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Methods for Optimizing Project Timelines Under Resource Constraints

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***Abstract*— *The article examines methods for reducing project implementation timelines under resource constraints, a critical challenge in project management. The lack of financial, human, and material resources presents managers with tasks that require comprehensive approaches to achieve the desired results within tight deadlines. In such conditions, it is essential to develop planning strategies that minimize timelines while maintaining the necessary quality of work. The purpose of this study is to review existing methods for optimizing timelines under resource constraints. The methodology involves mathematical modeling, such as linear and integer programming, network planning tools, Gantt charts, PERT, and CPM. The application of these approaches facilitates the reduction of project durations and the efficient reallocation of resources while accounting for changing external factors. The results of the study confirm that selecting the right strategy can significantly reduce time expenditures without compromising task quality. The critical path method (CPM), combined with resource constraint optimization, improves project timeline performance. The use of flexible project management methods, such as adaptive planning and task schedule updates, accelerates task completion under resource shortages. This article is intended for project management specialists, project managers, and consultants involved in optimizing business processes. The application of the proposed methods helps mitigate the risks of delays and resource overruns. The study's materials may also be useful for educational institutions training students and specialists in project management. The conclusions emphasize the need for a comprehensive approach to timeline optimization. Combining mathematical models with practical planning tools enables effective achievement of goals under constrained resources and changing external factors*.

Keywords*— *Timeline optimization, resource constraints, project management, mathematical modeling, network planning methods, critical path, adaptive planning.

I. Introduction

Project management under resource constraints is one of the key challenges in business. In the context of rapid changes in market conditions, technological breakthroughs, and intense competition, the successful implementation of projects requires strategic planning and the ability to efficiently allocate limited resources such as time, finances, personnel, and materials. This becomes particularly critical in large-scale projects, where timeline optimization directly impacts outcomes and profitability.

Resource limitations impose significant restrictions on planning processes, necessitating the use of specific methods and tools to effectively allocate resources and minimize time expenditures. Under these conditions, the optimization of project timelines becomes a crucial aspect of project management. While methods such as the critical path method and project evaluation and review techniques are widely used, the task of optimization remains complex and multifaceted. Solving this problem requires a comprehensive approach that incorporates mathematical modeling and adaptive management methods, which take into account changes occurring during project execution.

The lack of clear recommendations for applying these methods under resource-constrained conditions and the high uncertainty of project environments necessitate a deeper analysis and the development of new approaches. Reducing timelines is achievable only through the efficient use of all available tools and the adjustment of plans based on current circumstances.

The objective of this study is to review existing methods for optimizing project timelines under resource constraints.

II. Materials and Methods

In the article by Abishek S. et al. [1], the use of artificial intelligence algorithms is discussed as a means to improve the accuracy of forecasting project requirements and reduce the risk of delays at various stages. The authors also explore machine learning methods that adapt to changing conditions, enabling precise demand prediction. In construction projects, where planning accuracy is critical, optimization algorithms help identify appropriate strategies for resource and time allocation, contributing to the successful completion of tasks.

Artificial intelligence also plays a significant role in automating processes such as data analysis, schedule creation, and plan adjustments in response to new conditions. These technologies accelerate planning and improve its accuracy.

Dynamic programming is another method utilized for optimizing resource allocation under constraints of time and budget. In the article by Goda D. R. et al. [2], this approach is discussed as a tool for addressing multitasking challenges while minimizing resource losses within limited timeframes and budgets. This method divides a complex task into simpler stages, facilitating decision-making at each step. As such, it is well-suited for projects with variable conditions and dependencies.

The articles by Hauder V. A. et al. and Yuan Z. et al. [3,4] describe the application of an enhanced NSGA-II algorithm for multi-objective project planning, focusing on minimizing timelines, reducing costs, and maintaining quality. This approach allows for consideration of multiple criteria, which is essential for complex projects that require balancing competing priorities. The NSGA-II algorithm identifies solutions that meet requirements for time, cost, and quality while accounting for

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various uncertainty scenarios, enabling timely responses to changes and risks arising during project implementation.

In addition, scientific studies often emphasize algorithms designed for specific planning tasks in certain conditions. For instance, the article by Rauf M. et al. [5] introduces the Raccoon Family Optimization algorithm, applied to multi-project planning in the manufacturing sector. This algorithm is effective under multitasking conditions, where managing multiple projects with limited resources is required. It also handles systems with numerous variables and constraints, optimizing resources and timelines both for individual projects and for the system as a whole.

Another example of optimization is provided in the article by Bold M. and Goerigk M. A. [6], which proposes robust optimization methods for managing uncertainties related to task durations. This approach is critical for projects involving risks and variable conditions, offering solutions that are essential for managing uncertainty.

However, despite the significant number of studies describing project timeline optimization processes, unresolved issues and contradictions remain. Additionally, the literature pays insufficient attention to the integration of multiple optimization methods within a single project.

The methodological foundation for this research includes various techniques such as mathematical modeling (e.g., linear and integer programming), network planning tools, Gantt charts, PERT, and CPM.

III. Results and Discussion

Improving project completion time under resource constraints requires the use of diverse approaches. It is necessary to consider not only direct limitations, such as resource shortages, but also the interaction of various factors, including task interdependencies, risks, uncertainties, and environmental changes. Methods for improving project timelines under resource-constrained conditions are presented in Figure1.

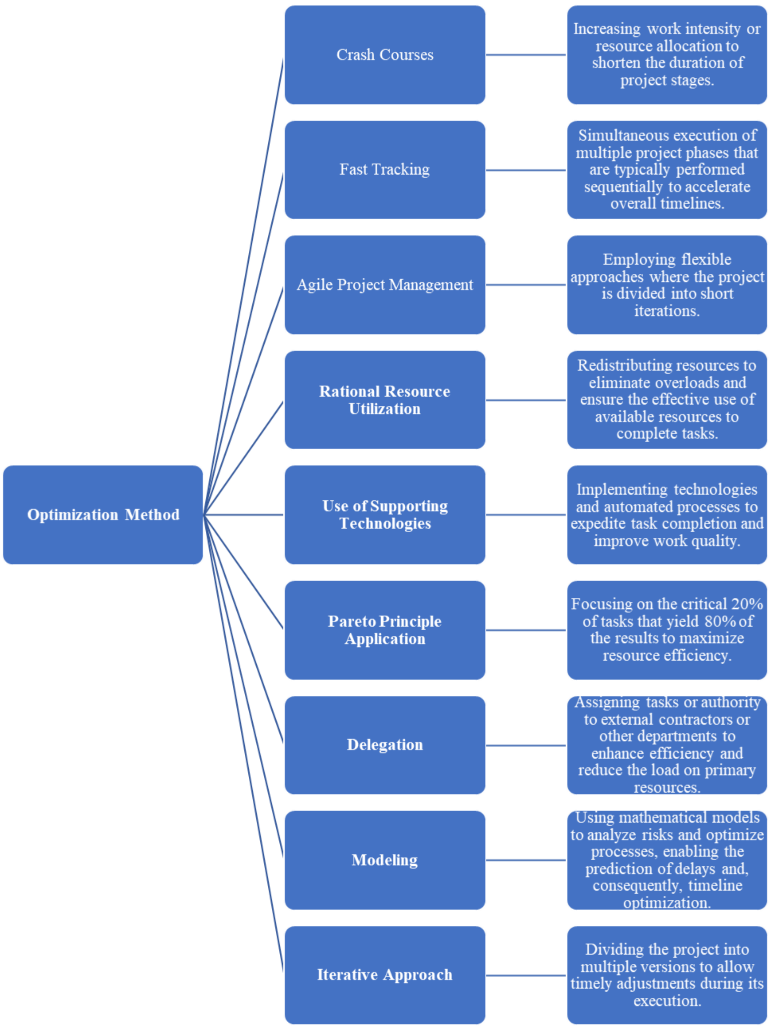

Fig.1. Methods for optimizing project implementation time under resource constraints [1,2,5]

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Advanced methods, such as resource-constrained network planning, are used in project management. These methods take into account the impact of resource allocation on project duration and the possibility of parallel task execution. The goal of such models is to find an optimal resource distribution that ensures project completion within the established timeframe without exceeding set limits.

Mathematical optimization is an essential tool in project management under resource constraints. Tasks are solved using linear and nonlinear programming. Linear models effectively allocate resources when the relationships between costs and task durations are clearly defined. Nonlinear methods are applied when resource costs vary depending on their intensity or workload. These methods account for such changes, improving the accuracy of planning.

Metamodels play a critical role in approximating processes characteristic of multitasking projects. They simplify calculations while maintaining accuracy, especially when analyzing each individual aspect would require significant resource expenditures. Methods such as hierarchical analysis and multi-objective optimization allow the selection of appropriate solutions while considering a variety of factors. These approaches provide flexibility in decision-making, accounting for changes in the external environment and client priorities [3,5].

A Gantt chart is a tool for visually representing project progress. It displays tasks on a timeline with their corresponding deadlines, allowing for a clear understanding of the relationships between project phases. This approach helps identify potential bottlenecks where resource shortages or issues in task execution may arise. The Gantt chart also highlights which phases can be performed in parallel and which must be completed before subsequent stages can begin [2,4,6].

The PERT method is applied in projects with a high degree of uncertainty. It differs from the critical path method by including multiple time estimates for each task: optimistic, pessimistic, and most likely. This approach accounts for various scenarios and allows for more precise planning of timeframes for each phase. Incorporating these estimates enables the creation of realistic schedules, minimizes risks, and provides flexibility in project management [3,6].

The Agile methodology allows projects to adapt to changing conditions. The process is divided into stages, while systems such as Scrum and Kanban provide task control, accelerate processes, minimize time and resource losses, and adjust plans as necessary [1,4,6]. Table 1 will compare the previously described methods in the process of optimizing project implementation times under resource constraints.

TABLE 1. Comparison of methods in the process of optimizing project implementation time in conditions of limited resources. (compiled by the author)

Method	Goal	Resources	Resource Requirements	Strengths	Weaknesses	Effectiveness in Resource-Constrained Conditions
Gantt Chart	Graphical representation of project duration, clearly displaying all project stages and their timelines.	Implicitly considered: resource constraints can be included in the plan using the chart.	Resource constraints are often fixed; tasks are performed when necessary resources are available.	- Easy to use and visualize. - Works well for projects with fixed deadlines.	- Challenges in managing changes during the project. - Difficulties in adding new tasks or changes mid-process. - Does not account for potential risks.	- Effective for projects with predefined timelines and limited resources. - In resource-constrained conditions, adjustments to timelines or task redistribution may be required.
PERT Method	Planning under uncertainty, focusing on identifying possible delays and alternative paths.	Resource determination is critical for project completion; possible paths with constraints are analyzed.	Clearly defined at the project start, with the possibility of adjustments.	- Able to account for risks. - Considers various task execution scenarios (optimistic, pessimistic, most likely). - Suitable for complex projects with multiple factors.	- Requires precise time estimates for task execution. - Complex calculations and frequent data updates needed.	- Effective when a project has "floating" parameters. - In resource-constrained conditions, helps adjust forecasts and account for delay risks or resource shortages.
Agile Methodology	Iterative process, focused on project adaptation during implementation; changes are possible mid-project.	Resources are adjusted as needed in each sprint and can be redistributed.	Flexibility in resource requirements depending on sprint results.	- Flexibility, adaptability to changes in the project. - Provides constant feedback from users. - Enables timely responses to external changes.	- Requires team qualification and self-organization. - Challenges in implementation for large projects with predefined requirements.	- Effectively redistributes resources during the process, focusing on the most important tasks at the moment.

Resource planning plays a crucial role in the successful implementation of projects. Proper allocation of resources across tasks is essential to prevent overloading at any stage. Multitasking and parallel execution of work contribute to the efficient utilization of available resources while maintaining quality. This requires timely decision-making and plan adjustments based on changes. In this context, the theory of constraints focuses on identifying factors that hinder project progress.

The use of project management software facilitates planning, monitoring, and adjustment processes. Tools such as Microsoft Project, Primavera, Asana, and Jira provide functionalities for scheduling, task tracking, and resource

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redistribution. These tools enable timely responses to changes, allow adjustments to plans, and ensure work progress control.

However, timeline optimization is impossible without effective risk management. Forecasting potential challenges, such as supply delays, lack of specialists, or technological failures, enables proactive measures to be taken. Continuous risk monitoring and readiness to respond to changes minimize their impact on the project.

At the same time, quality control at all stages helps avoid errors that lead to additional time spent on corrections. A quality assurance system ensures that work is performed in compliance with established standards, eliminating the need for rework and conserving resources that would otherwise be spent on defect resolution. In this regard, machine learning algorithms analyze data, identify patterns, and predict potential delays and issues. These methods adjust schedules and reallocate tasks based on resource load [2,4,5].

At the initial stage of the project, it is crucial to accurately define constraints, such as financial, time, personnel, or technological limitations. For instance, a lack of qualified specialists, limited budgets, or difficulties in accessing necessary equipment can slow down progress. It is important not only to identify these factors but also to establish expectations regarding timelines, quality, and work scope. Next, Figure 2 will describe the steps for implementing methods for optimizing project deadlines with limited resources.

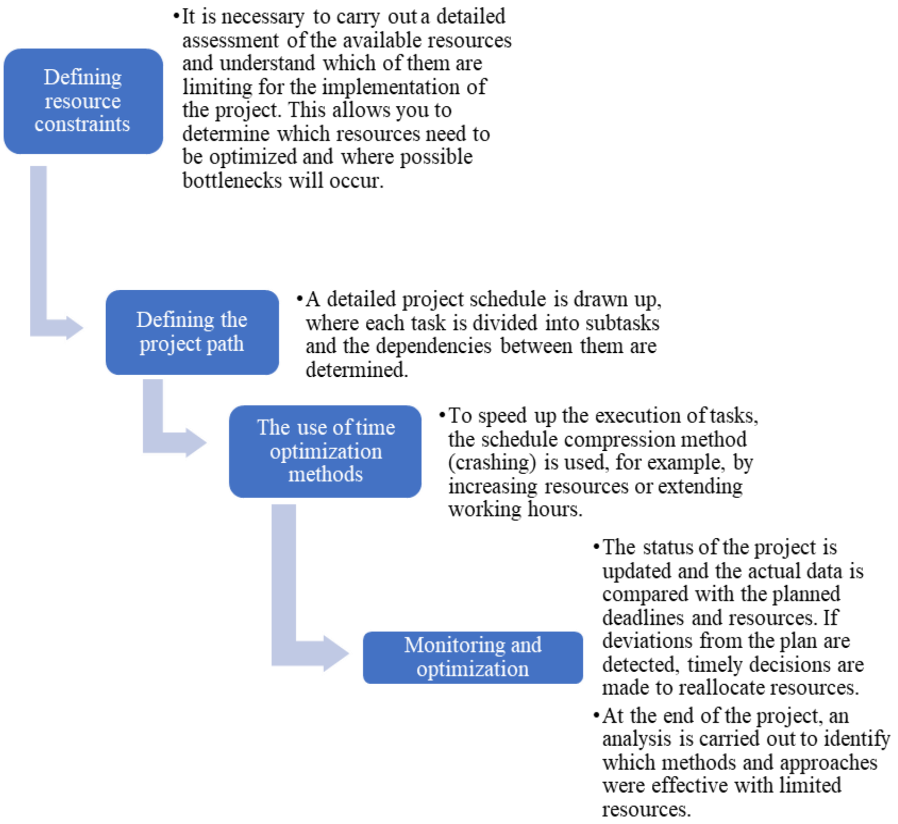

Fig.2. Steps to implement methods for optimizing project time with limited resources (compiled by the author).

Thus, successful timeline optimization under resource constraints requires a comprehensive approach, involving careful planning, the application of various management methods, risk monitoring, and efficient resource allocation. Combining these factors ensures the achievement of predefined project goals within established timeframes while maintaining the required quality standards.

IV. CONCLUSION

Optimizing project timelines under constrained conditions requires the application of various existing methods and tools. Methodologies based on mathematical modeling, such as linear and integer programming, along with network planning methods like Gantt charts, PERT, and CPM, effectively address this challenge. These approaches facilitate the development of

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plans with detailed stages and enable timely adjustments in response to changes caused by external or internal factors.

The results of the study confirm that timeline optimization is achieved through proper resource allocation and the use of flexible management methods. Specifically, critical path analysis accelerates task execution, while accounting for resource constraints reduces project duration and minimizes risks associated with delays and overruns. An important aspect is the ability of managers to promptly adapt plans in response to changing circumstances. This can be achieved by implementing adaptive planning methods and regularly updating information on project progress.

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