically efficient solutions, avoiding oversizing and inefficient use of resources and integrating eco-friendly options and energy efficiency elements to reduce the carbon footprint and long-term operational costs.

Investments in renewable energy and energy efficiency are progressive and green approaches to reducing road construction costs. These strategies not only bring economic benefits, but also contribute to the preservation of the environment. The use of renewable energy reduces greenhouse gas emissions, having a positive impact on human health and the environment. Energy efficiency, through more efficient use of energy, can reduce consumption and costs associated with the operation and maintenance of road infrastructure, contributing to sustainability and performance.

Innovation and digital technology are essential for optimizing the construction of major road infrastructure, bringing significant improvements in the efficiency and management of complex projects. These approaches help reduce costs and have a positive impact on the environment by streamlining processes, reducing resource consumption and CO_2 emissions, as well as extending the life of infrastructure.

All these technologies are essential for building sustainable road infrastructures and contributing to global climate change goals.

The benefits of integrating eco-friendly and renewable materials in road infrastructure projects

The use of eco-friendly and renewable materials in the construction road infrastructure projects offers multiple benefits. These materials contribute to the reduction of construction and maintenance costs, having efficiency in the construction process. They reduce the impact on the environment through less consumption of natural resources and carbon emissions. Innovative materials, such as self-healing or lightweight ones, can minimize subsequent costs and reduce transport and handling costs. The use of renewable and recycled materials promotes sustainability and reduces the carbon footprint, helping to combat climate change. These materials are durable, resistant to wear and corrosion, extending the life of road infrastructures and reducing long-term maintenance and repair costs. Adopting these materials represents a significant evolution in the construction industry, having a positive impact on the environment and ensuring more sustainable and efficient infrastructures.

The use of biopolymers in road infrastructure construction: a sustainable and innovative approach

In the context of increasing global concerns regarding environmental protection and sustainable development, the road construction sector is facing pressure to reduce its negative impact on the environment. Carbon emissions, intensive consumption of natural resources and generated waste have imposed strict requirements for road infrastructure projects, directing attention to the use of eco-friendly materials and sustainable practices. In this sense, the use of biopolymers in the construction and maintenance of road infrastructures becomes an innovative, ecological and attractive solution. Biopolymers, organic compounds obtained from natural sources, offer biodegradable and biocompatible alternatives to traditional materials, having the potential to improve the characteristics of road materials and contribute to a more sustainable and environmentally friendly road construction.

Key properties and characteristics of biopolymers

Biopolymers, as materials in the construction of road infrastructures, bring significant benefits in terms of sustainability and ecological impact. Properties such as biodegradability facilitate efficient waste management, and biocompatibility helps avoid toxic emissions into the environment. These compounds offer flexibility and adaptability, being able to be adjusted to meet specific requirements such as mechanical strength or water resistance. Thus, the use of biopolymers in road construction represents a versatile and sustainable solution, aligned with environmental protection requirements.

How biopolymers work in the context of road construction

Biopolymers are used in road construction to improve or replace traditional materials. In asphalt, the addition of biopolymers increases adhesion and water resistance, extending the life of the road surface. In concrete, they strengthen crack resistance and reduce shrinkage, contributing to increased durability. In addition, biopolymers are used for soil stabilization, preventing erosion and strengthening infrastructure. This innovative and sustainable approach aims to reduce the environmental impact and improve the sustainability of road projects.

The advantages of using biopolymers in road infrastructures

The use of biopolymers in road infrastructures offers multiple advantages. They help reduce carbon emissions and impact on climate change, provide improved durability and resilience, efficiency in resource management, reusability and recycling, and soil consolidation.

Current challenges and future perspectives associated with the use of biopolymers in road infrastructures

Implementing biopolymers in road infrastructures brings significant benefits for sustainability and the environment, but also involves major challenges. Collaboration between various stakeholders is essential for the development and implementation of sustainable solutions. This can contribute to addressing existing challenges and finding innovative ways to use biopolymers in the construction and maintenance of road infrastructures. Continuous research, improvement of production technologies and establishment of clear standards and regulations for their use are important aspects for increasing efficiency and reducing costs. In the context of increasing demand for sustainable construction solutions, biopolymers can play a decisive role in creating a future where road infrastructures are more sustainable and environmentally friendly.

Current challenges:

1. **Higher initial costs:** May deter decision-makers, but long-term benefits such as reduced carbon footprint and increased durability may offset this.
2. **Standardization and regulation:** generates uncertainty, highlighting the need for a rigorous regulatory framework and specific standards to ensure the quality and safety of the use of biopolymers in road infrastructures, as well as the implementation of methods and tests to evaluate the performance of biopolymers in this context.
3. **Long-term sustainability:** requires ongoing studies and monitoring to evaluate the behavior of biopolymers under heavy traffic and climatic variabilities and the aging process, with a focus on improving formulations and adopting advanced application technologies.

Future prospects:

The prospects of using biopolymers in road infrastructures are promising, highlighting the expansion of applications and the development of more efficient formulas and increasing awareness. Ongoing research will diversify uses, and education and public awareness will encourage the adoption of these innovative materials. Green infrastructure investments, research partnerships and global sustainability initiatives will facilitate the implementation of biopolymers, certification and accreditation will increase confidence in biopolymers, and specific regulations will provide clear guidelines and ensure safety and sustainability standards. In conclusion, the use of biopolymers in road infrastructures represents a promising solution for sustainability and environmental protection, with challenges to be overcome through continuous efforts and stakeholder involvement. With continued technological development and the involvement of multiple stakeholders, an effective transition to the use of biopolymers in the construction and maintenance of road infrastructure can be achieved, thus contributing to a more sustainable and resilient future in the field of transport.

CASE STUDY III. ASSESSMENT OF THE BENEFITS OF REPLACING THE STABILIZATION METHOD WITH A BIOPOLYMER THAT FIXES CARBON IN THE SOIL AND STIMULATES THE CIRCULARITY OF RESOURCES IN THE INDUSTRY

General context of the research

In the context of human evolution, improving soil quality has involved various methods, including stabilization and mixing with cement. Currently, there is an increase in demand for green alternatives to cement, given its significant impact on greenhouse gas emissions. Geosynthetics, chemical polymers, geopolymers, microbial induction processes and biopolymers are research topics with the potential to counteract the negative environmental impact and climate change associated with cement production.

The rationale for changing the soil stabilization method

The construction industry is currently dominated by Portland cement due to its strength, durability and low cost. However, the manufacturing process of this cement contributes significantly to carbon dioxide emissions, accounting for approximately 10% of global CO_2 emissions in 2012. In parallel, asphalt production in Europe in 2013 reached 277,3 million tons, representing an energy intensive process and a significant source of carbon dioxide emissions. The asphalt industry, a major consumer of energy, requires the adoption of more sustainable strategies. Highway construction, including the production of asphalt and cement, involves significant energy consumption.

Biopolymers as an ecological alternative

The adoption of biopolymers in asphalt pavements represents a sustainable alternative, offering significant benefits in energy efficiency and production costs. Known for their increased strength and biodegradable nature, biopolymers obtained from natural sources have the potential to replace cement in soil treatment, contributing to building a more sustainable environment. Lignin, an abundant compound in plants and the second most widespread plant polymer after cellulose, is an important source for these biopolymers, especially from the paper manufacturing industry and the production of second-generation biofuels.

The use of lignin in road construction

Lignin, coming from renewable natural sources, represents a sustainable alternative in road construction, acting as a modifying agent to improve the durability of asphalt. Integrating lignin into asphalt reduces the carbon footprint, asphalt consumption and promotes an efficient and sustainable road infrastructure, having multiple benefits in reducing CO_2 emissions and maintenance costs. Lignin can be integrated into asphalt as a binder, in mixtures in the form of fibers and as a soil stabilizer, as well as an asphalt extender agent.

Lignin as an asphalt binder

Lignin, used in pavement engineering, acts as an asphalt modifier, antioxidant, coupling agent and emulsifier. Through multiple applications, it improves the strength and durability of asphalt, reducing the risk of cracking and improving fatigue resistance. With abundant availability and low cost, lignin is an attractive option for improving asphalt pavement performance and durability, bringing significant environmental benefits.

Lignin in asphalt mixtures

Lignin, added directly to asphalt mixtures, influences their behavior at different temperatures and deformations. In cold conditions, it contributes to crack resistance and improves deformation resistance at high temperatures, maintaining viscoelastic properties at intermediate temperatures. Thus, the use of lignin can improve the performance of asphalt mixtures under various traffic and temperature conditions.

Lignin as a soil stabilizer for road bases

Lignin, having an important role in stabilizing soils for road construction, represents an ecological alternative to traditional materials. Its ability to bind soil particles contributes to the formation of a solid structure in asphalt pavements, offering advantages such as reduced energy consumption and improved technical characteristics. The life cycle assessment shows the positive economic and social impact of using lignin as a renewable biopolymer, contributing to the reduction of greenhouse gas emissions and providing significant economic and social benefits.

Lignin as an asphalt extender agent

Lignin, used as an asphalt extender agent in pavements, brings multiple advantages, including reducing CO_2 emissions, increasing durability and resistance to low temperatures, lowering maintenance costs, promoting sustainability by reducing dependence on non-renewable resources and achieving significant economic benefits in the construction and maintenance of road infrastructure.

Overview of the proposed method

The proposed method comes with an innovative and sustainable solution for road rehabilitation, based on local recycling of road material and the use of a biological lignin-based binder to replace bitumen. Tested in Norway for 16 years, this method stands out for its resistance to varied conditions and temperature fluctuations, extending the durability of roads to over 20 years. The reduction of CO_2 emissions by up to 80%, removing approximately 3,5 tons of carbon for every 30 meters of rehabilitated road, and the benefits brought, such as increased flexibility and negative absorption of carbon from the atmosphere, contribute significantly to the quality and sustainability of road infrastructures.

Comparative efficiency analysis between the proposed method (lignin-based biopolymer) and the traditional method (bitumen)

The detailed analysis of the proposed method provides key advantages regarding costs and importance of the construction industry, as well as the need for its future development:

1. **Efficiency of lignin-based biopolymer:**

   - Biopolymer production involves mixing lignin and water in a specific ratio, diluting the binder and reducing the amount of carbon sequestered per liter of binder.
   - This process leads to the sequestration of approximately 0,768 kg of CO_2 per 1 liter of binder, resulting in a capture of 5,3 kg of CO_2 for a 1 m^2 road.

2. **Comparison with bitumen-based binder:**

   - Lignin-based biopolymer has a negative emission factor of approximately -1,2 kg CO_2 relative to 1 kg of lignin, including emissions generated during production and carbon sequestration.

- In comparison, the bitumen-based adhesive binder produces positive emissions, with values ranging from 1,06 to 1,13 kg CO_2 per kg of bituminous sealing material and approximately 0,5 kg CO_2 equivalent per kg of hot bituminous adhesive compound.

3. **Emissions related to road filling aggregates:**

- The proposed method does not require the use of additional aggregate materials to fill the road, since all the necessary aggregates are obtained from the road to be repaired.
- In contrast, the existing technology involves transporting additional aggregate to the site, which is then mixed with the binder, thus contributing to the emissions associated with this technology.

4. **Carbon sequestration during the production of lignin-based biopolymer:**

- The production of lignin-based biopolymer captures over 1,4 kg of CO_2 equivalent per kg of lignin produced.
- Lignin has a negative carbon footprint, due to carbon sequestration from the trees used in lignin production.
- The lifetime of lignin in the proposed method allows sequestration of the carbon captured during the production process.

5. **CO_2 emissions in lignin production:**

- Lignin production generates emissions of approximately 0,26 kg CO_2 per kg of lignin produced, including all stages from raw materials to transport to the production facility and the production process.

6. **CO_2 emissions related to lignin transport:**

- Transporting 1 kg of lignin over a distance of 1000 km emits approximately 0,05 kg of CO_2 .
- Transport emissions come from three different modes, with around 80% from maritime transport, 15% from road transport and 5% from rail transport.

7. **CO_2 emissions related to filler materials:**

- Different types of filler materials have slightly different emission factors, such as crushed limestone (0,0029 kg CO_2 per kg), round gravel (0,003 kg CO_2 per kg), and crushed gravel (0,0048 kg CO_2 per kg).
- The differences between these emission factors are considered insignificant compared to other emission factors in the road construction process.

8. **CO_2 emissions related to the transport of filler materials:**

- Using a freight train generates approximately 0,048 kg CO_2 per ton transported over a distance of 1 km. For trucks, emissions vary according to their capacity, with values between 0,13 and 0,52 kg CO_2 per ton per 1 km. Maritime transport has the lowest impact, emitting an average of 0,0079 kg CO_2 per ton per 1 km.

- The CO_2 emissions per 1 m^2 of road generated by the proposed method in terms of filler material requirements are 0, as no additional material is required.

9. CO_2 emissions related to machinery/equipment fuels:

- Supplying 1 liter of diesel in Europe produces approximately 0,48 kg of CO_2 .
- Fuel consumption for heating binders, lignin and bitumen contributes to emissions.

10. CO_2 emissions from heating bitumen and biopolymer:

- Heating bitumen requires about 11,5 liters of fuel per hour and generates emissions of about 0,0033 kg CO_2 per m^2 of road.
- The lignin-based biopolymer does not require heating, leading to 0 emissions.

11. Equivalent fuel use for heating biopolymer compared to bitumen:

- The emission resulting from diesel combustion is approximately 2,29 kg of CO_2 equivalent for each kg of diesel consumed.
- Diesel consumption for heating bitumen generates significant emissions (0,0157 kg CO_2 per 1 m^2 of road).
- Lignin-based biopolymer does not require heating.

12. Benefits of reusing road materials:

- The reuse of road material in combination with biopolymer reduces the need to transport and produce new road materials, saving natural resources and reducing emissions associated with the transport and production of new materials and the disposal of waste from the demolition of old roads.

13. Road lifetime:

- The lifetime of roads built with biopolymer is similar to or even longer than thant of traditional roads.

14. Road refurbishment and cost reduction:

- Refurbishing roads with reused road materials reduces costs and environmental impact.
- Replacing the soil stabilization method with the proposed method leads to a reduction of costs per square meter by approximately 30-35% compared to traditional methods.

The behavior over time of roads subject to the presented method

Between 2007 and 2020, the proposed method was successfully implemented in road renovation, redefining the rehabilitation process by recycling existing materials and adopting ecological solutions. This advanced approach has transformed used roadways into modern, sustainable and environmentally friendly infrastructures, demonstrating effectiveness in reducing carbon emissions and negative environmental impact. The ongoing projects provided inspirational examples for the future development of road infrastructure. The selection of roads to be renovated took into account criteria such as data availability, project size and road age.

Work performed:

By applying an innovative road renovation method, the roads were subjected to a deep "crushing" process, transforming the existing material into a stable base. The use of lignin-based biopolymer strengthened the road structure by reusing existing materials and adding binders to create a new sustainable road structure. This approach generated resource savings by reusing existing materials, reducing waste and minimizing environmental impact, resulting in a more reliable and time-resilient road infrastructure at reduced costs and resources. Road inspection in 2022 revealed a smooth and stable surface, reflecting the optimal quality and performance achieved by the implemented method. The overall condition of the roads inspected in 2022 was assessed as good, with a uniform surface, free of obvious bumps and cracks.

Figures no. 161 - 164. The quality of the roads Bøenvegen, Gransherad/Notodden, Roheimvegen, Bø, Route 301, Finsland, Agder and Kleivdalsveien, Lindås outside Bergen at the inspection in 2022 [260].

Experimental research on the proposed intervention method, under the specific site and climate conditions of Romania

The proposed method is applied in an experimental phase in Boldur Commune, in the southeast of Timiș County, on the Ohaba Forgaci-Boldur communal road and the streets of local interest DS 37, DS 38, DS 39, DS 40, DS 50 and DS 52 in Boldur commune [258].

Figure no. 181 . Location plan in the area of studied streets [258].

Initial situation

The poor technical condition of the communal road and streets in Ohaba Forgaci negatively affects the lives of the residents. The road exhibits a degraded asphalt coating, potholes and cracks, while local streets have problems with subsidence, bumps and water infiltration. These deficiencies disrupt traffic, generating noise and vibrations, having negative consequences on the social and economic development of the area. The need for an urgent intervention to rehabilitate and improve traffic conditions is obvious.

Comparative situation

Figures no. 182 - 183. Street quality in Boldur Commune before and during the application of the proposed method [258].

 

Figures no. 186 - 187. Street quality in Boldur Commune after applying the proposed method [258].

The method proposes an innovative solution for road rehabilitation, focusing on recycling the top layer to strengthen the existing structure. By using an eco-friendly organic binder, the approach improves road geometry, strength and load-bearing capacity, providing a sustainable solution to road infrastructure degradation issues. The result is a stabilized road surface, which can be maintained in its current form or covered with a new layer of asphalt after a polymerization period of 2 - 6 weeks [258]. Moreover, a major advantage of the method, in addition to cost reduction, is the fact that it is possible to allow the immediate circulation of light vehicles, while the access of heavy vehicles is recommended to be delayed for a period of 14 days.

VIII. GENERAL CONCLUSIONS

Main conclusions of the study

The construction sector, vital to economic growth, contributes significantly to GDP and employment. In Romania, this sector is experiencing notable growth, but faces challenges such material availability and poor coordination. The development of road infrastructure requires constant investment for the safety and mobility of the population. With a focus on cost reduction and efficient resource management, continued infrastructure development is essential to support technological innovation and a sustainable future.

The construction industry, with the potential to become a model of smart and responsible development, faces challenges related to market demand, legislative changes and economic fluctuations.

Current trends in the construction sector indicate an increase in activity, but also challenges related to inflation and sustainability. The development of the sector, focused on innovation and sustainability, represents a strategic investment in the future of society and the economy, although it faces sensitivity to political and environmental factors, presenting a significant failure rate. The industry frequently faces significant deviations from the estimated costs, and in the context of rapid technological development, the need for a strict control of the projects is imposed.

The objective of cost control is to maximize profit over a specified period while maintaining the quality of work. Major infrastructure construction projects have a significant impact on society, influencing economic growth, social welfare and political sustainability, representing complex efforts involving the coordination of resources and stakeholders involved.

The construction industry faces challenges in controlling costs and time, with a focus on effective management for sustainable development. Budgeting, cost control, estimation, cost analysis, planning and scheduling are key elements in cost management. Construction, a dynamic process, brings new circumstances and challenges, and initial planning tries to anticipate obstacles. Continuous project monitoring, through project control, ensures the achievement of time, cost and quality objectives.

Multi-stage control in construction, adapting the plan and budget according to the reality of the construction site, and risk management are priorities in the context of globalization and digital technology. Integrated risk management systems facilitate the identification and quantification of risks in infrastructure projects, with a focus on road construction. Anticipating and effectively managing risks contributes to user safety and sustainable road maintenance.

Proper planning and analysis for risk mitigation support risk management decision-making, ensuring contract compliance and saving resources in construction and maintenance. Effective risk management in construction projects, rigorous risk assessment and research are fundamental at every stage of the project, with the priority of protecting the environment by reducing emissions and conserving biodiversity.

Following Case Study I, it is found that during the period 2019-2022, CNAIR made significant efforts to maintain and improve the road infrastructure in Romania, but the funding deficit for maintenance remains a major problem. Spending during this period highlights challenges in the effective management of financial resources, with some activities exceeding budget limits. Reducing costs in construction is a challenge, but careful management of resources and technology adoption can help keep them at sustainable levels. The case study on highway options underlines the importance of the relevant assessment of the road structure for a sustainable investment, considering the costs of execution, maintenance and the possible consolidation needs of the proposed structures.

Through Case Study II we performed the profitability analysis for road structure options using the Net Present Value (NPV) as a key indicator. The updated total costs show that the semi-rigid road structure is recommended for the studied highway section, having a balance between strength and cost. This shows a significant reduction of 27,67% compared to the rigid road structure with cement concrete coating. The analysis emphasizes the importance of choosing the type of road structure, with a significant impact on total costs, highlighting the semi-rigid road structure as an economically advantageous alternative compared to the other options.

Reducing the carbon footprint focuses on the use of less emissive materials and energy-efficient technologies, essential for sustainability and environmental protection. The importance of reducing execution costs, optimizing maintenance, choosing the best alternative and continuous development of the construction sector are emphasized in the project analysis, highlighting the need for an ecological and economic approach. Flexible and semi-rigid road structures appear to offer benefits in reducing environmental impact, while promoting more efficient circulation and lower traffic-related carbon emissions.

The environmental impact of road construction and maintenance implies the need for cleaner technologies and materials. Carbon footprint reduction is essential for the sustainability of road infrastructure, and the quality of the road surface contributes to comfort and safety in traffic. In the context of climate change, carbon footprint evaluation and global warming potential assessment must be integrated into road development planning. The approach to road infrastructure development must be sustainable, minimizing negative environmental impact and reducing carbon emissions. Innovation plays a major role in improving performance and efficiency in road construction, contributing to a more sustainable and safe future in this field.

Consequently, it is important to adopt innovative methods and materials that support sustainable development and environmental protection during road infrastructure construction. For example, biopolymers can improve the properties of construction materials and at the same time reduce the negative impact on the environment by being biodegradable and contributing to the reduction of greenhouse gas emissions, which makes their use instead of synthetic materials a significant solution in this regard.

Biopolymers, biodegradable and biocompatible compounds obtained from renewable sources, represent a sustainable alternative to synthetic materials in construction. Their integration improves the mechanical properties of materials, such as tensile strength, contributing to reduce greenhouse gas emissions associated with the processing of synthetic materials. Their use supports the circularity of resources and provides comparable or superior performance at a similar or even lower cost.

The use of biopolymers in road infrastructure brings multiple ecological advantages, such as reducing greenhouse gas emissions, minimizing residues and improving air quality. By conserving resources, promoting sustainability, efficiency in use and improved durability, biopolymers emerge as an eco-friendly alternative in soil stabilization. They can play a significant role in promoting a circular economy and protecting the environment, while also providing long-term economic benefits in road infrastructure construction due to lower costs. Furthermore, the adoption of biopolymers can strengthen the positioning in an innovative and sustainable market, attracting investment and generating new business opportunities in the future.

The time interval required for a road to be used after a material is applied varies depending on the type of material and specific construction conditions. Asphalt, commonly used in road construction, becomes suitable for light vehicle traffic within 24-48 hours, with variations determined by layer thickness and weather conditions. Cement concrete, used in rigid road structures, typically requires 7-10 days to allow traffic, with variations related to composition and conditions.

The method proposed and analyzed within Case Study III allows immediate access for light vehicles after applying the method, significantly reducing the commissioning time compared to traditional solutions. For heavy vehicles, access is recommended after approximately 14 days, however, providing a significant 100% reduction in commissioning time compared to conventional methods. By implementing the proposed method instead of traditional soil stabilization techniques, significant cost-saving prospects are opened, estimating a reduction in road surface unit costs by approximately 30-35%.

The proposed method, based on a lignin biopolymer, rehabilitates roads with existing materials, having the potential to reduce costs and carbon emissions associated with road construction and maintenance, promoting sustainable development. Adopting this method represents a promising perspective in the context of sustainability goals and carbon emisiion reduction in road infrastructure construction and maintenance projects, considering, however, the need for continuous monitoring, research and development to ensure the success and sustainability of this approach in the future.

The information and studies presented underline the importance of the construction sector, with an emphasis on the construction and maintenance of infrastructure, in the development of society and the economy. The complex evolution of this field is influenced by economic, social and technological factors, with varied trends in investments, building permits and the state of the infrastructure. The construction sector has a significant economic impact, generating income, employment opportunities and stimulating demand throughout the economic network. The global pressure on climate change requires the adoption of sustainable solutions and innovative technologies in construction, with an emphasis on green buildings, energy efficiency and sustainable materials.

In the context of a constantly changing world, the development and increased interest in the field of construction and infrastructure sector are seen as essential needs and strategic investments. Infrastructure is considered the foundation of a modern economy and advanced society, supporting technological innovation and creating functional cities. The interest in the development of this sector is motivated by the aspiration to ensure access to services, to support technological innovations and to contribute to a sustainable future that meets both the needs of the present and those of future generations.

Contributions of the research study

This work contributes to deepening knowledge and understanding of the essential role of cost and time control in construction project management, as well as providing insights and guidance for professionals in the field and all those interested in effective construction project management.

The study makes significant contributions to construction project management by advancing theoretical knowledge, highlighting the specific complexity of the construction industry, and addressing key issues such as cost and time management. It promotes sustainable practices, improves project performance and explores an innovative perspective with a focus on the use of biopolymers in road construction. The research raises awareness of sustainability in construction, highlighting the importance of a comprehensive assessment of the ecological impact of road infrastructure. It also encourages further research, highlighting the potential for innovation and new construction industries.

This paper addresses a variety of stakeholders in the construction sector. Businesses find essential information about the construction industry, while investors can make informed decisions regarding capital allocation. Specialists in project management and cost management benefit from comprehensive knowledge of costs, planning and implementation. Others interested in the field, less familiar with the construction industry, may use the work as a source of information. Researchers and students find it a useful resource for market analysis and comparative studies. Public authorities and decision-makers can use the study to support construction policies and regulations.

In an constantly changing environment, this work sheds light on construction trends, strategies and influencing factors in the construction industry, providing a solid foundation for informed decisions and success in an industry essential to the development and progress of society. By fulfilling the above objectives, the paper aims to provide a broad perspective on project management, enriching the understanding of its advantages, challenges and implications in the effective management of construction projects and other similar fields.

Limitations and directions for future research

The paper highlights significant aspects of the evolution of the construction industry and cost management in construction projects. However, like any study, it also presents certain limitations and, at the same time, opens up new horizons for future research, which has the potential to provide deeper insights and understanding, suggesting the exploration of economic trends, assessing the impact of macroeconomic factors on the construction sector in Romania and focusing on solutions for the modernization of the road infrastructure. Future research should also focus on sustainable development in construction, analyzing environmental impacts and developing innovative strategies to reduce the environmental impact of construction projects.

The paper focuses on sustainable development in construction with an emphasis on the use of biopolymers, highlighting the challenges and unexplored aspects of their implementation. Future studies should focus on improving the properties of biopolymers and reducing production costs, promoting their efficiency and sustainability. The government can support research through investment and subsidy programs, and the private sector through the development of advanced technologies.

The integration of biopolymers into road infrastructure exemplifies the collaboration between sustainability and innovation, contributing to environmental conservation and promoting a green future. Investing in biopolymer-based projects is a step towards a sustainable future, supporting both economic success and environmental responsibility. Future research should focus on improving biopolymer properties, reducing costs, advancing application technology, and environmental impact assessment to promote the widespread adoption of biopolymers in road infrastructure construction. By continuing the commitment in research and development, the evolution of biopolymers towards practical, sustainable, innovative and widespread solutions in road infrastructure construction is anticipated.

Promoting research, innovation and development in the implementation of biopolymers in major road infrastructures can significantly contribute to achieving a more sustainable future in construction, characterized by durability and respect for the environment. In parallel, the ever-evolving construction project management presents complex challenges, and future research could focus on addressing these challenges and explore new directions to promote efficiency, sustainability and responsibility in construction project management.

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