Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-51301
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 22, No. 2, 2024
Original Scientific Paper
Paper number: 22(2024)2, 1198, 336-341

A FRAMEWORK FOR PROGRESS MEASUREMENT BASED ON INTEGRATED MONITORING OF PREREQUISITES AND WORK PERFORMANCE

Dejan Marinković*, Marija Ivanović, Nevena Simić, Nikola Knežević
Faculty of Civil Engineering, University of Belgrade, Belgrade, Serbia
dejan@grf.bg.ac.rs

The successful implementation of construction projects necessitates the establishment of an efficient system for project execution planning and control, with parameters that ensure an effective assessment of the construction work status, timely detection of variance causes, and reliable trend analysis. In this regard, a set of parameters has been developed, among which the actual progress of works on a project holds a significant place. Existing approaches to progress measurement is mostly focused on studying methods for calculating the percentage of completed works and their applicability to specific types of works and organizational levels. However, key issues persist, such as delayed identification of variance causes and inadequate method sensitivity to initial variances when damages are still minor, and potential effects of corrective measures are greatest. Therefore, this paper proposes a framework for progress measurement based on integrated monitoring of prerequisites for tasks and work performances. While progress monitoring at the project level is organized within workflows, monitoring within each workflow is provided for sub-workflows related to ensuring prerequisites, material procurement, and construction work execution. Visualization of sub-workflows is facilitated through planned and actual cumulative curves of completed works in percentage, whose interrelationships promptly indicate potential project issues. The application of the proposed framework ensures better synchronization of construction works, improved control of prerequisites, rapid detection of causes, along with efficient variance management. The framework includes a clear division of responsibilities for implementing sub-workflows, where site management and specialized services of a company are responsible for ensuring prerequisites and material procurement, while production forces of a company primarily handle the execution of construction works. Such an approach allows for direct determination of issues or quick and efficient delineation of responsibilities, which represents a common issue in practice. This contributes to the motivation of employees and enhances the performance of the project management team.

Keywords: progress measurement, workflows and sub-workflows, integrated monitoring, prerequisites, procurement, performance, responsibility

1 INTRODUCTION

The selection and implementation of efficient systems for project planning and control are of utmost importance for the successful operation of construction companies. This contributes to reducing unnecessary costs and enables firms to achieve higher profits or improve their competitiveness in the market. Due to the specificity of production in the construction field and exposure to a large number of risks, it is essential to create high-quality time schedules at the beginning of project implementation. This involves a series of procedures such as analyzing optimal technological and organizational solutions, understanding the prerequisites for task realization, considering constraint conditions, etc. To make the schedule usable in practice, it is necessary to optimize it before construction works commence so that the continuity of construction operations/works is ensured and the tasks of work teams are maximized. The application of such schedules creates favorable conditions for achieving high performance in the construction production, i.e. construction output.

For successful control during project implementation, it is necessary to periodically conduct status checks, determine variances, analyze consequences, and implement corrective measures. In this sense, a set of parameters has been developed, among which the percentage of project completion occupies a very significant place. Timely and accurate measurement of the progress of construction works greatly influences the quality and correctness of managerial decisions. Various approaches have been developed for measuring the percentage of construction work completion, which can be successfully applied in practice. The methods include calculation procedures, the quantities that need to be measured, as well as the conditions and limitations for their application. However, there are only few examples in the literature that provide corresponding rules and propose a framework for the efficient application of these methods, thus indicating a need for further research.

The aim of this paper is to develop a framework for measuring progress on construction projects, enabling integrated monitoring of the prerequisite provision and work execution on the construction site. This would contribute to improving the process of identifying the variance causes and responsible parties, which is a common issue in practice. Thus, there would be an improvement in the quality and speed of making managerial decisions, which is one of the main conditions for efficient project implementation control.

1.1 Existing approaches to progress measurement

Existing approaches to progress measurement in project implementation are mainly focused on studying the calculating methods for the percentage of work completion and their applicability to specific types of works and organizational levels. Percent (%) Complete are measured periodically and primarily serve to assess the status of works on the project, identify variances, and analyze consequences. Determining the variance causes is usually done retrospectively and often with a delay, when the variances have already become significant. The expected effects of corrections are then considerably smaller. Successful project implementation management requires preventive actions, involving timely consideration of potential causes of variances, their early detection, and elimination. Therefore, the research focus in this paper is primarily on forming a framework for progress measurement that can contribute to better management of the variance causes.

According to the classical approach to planning and control of project implementation, based on the Critical Path Method (CPM) [1], progress measurement and control are primarily carried out at the task level and then at the overall project level. According to Location Based Management (LBM), progress control is performed at the task level, workflow level, and project level [2]. LBM is a planning approach based on workflows, representing specific technological and organizational units assigned to a resource team. Tasks in LBM are represented by lines in a time-space coordinate system [3]. It is crucial for workflows to be continuous in order to avoid interruptions in work of teams and unnecessary costs. However, within Location Based Management (LBM), adequate attention is not devoted to the prerequisites for work execution nor specific tool for their planning and control.

The Last Planner System (LPS) represents a planning system where more comprehensive planning levels (long-term plans) are entrusted to leading planners, while operational planning is handled by last planners (foremen) [4,5]. LPS recognizes the importance of prerequisites and addresses them through a specific type of medium-term plans, so-called Lookahead plans. These plans cover a period of 4 to 6 weeks and include tasks for work execution. In addition to this, they encompass the tasks related to prerequisite provision [6]. These plans are based on estimates and coordination among last planners responsible for specific groups of construction works. In practice last planners may be subjective, i.e. some of them being very optimistic and others being very pessimistic in relation to the estimates of their work progress. Therefore, enhancing trust among team membersis essential for subjectivity reduction [4].

In the LPS, detailed planning is carried out while approaching specific works, whereas weekly operational plans only include the tasks for which prerequisites have been secured. According to [6], this ensures stability and reliability of workflows.

The Percent Plan Complete (PPC) is used as a metric for determining the percentage of completion within the LPS, defined as the ratio of completed to planned tasks [4], typically measured on a weekly basis. However, the reasonableness and subjectivity of last planners significantly affect the accuracy of the obtained results. It is pointed out in the literature that tasks are not of equal weight, and thus it is necessary to introduce weighting coefficients. Additionally, the integration of operational and long-term plans, the so-called vertical integration of planning levels [7], is not well established in the LPS, making it challenging to understand trends and analyze consequences. As a result, this can impact the accuracy of managerial decisions.

Regarding methods for progress measurement, the literature mentions several methods along with descriptions of their application. For example, Estimated Percent Complete, Physical Progress Measurement, and Earned Value Method (EVM) are highlighted in a study [8]. In [9] suggested using methods such as Unit Completed, Incremental Milestone, Start/Finish, Supervisor Opinion, Cost Ratio, and Weighted or Equivalent Units. Depending on the nature of specific construction works and available data, it is possible to choose a method that will yield the best results for the project in question. In this context, calculations for some of the chosen methods have been explained. Physical progress measurement is calculated as the ratio of the performed to the total quantity of work items. Since tasks and workflows include various work items, the introduction of weighting coefficients is necessary. In EVM, the percentage of completion is calculated as the ratio of Earned Value (EV) to the budget for particular activity or task, workflow, or project [9,10]. Current EV is the sum of the budget for the activities accomplished in a given period. However, the focus of research in this paper is primarily on forming a framework for progress measurement that would enable the rapid detection of the variance causes, which is recognized as a common problem in practice.

2 METHODOLOGY

2.1 Progress Measurement Framework

In order to enhance the effectiveness of project progress measurement and better management of the variance causes, a framework for progress measurement is proposed in this paper. The framework is based on parallel monitoring of work execution, ensuring prerequisites, and procuring materials. Although it belongs to prerequisites, material procurement is specifically highlighted due to its significant contribution to costs and the fact that materials need to be delivered to the construction site in advance. Figure 1 illustrates the block diagram of the proposed approach.

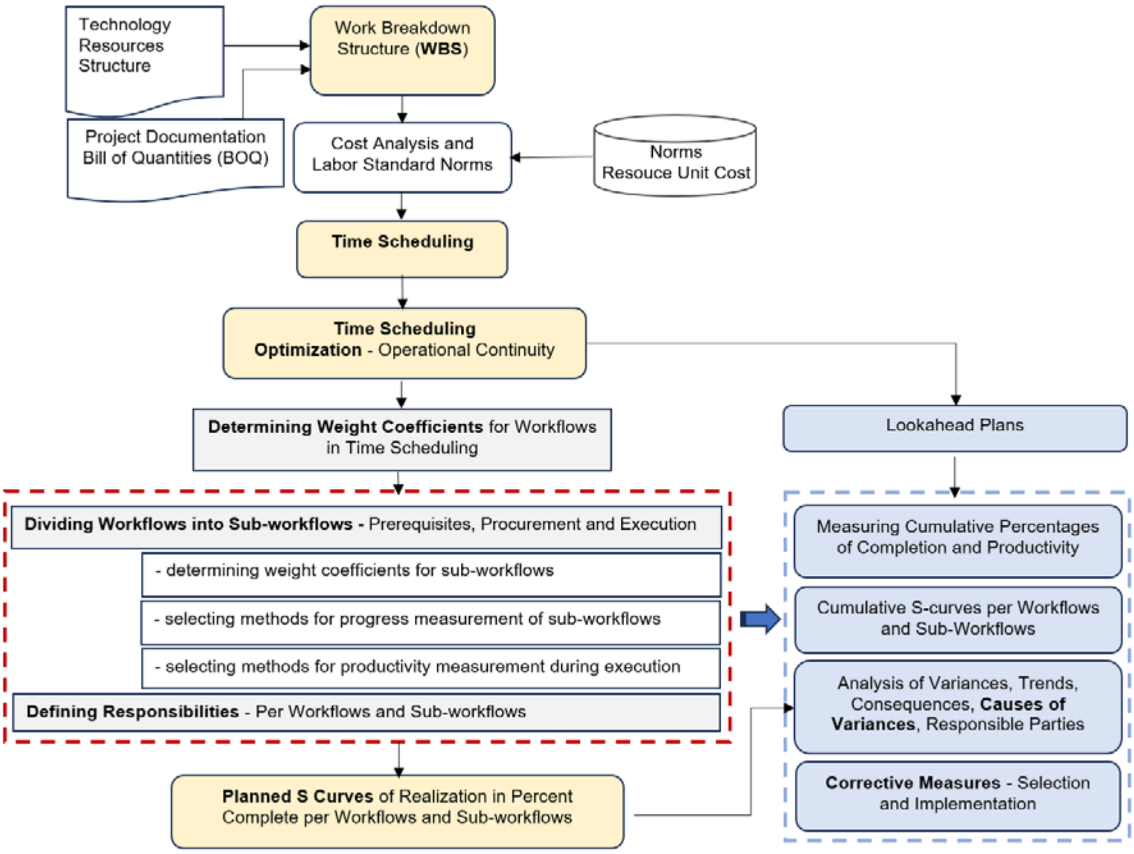


Fig. 1. Framework for progress measurement based on integrated monitoring of prerequisites and work performance

According to the proposed framework (Figure 1), it is envisaged that workflows are primarily defined for efficient progress monitoring and an initial time schedule/baseline schedule creation. Subsequently, plan optimization is mandatory to ensure operational continuity and synchronization of work teams, thus creating conditions for high production levels.

Weight coefficients, which are used for calculating the Percent (%) Complete for the entire project, are assigned to workflows. Within each workflow, sub-workflows related to prerequisite provision, material procurement, and work execution are defined. Weight coefficients are then assigned to these sub-workflows to determine the total Percent (%) Complete value for the corresponding workflow (Figure 2). Depending on the nature of the workflows and sub-workflows, progress measurement methods are selected. Measurements of other performance indicators, such as productivity, are included in this approach in order that a comprehensive understanding of the status of construction works is gained. Adequate methods for productivity measurement are also chosen for each workflow, followed by the assignment of responsibilities for the workflows and sub-workflows.

Cumulative curves (S-curves) depicting planned progress for workflows and sub-workflows (Figure 2) are derived from the optimized time schedule (schedule baseline). These curves serve as a benchmark for comparison with actual values. Before commencing construction works, Lookahead plans are to be developed for a period of 4 to 6 weeks, primarily focusing on ensuring prerequisites. These plans must align with the optimized time schedule (schedule baseline) and include detailed elaboration of tasks from the schedule baseline, synchronization of teams at the operational level, and material procurement. Tasks in Lookahead plans are grouped by sub-workflows, similar to the schedule baseline.

During the execution of construction works, weekly measurements of Percent (%) Complete for sub-workflows and workflows are conducted. S-curves representing actual progress are drawn, compared with planned S-curves, variances are identified, trends are determined, and consequences are analyzed. The actual S-curves for sub-workflows provide separate insights into ensuring prerequisites, material procurement, and work execution for each workflow. If the S-curves for sub-workflows approach or intersect, it immediately indicates issues with prerequisites or procurement, significantly impacting the progress of construction works. This approach allows for immediate understanding of key issues (Figure 3) and efficient response.

The site management and professional services of a company are responsible for prerequisite provision, material procurement, and work organization. The goal is to proactively eliminate interruptions/delays in works and create ideal working conditions. Under such conditions, the progress of works depends directly on the workforce performance. To distinguish between the cases where there are shortcomings in both the site management and among the workforce themselves, it is necessary to measure interruptions/delays in works and determine whether workforce achieved the planned productivity outputs during non-delay periods. The proposed division of workflows into sub-workflows clearly defines responsibility, positively influencing the motivation of employees.

The choice of progress measurement methods based on the nature of sub-workflows is effective for determining individual Percent (%) Complete for sub-workflows. For example, the PPC method with weight coefficients can be applied so that prerequisites are ensured, while the physical percentage method with weight coefficients or the Earned Value Method can be used for material procurement. Due to the diversity of sub-workflows for work execution, detailed analyses, i.e. further research, are required. When choosing progress measurement methods, it should be considered whether time control or cost control is being exercised. Existing approaches often do not pay sufficient attention to this aspect of control, whereas measurement results in practice show variations depending on the chosen method.

Based on the overview of the current status of the construction works, variances in workflows have been identified, and subsequently, corrective measures have first been applied to them.

3 RESULTS AND DISCUSSION

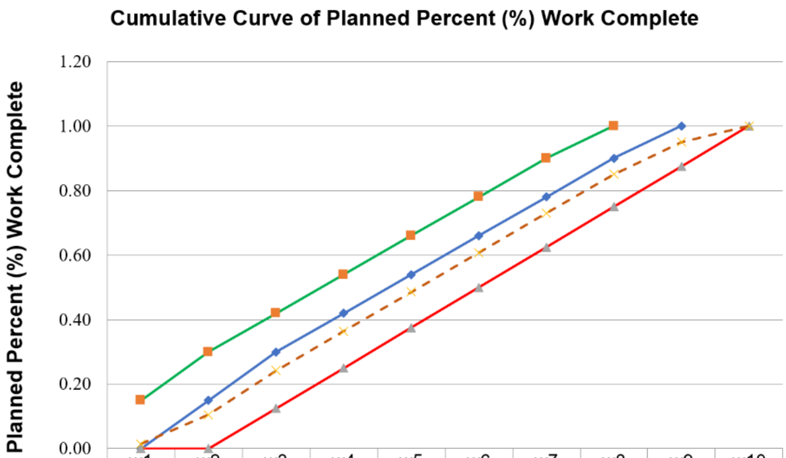
3.1 The case study of a residential-commercial building

The case study covers the progress control of construction works on a residential-commercial building with a structure consisting of one underground and 5 above ground floors with gross area 5374 m^2. The building structure is a reinforced concrete with reinforced concrete walls for elevators and stairs. External walls are made of hollow clay blocks, while internal walls are constructed using hollow clay blocks and bricks. The interior finishes and facade are of a medium-quality level. The main contractor is responsible for the construction, masonry, facade carpentry, ceramic and parquet flooring works. The gross area of the underground part of the building is 1270 m^2, whereas the above-ground part is 4104 m^2. A time schedule has been developed, and optimization has been carried out for the project to ensure the operational continuity, full utilization of workforce capacity, and their synchronization. As a result, the prerequisites for achieving the high-performance of construction production have been created.

The study focuses on the above-ground part of the building. Progress control has been conducted for all contracted works of the main contractor. The study presents the extracts from measurements and analyses of the Percent (%) Complete for reinforcing works as part of the building construction. The Percent (%) Complete was measured on a weekly basis and expressed in relation to the overall reinforcing works.

For the first three weeks, the contractor and workforce teams had been allowed to organize themselves and execute work in the usual manner. After this period, the procedure proposed in the study was implemented. During the initial three weeks, all necessary measurements had been taken without disclosing the results to the immediate executors. This approach allowed for the identification and quantification of differences in various approaches.

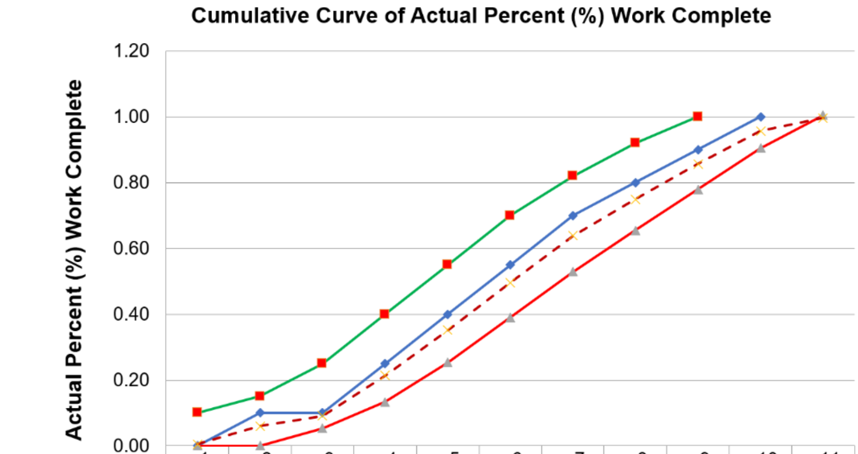
In line with the proposed approach, reinforcing works were divided into three sub-workflows: ensuring prerequisites, procuring reinforcement, and performing reinforcing works on the construction site. Lookahead plans were developed for a 5-week period. Ensuring prerequisites was planned to be completed no later than two weeks before commencing works. As for the delivery of reinforcement to the construction site, it was intended to be completed no later than one week before its installation to mitigate potential disruptions in the supply chain. The planned method of material procurement and delivery aligns with the Just-in-Time approach, enabling the rational use of financial resources. A resource analysis determined the need for 15 steel fixers. Figure 2 depicts the planned S-curves of Percent (%) Complete for the specified sub-workflows. They are separated and phased to ensure that prerequisites and procurement do not jeopardize the continuity of work execution.



	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10
Prerequisites	0.15	0.30	0.42	0.54	0.66	0.78	0.90	1.00		
Procurement	0.00	0.15	0.30	0.42	0.54	0.66	0.78	0.90	1.00	
Execution	0.00	0.00	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000
Cumulative	0.02	0.11	0.24	0.36	0.49	0.61	0.73	0.85	0.95	1.00

Fig. 2. Cumulative curves (S-curves) of the planned Percent (%) Work Complete of sub-workflows

Figure 3 depicts S-curves of the actual Percent (%) Work Complete for sub-workflows along with their cumulative value. Initially, characteristic weaknesses of the contractor were observed, such as delays in preparatory tasks. In the second week (w2), issues arose due to incomplete project details, leading to delayed ordering and procurement of materials for the following week (w3). This is manifested on the diagram in Figure 3 through the convergence of the S-curve for material procurement and the S-curve for work execution to an extent that could have caused a halt at the construction site. Since the proposed framework allows for the timely identification of such issues and proactive intervention, it was implemented from the fourth week (w4), gradually leading to improvements in all sub-workflows (Figure 3). Due to a shortage of workforce and lower productivity (0.8) in the first two weeks of execution (w3 and w4), delays occurred, which were eventually brought under control by the end of the workflow. As a result of significantly improved productivity, planned weekly workforce performances were achieved. The study demonstrated that the proposed framework application enables proactive intervention and successful management of the variance causes.



	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11
Prerequisites	0.10	0.15	0.25	0.40	0.55	0.70	0.82	0.92	1.00		
Procurement	0.00	0.10	0.10	0.25	0.40	0.55	0.70	0.80	0.90	1.00	
Execution	0.00	0.00	0.053	0.133	0.253	0.390	0.529	0.654	0.779	0.904	1.00
Cumulative	0.01	0.06	0.09	0.21	0.35	0.50	0.64	0.75	0.86	0.96	1.00

Fig. 3. Cumulative curves (S-curves) of the actual Percent (%) Work Complete of sub-workflows

4 CONCLUSIONS

The paper proposes a framework for progress measurement in construction projects based on integrated monitoring of ensuring prerequisites for tasks and work performances. This approach is primarily focused on the rapid identification of the causes of variances and their elimination. Project progress monitoring is organized for workflows as well as within each workflow. In other words, progress is monitored for sub-workflows related to ensuring prerequisites, material procurement, and on-site work execution. During the planning phase, the quantification, synchronization, and visualization of sub-workflows are conducted. The visualization of sub-workflows is achieved through S-curves of Percent (%) Work Complete. Interruption risks are managed with buffers between sub-workflows (phase-shifting of S-curves). By comparing planned and actual S-curves, as well as analyzing the relationships between actual S-curves of sub-workflows, interruptions in works and key causes of variances in the early stages can be identified. This enables project participants to anticipate potential causes of variances, apply corrective measures, and eliminate interruptions in works before they become significant and cause substantial damage.

The implementation of the model involes teamwork among planners, technical staff, company departments, with clearly defined hierarchy, roles, obligations, and responsabilities of individuals. In this regard, it is necessary for the company and its projects to have a clear organizational structure and established information flows. The existence of a quality information system in the company contributes to the more efficient use of the proposed model.

The proposed model is developed for projects where the tasks can be clearly grouped by workflows. The paper provides general recommendations for applying methods to measure progress. Depending on the nature of the workflows and sub-workflows, it is necessary to analyze which methods are most effective.

Tracking the progress of material procurement can require processing a large amount of data, which may slow down the progress measurement process and decision-making. By focusing only on key materials, the process can be significantly accelerated, which is one of the directions for further research.

The clear and transparent division of responsibilities by workflows and sub-workflows acts as a motivating factor for employees, both for production workforce, the site management and professional services of a company. Through combined measurements of Percent (%) Complete and productivity, along with the application of appropriate corrective measures, variances can be timely identified, and high production performance can be achieved.

The case study demonstrates that the proposed framework can be successfully applied in the construction of residential-commercial buildings and yield positive results. Lookahead plans for ensuring prerequisites and the S-curves of actual Percent (%) Work Complete have proven particularly useful. The proposed framework for project progress measurement can generally be applied to other types of building structures; however, further research needs to be conducted for that purpose.

5 REFERENCES

[1] Nisar, S. L., & Suzuki, K. (2015). Critical Activity Analysis in Precedence Diagram Method Scheduling Network. Proceedings of the 4th International Conference on Operations Research and Enterprise Systems (ICORES 2015), Lisbon, Portugal, pp. 232–247. DOI: 10.1007/978-3-319-27680-9_14

[2] Seppanen, O. (2009). Empirical research on the success of production control in building construction projects (Doctoral dissertation). Faculty of Engineering and Architecture, Helsinki University of Technology, Finland.

[3] Kenley, R., Seppanen, O. (2009). Location-based management of construction projects: part of a new typology for project scheduling methodologies. Proceedings of the 2009 Winter Simulation Conference (WSC 2009), Austin, USA, pp. 2563-2570. DOI: 10.1109/WSC.2009.5429669

[4] Ballard, G. (2000). The Last Planner System of production control (Doctoral thesis). Faculty of engineering, University of Birmingham, UK.

[5] Warld, O., Hamani, K. (2023). Lean Construction in the UAE: Implementation of Last Planner System. *Lean Construction Journal*, 2023(1), 1-20.

[6] Hamzeh, F., Ballard, G., Tommelein, I. (2012). Rethinking Lookahead Planning to Optimize Construction Workflow. *Lean Construction Journal*, 2012(1), 15-34.

[7] Hamzeh, F. R. (2009). Improving Construction Workflow – The Role of Production Planning and Control (Doctoral dissertation). Department of Civil and Environmental Engineering, University of California, Berkeley, USA.

[8] Thomas, H. R., Mathews, C. T. (1996). An analysis of the methods measuring construction productivity. Skills & Knowledge of Cost Engineering (5th ed., pp. 14.1-14.6). Morgantown, WV: AACE International.

[9] Orczyk, J. (201X). Progress Measurement and Earned Value (Chapter 14). Skills & Knowledge of Cost Engineering (5th ed., pp. 14.1-14.6). Morgantown, WV: AACE International.

[10] Vanhoucke, M. (2016). Integrated Project Management Sourcebook: A Technical Guide to Project Scheduling, Risk and Control. Cham, Springer International Publishing.

Paper submitted: 10.03.2024.

Paper accepted: 11.06.2024.