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Optimization methods for construction schedules to enhance project efficiency

Mehdi Huseynov

Senior Scheduler, WOOD Group USA, Sanford, Florida

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Abstract: This article examines modern methodological developments in the field of construction schedule optimization as a tool to improve the management efficiency of related projects. The relevance of the topic is justified by the urgent need to adapt traditional planning approaches to the realities of digitalization, the growth of project scales, and the complexity of infrastructure design. The aim of the study is to systematize and characterize approaches that ensure the minimization of time and resource costs (without compromising the quality of construction work). Following a review of contemporary scientific literature, discrepancies have been identified regarding the choice of optimal methods for different types of projects: on one hand, research shows high effectiveness of automated technologies (such as 4D BIM), while on the other hand, their implementation is often significantly limited by economic and organizational determinants. The conclusion is made that successful optimization actions in this area require the integration of classical methods (CPM, PERT) with adaptive algorithms and mathematical models. The author's contribution lies in the formulation of recommendations for improving the efficiency of construction schedules (a specific sequence of actions is proposed, taking into account both external and internal challenges). The materials presented will be useful for project managers, engineers, and researchers focused on improving the efficiency of construction processes.

Keywords: BIM, automation, algorithms, construction schedules, optimization, planning, project management, resources.

Introduction: One of the key challenges in the modern construction industry is ensuring that project timelines are met without increasing costs or compromising the quality of work.

Construction schedules serve as one of the main tools in project management. They coordinate all stages of the work, ensuring alignment between participants, primarily contractors, suppliers, and clients. These tools define the chronological framework for completing specific tasks, the order in which they are carried out, and the interconnections between phases, which helps reduce the likelihood of delays and resource overspending.

Against the backdrop of increasing competition and the growing complexity of infrastructure projects, the issue of optimizing construction schedules has become critically important. Inefficient planning of time resources can lead to delays, budget overruns, and a noticeable decrease in client satisfaction. This is why the development and implementation of methods aimed at improving the efficiency of construction schedules remain a relevant and in-demand area of research among modern scholars.

METHODS

The reviewed sources and materials can be grouped into several key thematic areas that reflect the variety of approaches and methods for optimization in the field under consideration.

For example, the works of S.A. Bolotin and colleagues focus on using a probabilistic approach to create construction schedules with Microsoft Project software [3], as well as studying uncertain resource factors and system correction of time conflicts [2]. P.C. Nolz [7] discusses optimization steps in the context of urban logistics, emphasizing the synchronization of construction schedules and material deliveries. These studies aim to minimize time and resource losses.

O. Doukari and colleagues [4] analyze the nuances of applying 4D BIM technology for automation in the field, comparing it with traditional methods. V. Undozerov [9] describes the functionality of dynamic visualization of schedules using Spring Chart techniques, proposing an approach for more visual control. Zh. Zhang and co-authors [10] use LSTM algorithms to analyze the impact of extreme weather conditions on schedules, highlighting the importance of adaptive solutions in modern realities.

The work of J. Zhou and colleagues [11] provides an overview of methods and algorithms used for optimization in the analyzed area, accompanied by statistical data, with a focus on mathematical models and computational developments. Y. Hong and co-authors [5] offer a graph-based approach for analyzing sequences of construction processes, which facilitates accurate assessment and adjustment.

K. Itani [6] explores the integration of CPM and PERT, highlighting their role in managing complex projects. In practice, this work is aimed at improving planning accuracy and controlling task execution. Integrative mechanisms are also reflected in the publication by S.Ju. Ahn and colleagues [1].

P. Srinath, K. Varghese [8] analyze the causes of discrepancies in quality in basic construction schedules. Their publication focuses on identifying systemic issues and improving planning.

The aforementioned studies demonstrate significant progress in the field of construction schedule optimization (including the development of automation technologies, adaptation to external conditions, the use of mathematical models, and the improvement of resource management methods). However, contradictions remain in defining universal approaches for different types of projects. There is insufficient development of the methodological framework for comprehensive interdisciplinary approaches. Limited attention is given to the integration of adaptive algorithms that consider external factors (such as climate conditions, market changes, etc.). Some studies show weak connections between practical realities and theoretical models.

In preparing this article, comparative analysis, systematization, statistical data evaluation, and generalization were applied.

RESULTS AND DISCUSSION

The primary purpose of construction schedules is to create a clear structure for project execution. They help identify the critical path—the sequence of tasks that determines the overall completion time of the construction. This allows the focus to be placed on stages that have the greatest impact on the timeline, preventing delays [2, 6]. Essentially, construction schedule optimization (CSO) is a form of project planning optimization [11].

In addition, these tools serve as a means for monitoring and controlling the progress of a given project. They allow the tracking of progress, identification of deviations from the plan, and prompt corrective actions. They are also used to evaluate the effectiveness of resource utilization, contributing to cost optimization.

Construction schedules play a significant role in communication between project participants. They help visualize complex processes, making the work plan easier to understand for all stakeholders. This is especially important when implementing large infrastructure projects, where coordinating actions requires a high degree of coordination.

Thus, the described tools should be viewed as an essential component of successful design, ensuring:

- structure;
- transparency;
- control [3].

They contribute to more effective management, risk minimization, and achieving set goals within established deadlines.

As for construction schedule optimization, it represents the process of improving the timing parameters of project execution, taking into account available resources and set constraints. This process involves a combination of:

- mathematical methods;
- digital technologies;
- management experience.

Optimization in the analyzed area is based on numerous principles aimed at minimizing time losses, maximizing the use of available resources, and reducing costs (Fig. 1).

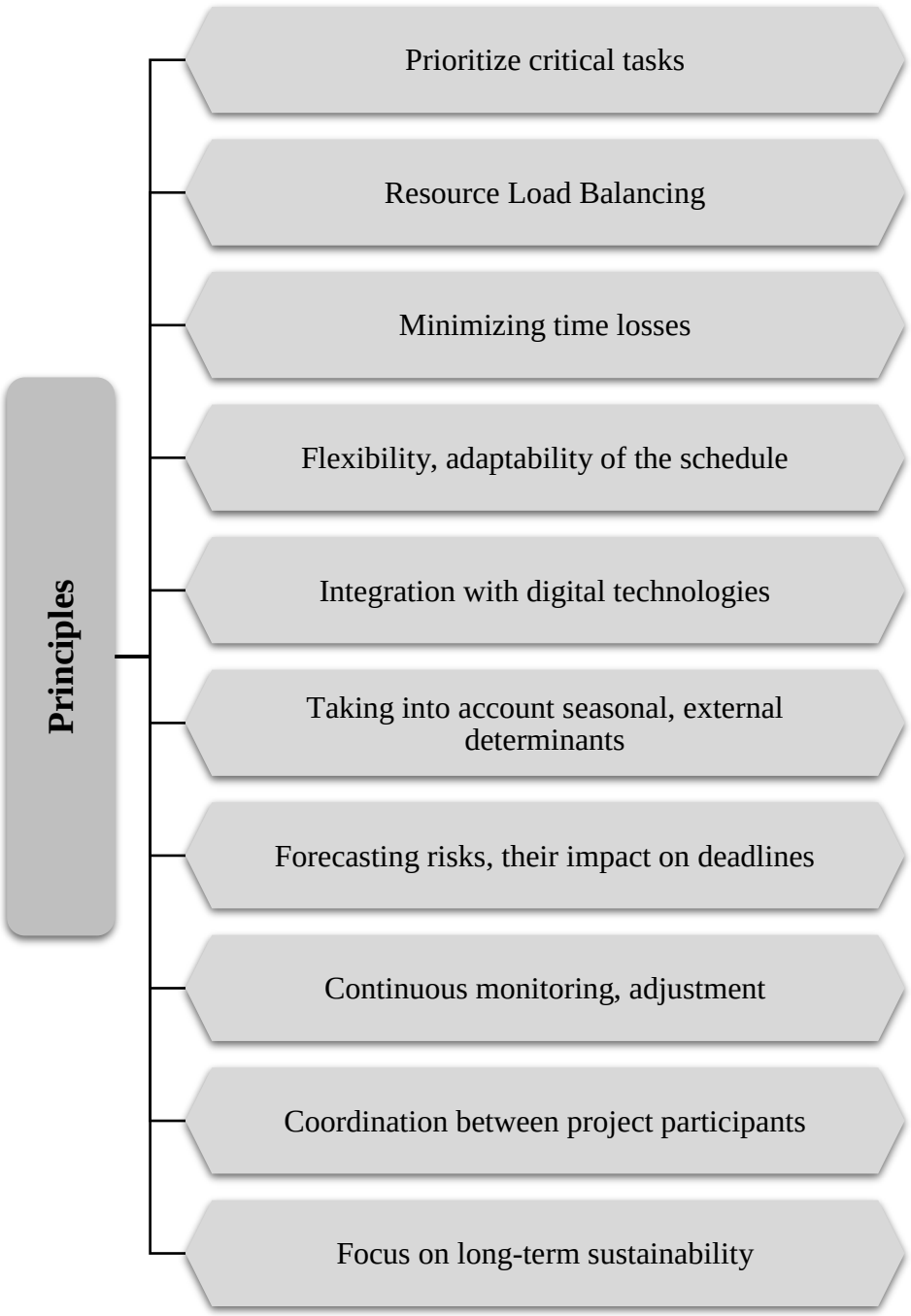

Fig. 1. Systematization of the principles of optimizing construction schedules to increase the efficiency of projects (compiled by the author on the basis of [1-3, 6, 9])

Modern approaches to optimization procedures are represented by the use of network models—Gantt charts, the Critical Path Method (CPM), as well as the application of digital tools, including Building Information Modeling (BIM) systems and specialized project management software. The methods for optimizing construction schedules are listed in Figure 2.

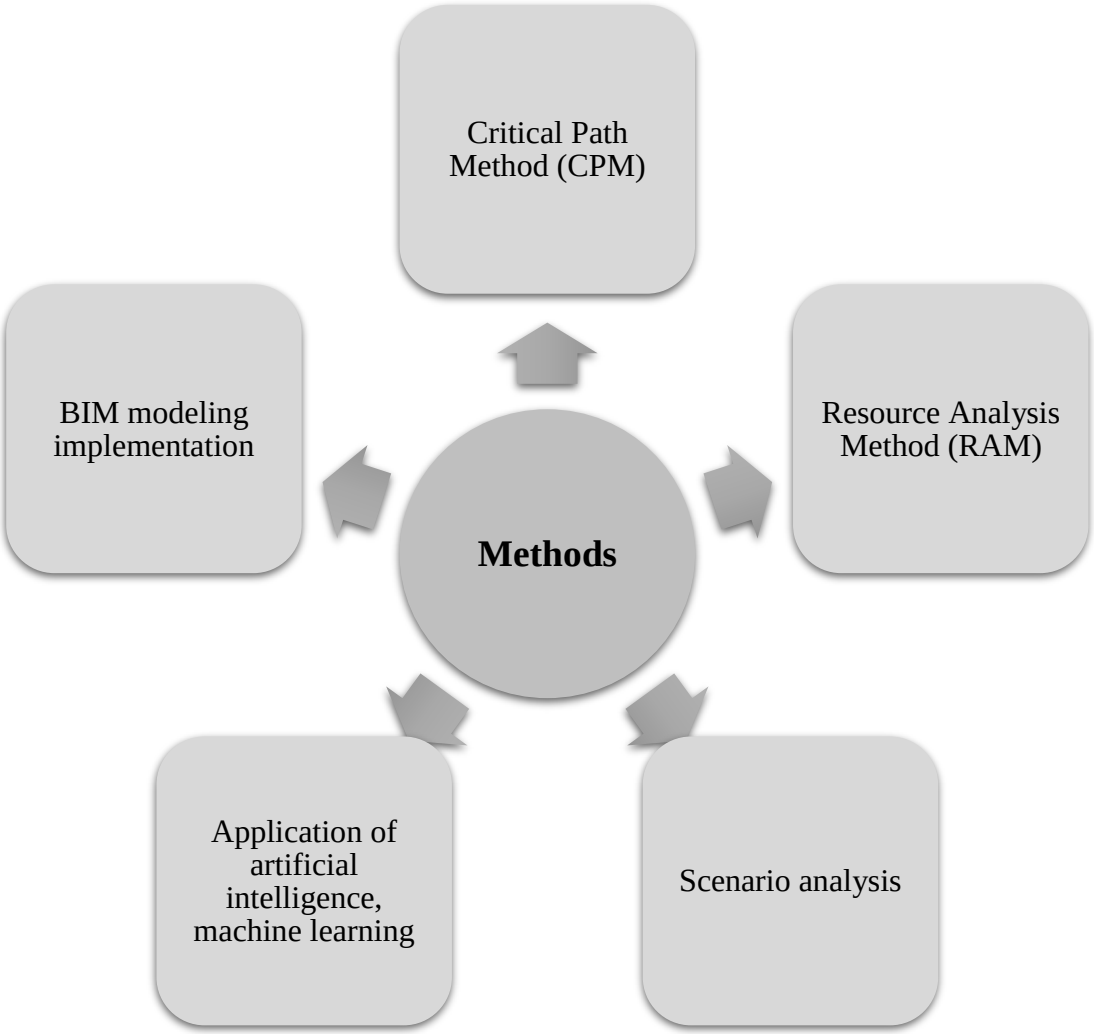

Fig. 2. Highlighting the main methods of optimizing construction schedules to improve project efficiency (compiled by the author based on [2, 4, 5, 10])

The Critical Path Method helps identify sequences of steps that define the minimum duration of a project. This approach is effective for large infrastructure projects with many interrelated stages. Schedule optimization using CPM includes reviewing the duration of tasks, utilizing slack time for non-critical tasks, and redistributing resources.

Optimization measures that consider the availability of the resource base rely on analyzing and balancing its use. Redistributing workgroups, machinery, and materials helps avoid bottlenecks that lead to downtime. The use of RAM is most productive and justified when implementing projects with limited budgets.

Meanwhile, the scenario approach involves modeling various options for implementing construction schedules while considering potential risks and uncertainties. This method allows for the preparation of corrective actions in advance, minimizing negative consequences in case of deviations from the initial plan.

The introduction of artificial intelligence algorithms into the planning process provides additional options and functionalities in optimization. AI solutions allow the analysis of large amounts of data, detect hidden relationships between tasks, and successfully predict potential issues. These tools are actively used for real-time automatic adjustments.

The integration of schedules into a digital model of a building or structure helps visualize the temporal and spatial aspects of project implementation. BIM

technologies enable the synchronization of planning, design, and construction processes, reducing the likelihood of errors and duplication of work.

Despite the availability of many tools, the implementation of optimization methods in the discussed field faces a number of problems (Figure 3).

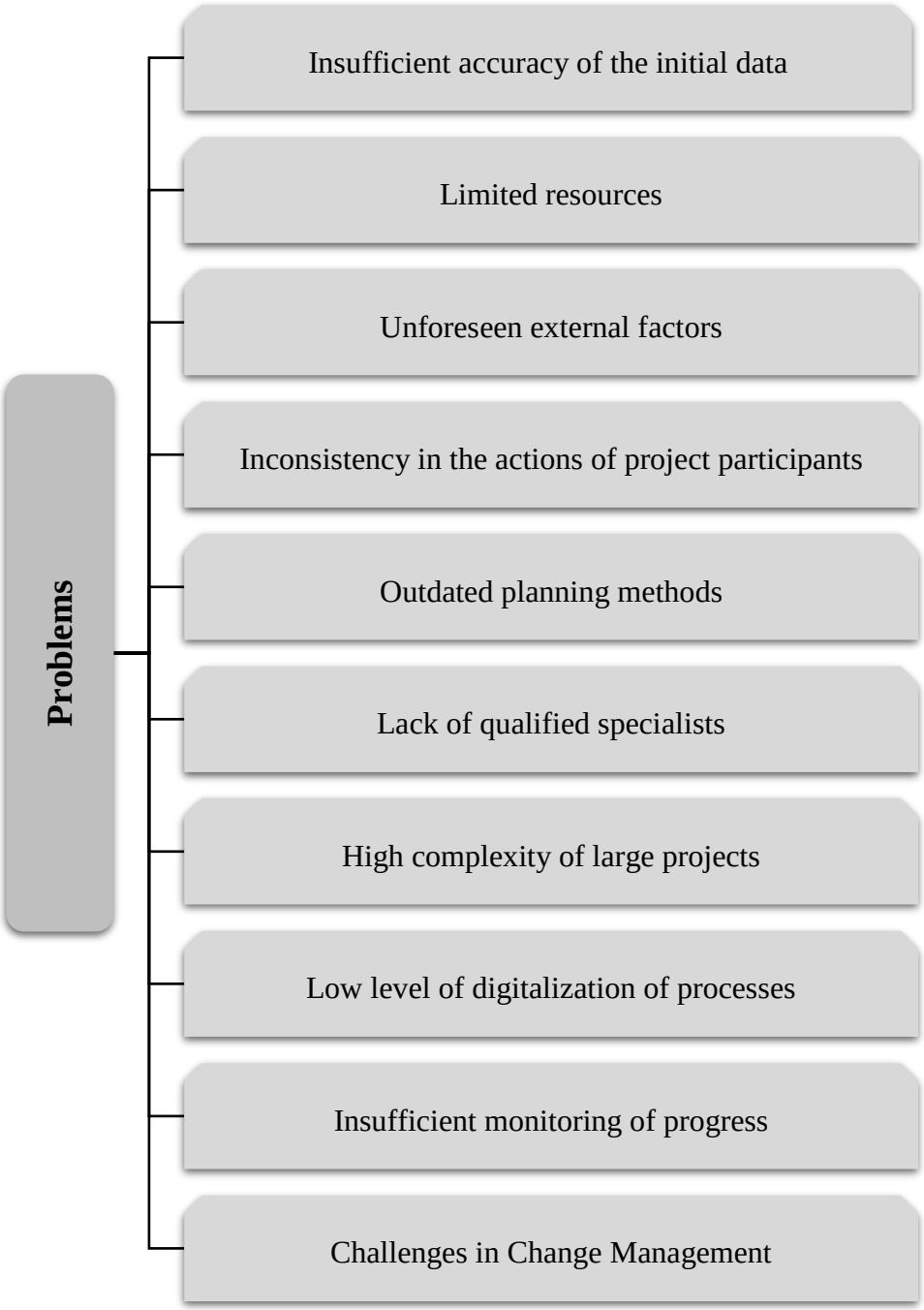

Fig. 3. The main problems of using methods of optimizing construction schedules to increase the efficiency of projects (compiled by the author based on [1, 8, 9])

Thus, the high cost of implementing digital solutions limits their use in small and medium-sized construction businesses. Additionally, the lack of qualified specialists significantly hinders the use of complex mathematical methods and IT tools. Furthermore, incomplete or inaccurate project information often leads to errors in calculations.

CONCLUSION

Construction schedule optimization is a complex but necessary process aimed primarily at improving project execution efficiency. The application of modern methods and technologies allows for significant reductions in time and financial costs, while substantially improving the quality of the final outcome. However, success requires a systematic approach combining mathematical analysis, digital tools, and the

development of professional skills among project participants.

To improve construction schedule efficiency, the following sequence of actions is proposed: auditing the current schedule (identifying areas with the highest risk of deviation); integrating automated monitoring systems (using AI for analysis and forecasting); integrating digital technologies (implementing BIM for process synchronization and enhancing schedule transparency); training specialists (improving project managers' qualifications in time resource management).

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