Daniel PRZYWARA, Ph.D., Eng.
Adam RAK, Ph.D., D.Sc., Professor

Opole University of Technology
Faculty of Civil Engineering and Architecture
Department of Civil Engineering and Construction Processes

C-S & S-C Monitoring of Time and Cost Variances of Schedule Using Complex Earned Value Method Indicators

Key words: Earned Value Method – EVM, time variances, cost variances, schedule

Summary

Planning and implementation of construction projects are difficult processes and are burdened with many risk elements. The budget spread over time, which is developed on the basis of the schedule, presents the expected distribution of costs throughout the duration of the works, which during the implementation of the project is subject to constant changes resulting from time, cost and organizational factors.

Managing construction contracts requires managers to be able to analyze on an ongoing basis the variances of production costs - from the values calculated in the offer cost estimate and assumed in the Budgeted Cost of Work Scheduled.

The article attempts to analyze the emerging time and cost variances using proprietary C-S and S-C monitoring, based on simple indicators of the EVM method. An example of construction of a multi-family housing development was used to study the variances of planned and incurred costs.

1. Introduction

The growing number and growing importance of unique, often complex construction projects, results in unflagging interest in project management.

Despite the undisputed, more significant than ever, development of effective methods of planning, coordinating and controlling, the increase in the complexity of operating conditions of the enterprise on the market means that, success in project management is not easier.

The selection of production control methods depends on many factors - primarily the degree of production repeatability, as well as the degree of details of available data, the details of the records kept, the use of planning documentation, the degree of use of computer techniques and the organizational culture prevailing in the company. Construction production is characterized with significant seasonal fluctuations. They constitute a cycle of repetitive changes, in more or less equal periods of time, with similar intensity. Their identification and inclusion considerably increases the precision of predictions. [7, p.94].

Earned Value Method (EVM) is recognized as an advanced method of controlling production ventures, which provides working results in the form of quantitative and qualitative indicators.

The purpose of developing the EVM method was to link the material progress of works and the costs incurred - against the background of planned values. This tool, "introduced" to construction sites, has been effectively implemented and disseminated.

 doi:10.20944/preprints201911.0188.v1

Managers managing complex construction contracts use key words to assess the progress of their schedules, fully describing planned and actual turnover, budget and timeliness of implementation. These include simple control indicators of the earned value method, used in the strategic assessment of the condition of the project - when monitoring the progress of works using the indicator method.

The EVM method is one of performance-based project management methods and is an effective tool for controlling projects in terms of costs, time and scope of works done [13, p. 115]. It consists of controlling the implementation of the project by comparing the scope of works executed and the costs actually incurred against the project schedule and budget adopted in the base plan.

Compared to the traditional method of checking the project progress, the EVM method includes the third dimension: earned value, which represents the planned value of the scope of work actually executed, in the assessment of the condition of the project, in addition to planned and actually incurred costs. By developing this method, not only measurement possibilities and assessment of the actual results of operations based on the data found during control periods were obtained, but also analysis of performance trends and forecasts of the future cost of project activities and projections of the final project budget. Appropriate indicators allow at each stage of the implementation of works to assess the current status of the project and the possibility of its implementation within the planned budget and schedule. The indicators used in the EVM method can be calculated for both individual tasks and the entire project, as cumulative earned value.

The basis of the earned value method is the Budgeted Cost of Work Performed (BCWP). It shows how much the work done as planned costs. If one wants to calculate it, they should have information on the planned cost of work to be incurred by the date of the inspection, and on the amount of work actually executed to that day.

Following composite indicators are part of EVM method: [13, p. 125]

- *Cost Performance Index - CPI*:

$$CPI = \frac{BCWP}{ACWP} \quad (1)$$

- *Schedule Performance Index - SPI*:

$$SPI = \frac{BCWP}{BCWS} \quad (2)$$

where:

BCWS – planned cost of the planned work until the day of inspection of the quantity of work of a given task,

ACWP – actual cost of the work executed up to the date of inspection of the quantity of work of a given task,

BCWP – the planned cost of the work executed to the day of work inspection of this task; value checking how much, according to plan, was paid for the work actually executed.

The CPI indicator shows the current ratio of planned to real unit costs, and also allows to adjust the total project costs, assuming constant price rates that have occurred so far.

The earned method value for many research centers around the world forms the basis for extensive research into innovation. Despite the constantly proposed improvements to its composite indicators (CPI, SPI), EVM forecasts are still there under the influence of design risk and uncertainty. This leads to a discrepancy between the results of final actual costs of projects and their forecasts using this method [12, p. 29-31].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

In the study [1, p. 12] a simplification of the EVM method was proposed in the context of its CPI and SPI indicators. This technique consists in replacing its complex control parameters with a factor defined as Critical Ratio(CR) which was also called the Cost-Schedule Index (CSI) [14, p. 33].This coefficient is calculated as follows:

$$CR = CPI \cdot SPI \tag{3}$$

If one of the indicators shows values smaller than one, signaling an underestimation or delay, the other one should reach a level above one, so that finally CR is close to one. In the case when both indicators assume undesirable relations (CPI, SPI <1), the CSI coefficient represents their resultant value capturing both cases of the resulting variances simultaneously. This situation indicates that, the overall performance of the project is poor.
This work also classifies the results of the CR coefficient, giving three ranges of earned values (Figure 1).

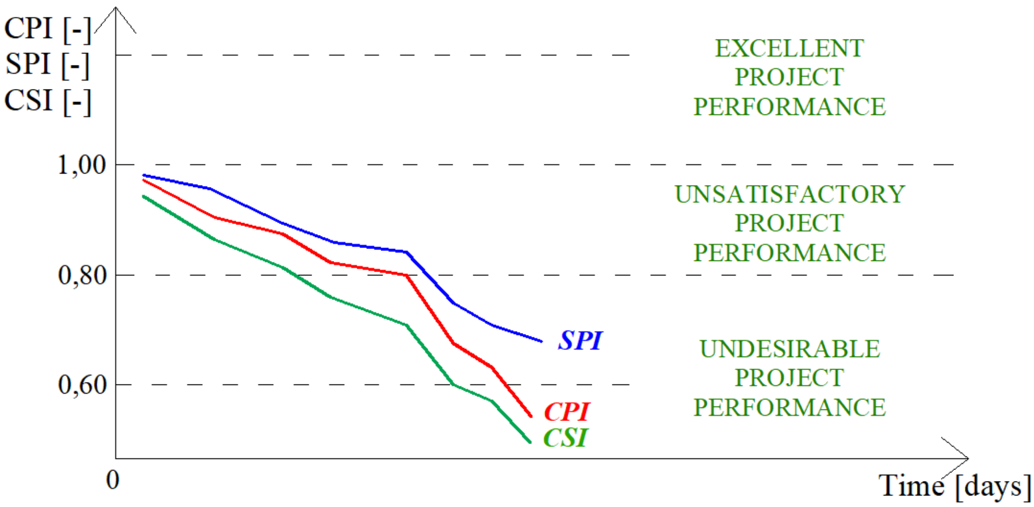

Fig. 1. *Target performance chart based on the CSI cost-planning indicator (description in the text). Source: own study based on: [1, p. 12].*

A detailed analysis of the schedule implementation indicator (SPI) was undertaken in the works [8, p. 8, 14, p. 51], proposing a new look at EVM, marked as ES (Earned Schedule).
The basic assumption of the ES method is a comparative analysis of the BCWP earned value indicator and the BCWS planned costs. The algorithm results are the values of time variances at individual moments of the project (t), reflecting the periods in which the equality was to take place: BCWP = BCWS, determined by the indicator of the schedule earned value (ES). The time indicator of the method is calculated as:

$$SPI(t) = \frac{ES}{AT} \tag{4}$$

where:
ES – indicator of the schedule earned value,
AT – the time elapsed from the beginning until the registration of the works.

The results of studies on the stability of the SPI (t) indicator are shown in Figure 2.
The results illustrate the analogy in the monotonicity of the compared indicators, the second of which (SPI) is shown in cumulative values.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

Instability of the schedule execution indicator analyzed over time - SPI (t) in the first phase of the undertaking (up to approx. 20% involvement) indicates here to one of EVM defects, defined as the instability of its indicators at the initial stage of analysis.

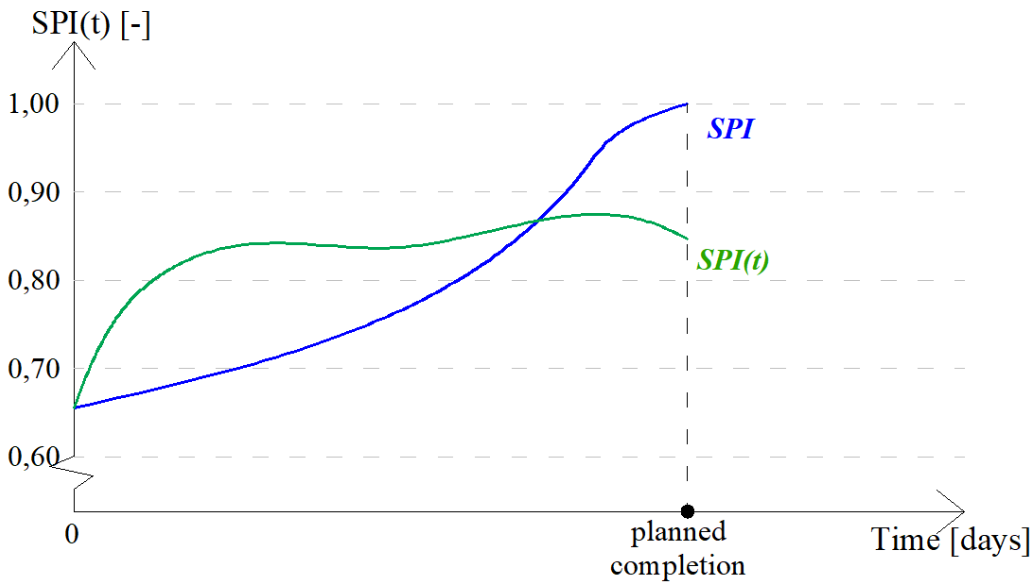

Fig. 2. The difference between SPI (EVM) and SPI (t) (ES) (description in the text).

Source: own study based on [8, p. 12].

In the study [2, p. 143], experimentally estimating the project's Estimated At Completion (EAC), the EVM analysis was extended to include the "Risk Performance Index" (RPI). The traditional approach to EVM focuses its predictions on two composite parameters: cost performance (CPI) and schedule performance (SPI), without addressing other important aspects. An integrated model was created, covering three quality identifiers for project implementation: CPI, SPI and RPI.

The results of the authors' research have obviously improved the efficiency of forecasts, although they have also contributed to an increase in the planned cost pool (BCWS) that irritates construction projects. The authors conclude that, the extension of EVM analysis with the RPI indicator in measuring the key project parameters will provide interested parties with a better tool for monitoring and making managerial decisions.

In turn, in the study [6, p. 424], calling into question the accuracy of prognostic estimates, which are the result of the EVM method, it was modified by an additional parameter: schedule forecast indicator (SFI: Schedule Forecast Indicator). The role of this indicator is to support management decisions regarding the undertaking at the strategic level.

A different approach to production monitoring has been proposed in the study [10, p. 33] in the EDM (Earned Duration Management) method. The role of this technique is to replace one of the tools of the EVM method, the schedule performance index (SPI) with its own EDI (Earned Duration Index) index in the form of an exponential function with a time argument.

This indicator allows to assess the pace of work at any time in the schedule.

In relation to the analyzed CPI and SPI indicators, in the study [9, p. 23] the attention was paid to the need to include in the EVM analysis the impact of the time value of money, especially in the case of long-term projects and discounted cash flows. The authors proposed the implementation in EVM of inflation variance index (IV: Inflation Variance), taking into account the impact of inflation reassessment of cost budgets.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

In the study [4, p. 162], it was proposed to extend EVM with three additional parameters: early start rate (ESR), early completion rate (ECR: Early Completion Rate) and cost overrun rate (COR: Cost Overrun Rate).

The analysis of composite EVM indicators was also carried out in the study [5, p. 65], noting that, project monitoring and the related decision-making process regarding the implementation of corrective actions are an important component of supporting audit decisions.

Therefore, an innovative multidimensional schedule control indicator (SPE) has been proposed to monitor the dynamics of changes in project implementation.

To sum up, the method of earned value has been subject to many modifications since its implementation in the practice of managing projects. At the same time, it was subject to constant criticism regarding the effectiveness of its indicators. Although the continuous presence of this algorithm in research confirms the fact that, it is still an up-to-date and popular tool for measuring the efficiency of time and cost of projects around the world.

2. C-S and S-C Monitoring

Based on the composite indicators of the EVM method, a developed time-cost analysis is proposed, examining the impact of the project implementation time on the costs incurred and costs on the planned time - by the ratio of the above measures of the schedule implementation effectiveness. The following indicators evaluation parameters have been introduced: [11, p. 210]

- Cost monitoring rate indicator (C-S):

$$C-S=\frac{CPI}{SPI}=\frac{\frac{BCWP}{ACWP}}{\frac{BCWP}{BCWS}}=\frac{BCWP}{ACWP}\cdot\frac{BCWS}{BCWP}=\frac{BCWS}{ACWP} \tag{5}$$

- Performance monitoring indicator in the context of costs incurred (S-C):

$$S-C=\frac{SPI}{CPI}=\frac{\frac{BCWP}{BCWS}}{\frac{BCWP}{ACWP}}=\frac{CWP}{BCWS}\cdot\frac{ACWP}{BCWP}=\frac{ACWP}{BCWS} \tag{6}$$

The monitoring of the rate of cost increase (model 5) consists in the analysis of the monotonicity of the cost performance index (CPI) during the implementation of schedule tasks, taking into account the actual performance of the work (SPI). Similarly, in the case of monitoring the performance of works in the context of costs incurred (model 6). The analysis of the monotonicity of the work rate performance index (SPI), taking into account the size of the cost performance index (CPI) allows the assessment of the schedule implementation speed while maintaining the cost measure.

3. Engineering application

3.1. Description of the schedule examined

To carry out the analysis of time and cost variances, the schedule of the implemented construction project, consisting of the construction of a multi-family housing development, planned for a period of seven months, with a budget of over PLN 20 million, was used.

The allocation of the means of production was planned using three basic structures of project implementation - methods of steady, parallel and sequence execution. Fig. 3 shows the obtained three scenarios for the implementation of works.

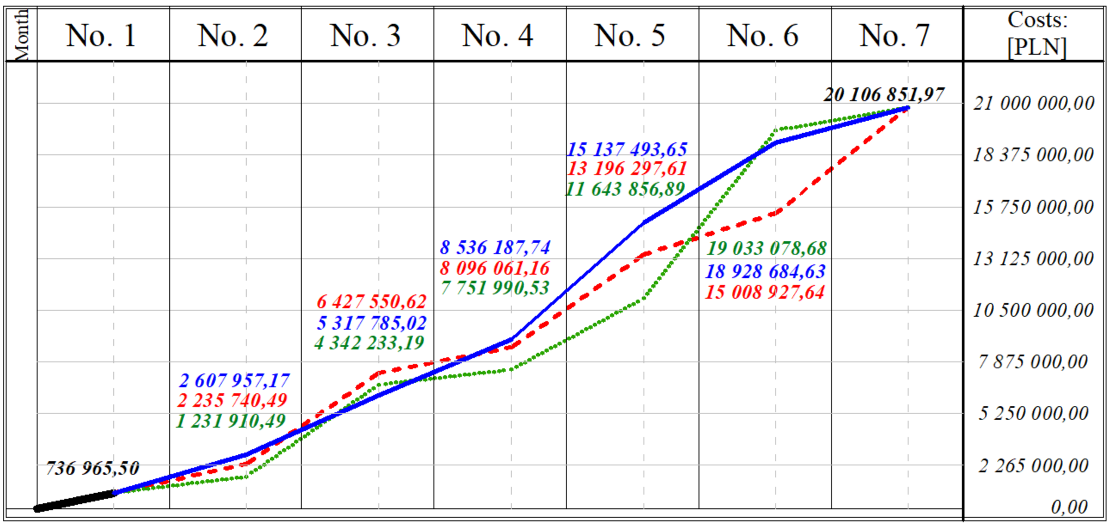

Fig. 3. *Cumulative values of planned costs (BCWS) of schedules - in implementation methods according to: steady (dot chart), parallel (continuous chart), sequence (intermittent chart) execution of works. Source*: [11, p. 131, 158, 211]

3.2. Application of C-S and S-C monitoring

Monitoring of C-S and S-C variances arising during the implementation of the works covered by the schedule, was divided into three scenarios of its implementation, according to the methods adopted above.

The adopted calculation models are characterized by a 10% increase in the budget of costs (C (1,2,3,4) = 110%, 120%, 130%, 140%) and a 5% increase in the time of works implementation (S (1,2,3,4) respectively = 105%, 110%, 115%, 120%). These models were described with symbols A1B1 ÷ A4B4, indicating the increase in variances [11].

The steady execution method assumes a global (overall) impact of variances (A, B) - for all schedule processes. In the methods of parallel and sequence work execution, the local (partial) impact of variances (a, b) was adopted - on selected process sequences.

This is due to the obvious characteristics of these methods, widely described in the literature (delays of the analyzed process sequences do not always affect the delays of their successors).

The analysis of the growth rate of unplanned costs and the work performance deviating from the plan consists in a gradual increase in expenditure on production (C), with a simultaneous systematic reduction of the production rate (S). These phenomena are reflected in the lowering of the value of simple indicators of the earned value method: cost performance index (CPI) and schedule performance indicator (SPI), which determine the monotonicity of C-S and S-C monitoring indicators.

The results of the analysis, with a description of the introduced time and cost disturbances and the division into four variances scenarios, are presented in Table 1.

The picture of emerging disturbances is presented in Fig. 4 (monitoring of variances from the assumed time T/S) and No. 5 (monitoring of variances from the assumed costs T/C).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

Table 1. Schedule models according to the method of parallel execution. Source: [11, p. 212-234]

Registration stage / Variance scenario	Steady execution method				Parallel execution method				Sequence execution method			
	Model A1B1: S=105%, C=110%				Model a1b1(II): s=105%, c=110%				Model a1c1(II): s=105%, c=110%			
	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C
31.03.2017	0,864	0,950	**0,909**	**1,100**	1,000	1,000	**1,000**	**1,000**	1,000	1,000	**1,000**	**1,000**
30.04.2017	0,850	0,943	**0,901**	**1,109**	0,964	0,989	**0,957**	**1,026**	1,000	1,000	**1,000**	**1,000**
31.05.2017	0,866	0,950	**0,912**	**1,097**	0,962	0,987	**0,975**	**1,026**	1,000	1,000	**1,000**	**1,000**
30.06.2017	0,864	0,951	**0,909**	**1,101**	0,965	0,988	**0,977**	**1,024**	0,982	0,994	**0,988**	**1,012**
31.07.2017	0,863	0,950	**0,908**	**1,101**	0,959	0,986	**0,973**	**1,028**	0,932	0,976	**0,955**	**1,047**
31.08.2017	0,864	0,950	**0,909**	**1,100**	0,963	0,985	**0,978**	**1,023**	0,934	0,973	**0,960**	**1,042**
30.09.2017	0,864	0,950	**0,909**	**1,100**	0,954	0,984	**0,970**	**1,031**	0,945	0,967	**0,977**	**1,023**
Registration stage / Variance scenario	Model A2B2: S=110%, C=120%				Model a2b2(II): s=110%, c=120%				Model a2c2(II): s=110%, c=120%			
	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C
31.03.2017	0,750	0,900	**0,833**	**1,200**	1,000	1,000	**1,000**	**1,000**	1,000	1,000	**1,000**	**1,000**
30.04.2017	0,728	0,888	**0,820**	**1,220**	0,931	0,976	**0,954**	**1,048**	1,000	1,000	**1,000**	**1,000**
31.05.2017	0,756	0,901	**0,839**	**1,192**	0,926	0,974	**0,951**	**1,052**	1,000	1,000	**1,000**	**1,000**
30.06.2017	0,752	0,901	**0,835**	**1,198**	0,929	0,974	**0,954**	**1,048**	0,964	0,988	**0,976**	**1,025**
31.07.2017	0,749	0,899	**0,833**	**1,200**	0,920	0,971	**0,947**	**1,055**	0,870	0,952	**0,914**	**1,094**
31.08.2017	0,751	0,900	**0,834**	**1,198**	0,919	0,968	**0,949**	**1,053**	0,873	0,948	**0,921**	**1,086**
30.09.2017	0,750	0,900	**0,833**	**1,200**	0,910	0,968	**0,940**	**1,064**	0,886	0,934	**0,949**	**1,054**
Registration stage / Variance scenario	Model A3B3: S=115%, C=130%				Model a3b3(II): s=115%, c=130%				Model a3c3(II): s=115%, c=130%			
	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C
31.03.2017	0,654	0,850	**0,769**	**1,300**	1,000	1,000	**1,000**	**1,000**	1,000	1,000	**1,000**	**1,000**
30.04.2017	0,626	0,833	**0,752**	**1,331**	0,889	0,961	**0,925**	**1,081**	1,000	1,000	**1,000**	**1,000**
31.05.2017	0,662	0,852	**0,777**	**1,287**	0,879	0,957	**0,918**	**1,089**	1,000	1,000	**1,000**	**1,000**
30.06.2017	0,657	0,851	**0,772**	**1,295**	0,882	0,960	**0,919**	**1,088**	0,947	0,982	**0,964**	**1,037**
31.07.2017	0,675	0,849	**0,795**	**1,258**	0,883	0,958	**0,922**	**1,085**	0,813	0,928	**0,876**	**1,141**
31.08.2017	0,669	0,850	**0,787**	**1,271**	0,879	0,954	**0,921**	**1,085**	0,817	0,922	**0,886**	**1,129**
30.09.2017	0,667	0,850	**0,785**	**1,274**	0,869	0,952	**0,913**	**1,096**	0,830	0,902	**0,920**	**1,087**
Registration stage / Variance scenario	Model A4B4: S=120%, C=140%				Model a4b4(II): s=120%, c=140%				Model a4c4(II): s=120%, c=140%			
	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C	CPI	SPI	C-S	S-C
31.03.2017	0,571	0,800	**0,714**	**1,401**	1,000	1,000	**1,000**	**1,000**	1,000	1,000	**1,000**	**1,000**
30.04.2017	0,539	0,777	**0,694**	**1,442**	0,855	0,945	**0,905**	**1,105**	1,000	1,000	**1,000**	**1,000**
31.05.2017	0,581	0,803	**0,724**	**1,382**	0,844	0,942	**0,896**	**1,116**	1,000	1,000	**1,000**	**1,000**
30.06.2017	0,574	0,800	**0,718**	**1,394**	0,848	0,947	**0,895**	**1,117**	0,930	0,976	**0,953**	**1,049**
31.07.2017	0,570	0,798	**0,714**	**1,400**	0,848	0,944	**0,898**	**1,113**	0,762	0,906	**0,841**	**1,189**
31.08.2017	0,573	0,801	**0,715**	**1,398**	0,840	0,938	**0,896**	**1,117**	0,767	0,898	**0,854**	**1,171**
30.09.2017	0,572	0,800	**0,715**	**1,399**	0,830	0,936	**0,887**	**1,128**	0,778	0,871	**0,893**	**1,120**

C-S MONITORING

The C-S cost growth rate monitoring indicator (Figure 4) in the steady execution method illustrates charts in the form of the time course of four schedule delay scenarios. Their location depends on the size of interference.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

Due to the way interferences affect the entire schedule, the functions describing the given scenarios assume close values of the necessary decrease in the rate of cost increase in subsequent registration stages - in the range of 9% for models A1B1 up to 28% for A4B4. Monitoring the rate of increase of C-S costs in the parallel execution method presents, as assumed, the planned course of works in the first month.

From the second stage of control to the last, the picture of the speed of cost increase illustrates the pool of planned monthly budgets against the background of costs incurred, which should be reduced to it, so that the project could end with the expected economic result. The monitoring shows the required 3% -4% slowdown in the cost growth rate to close the contract in its initial budget. The collapse of the function chart in the fifth stage of work registration reflects the planned, highest monthly throughput.

Monitoring the rate of cost increase in the sequence execution performance method illustrates the planned course of works in the first three stages of registering their progress. After starting work in the fourth month of construction, expenditure rate should be reduced, depending on from the cost overrun scenario (1,2,3,4) to the level between 95.3% and 98.8% - to fit the budget into the planned turnover. In the fifth stage of registration, ending the sequence of activities subjected to local variances, the values of the function of the modeled scenarios fall to the required levels of 84.1% ÷ 95.5%. In the sixth and seventh control stage, regarding works not subject to variances, C-S monitoring distributes the accrued financial losses.

S-C MONITORING

The S-C work performance monitoring indicator in the context of costs incurred (Figure 5) records the inverse forms of analysis compared to C-S monitoring.

For the steady performance method, there was a 10% jump in actual cost increases (ACWP) over the schedule (BCWS). They signal the schedule manager at what level - depending on the scenario (1,2,3,4) - the actual performance of works in particular periods should be placed - so that the contract can be implemented in the planned budget.

Analysis of the performance monitoring index (S-C) in the parallel execution method presents a set of scenarios for the pace of work, indicating their correct performance, at different percentages of interference that allows timely termination. The results here illustrate the cumulative excess costs incurred (ACWP) in relation to planned (BCWS). Analysis of the S-C indicator indicates the necessary acceleration of works in given periods, restoring the timeliness of the entire project.

For the method of parallel execution there was a 10% jump in actual cost increases (ACWP) over the schedule (BCWS). It is a signal for the schedule manager at what level - depending on the scenario (1,2,3,4) - the actual performance of works in particular periods should be placed - so that the contract can be implemented in the planned budget.

Analysis of the performance monitoring index (S-C) in the parallel execution method presents a set of scenarios for the pace of work, indicating their correct performance, at different percentages of interference that allows timely termination.

The results here illustrate the cumulative excess of costs incurred (ACWP) in relation to the planned (BCWS). Analysis of the S-C indicator indicates the necessary acceleration of works in given periods, restoring the timeliness of the entire project.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 16 November 2019 doi:10.20944/preprints201911.0188.v1

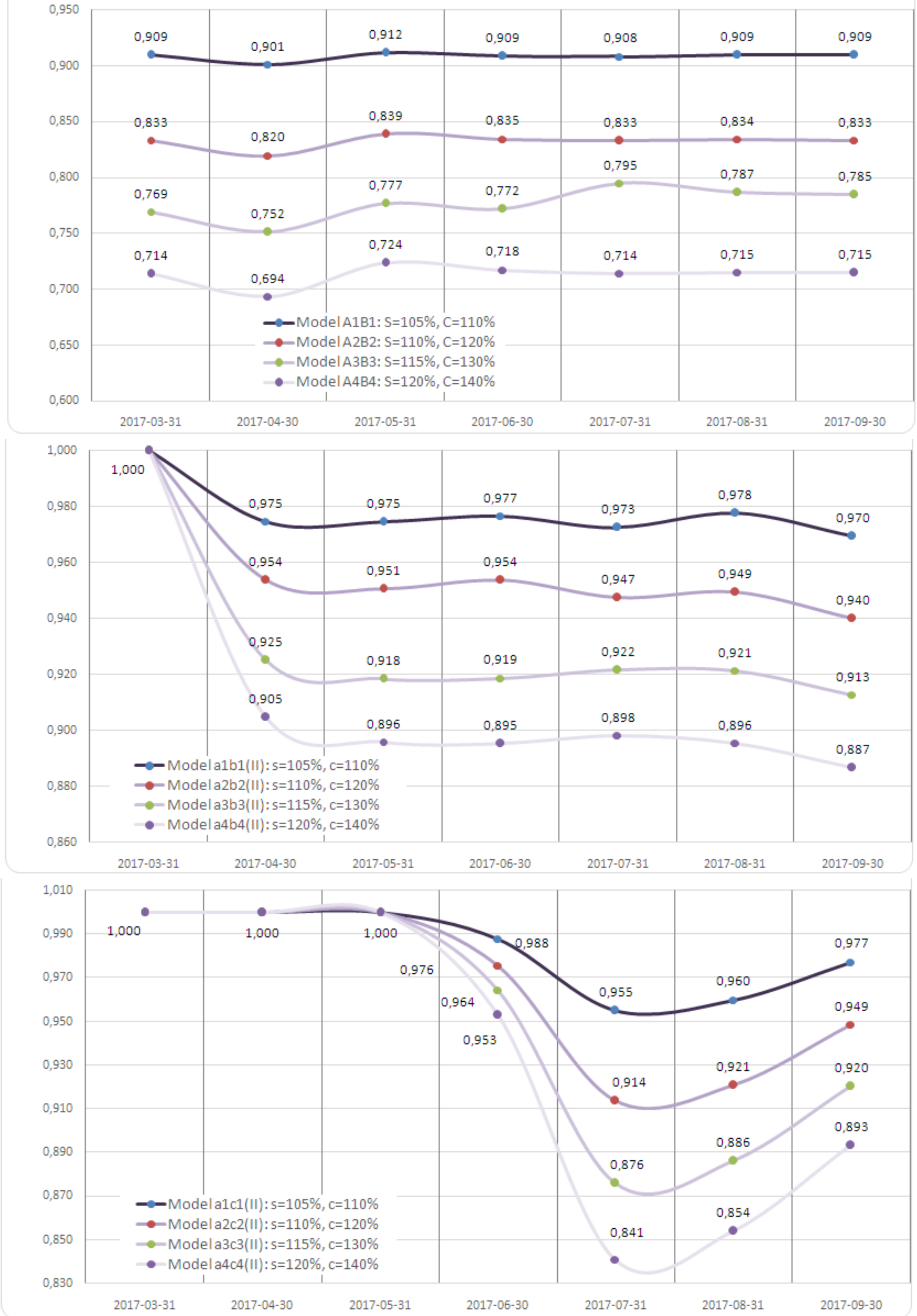

Fig. 4. Monitoring indicator charts of cost increase monitoring (C-S) in models with a gradually increasing time and cost variances - in the implementation methods according to (from the top): steady, parallel, sequence execution of works
Source: [11, p. 212-234]

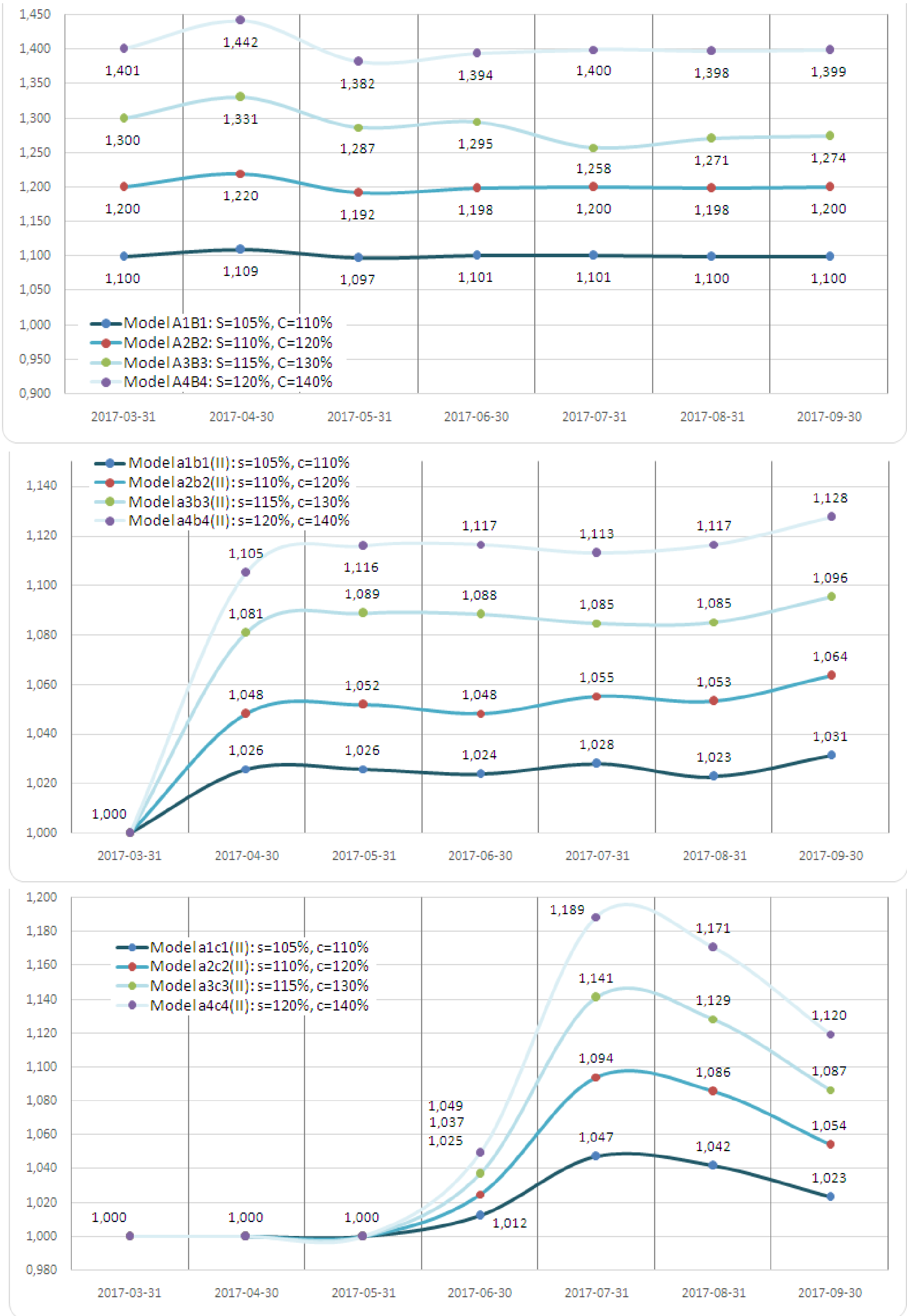

Fig. 5. Monitoring indicator charts of works performance in the context of costs incurred (S-C) in models with a gradually increasing time and cost variances - in the implementation methods according to (from the top): steady, parallel, sequence execution of works.
Source: [11, p. 212-234]

The monitoring indicator, analyzing the performance of works in the context of incurred costs (S-C) for the sequence implementation method, presents, as in the previous two methods, inversely proportional values to the C-S analysis. They indicate the required (in percentage) degree of increase in work efficiency for individual levels of modeled parameters (1,2,3,4), which should be implemented in relation to the plan. Then the venture will not bring a negative economic result.

The decrease in the value of the SC function set occurs, in accordance with the occurrence of time and cost interference, in the fourth stage of registration (1.2% ÷ 4.9%), its maximum values - in the fifth stage (4.7% ÷ 18.9%), after which it decreases, but not to unity. This proves the impact of partial budget overruns on its total value.

4. Conclusions from research and analyzes

The experiments carried out were aimed at attempting to implement the constructed C-S and S-C tools based on CPI and SPI indicators of the earned value method, in the schedule created on the basis of three classic implementation structures of construction projects.

The analysis of the presented test results illustrates the required slowdown in the rate of cost increase in given periods (C-S) so that the audited project can be completed in the planned financial budget (BCWS).

On the other hand, solutions of the work performance monitoring indicator in the context of incurred costs (S-C) signal to the control unit of the implemented schedule how the work pace should be exemplary so that the contract in question can be closed within the imposed deadline.

In the first case, monitoring generated values less than or equal to one.

In the second, however, results greater than or equal to one were obtained. It is worth noting that, the constructed indicator method can also be used to monitor scenarios opposite to the modeled, both in terms of global and local impacts: overestimation of processes at the stage of project valuation or unplanned acceleration of work in relation to the schedule. In this case, solutions will give opposite relations to the above inequalities.

Bibliography

[1] ANBARI T., *Earned Value project method and extensions.* Project Management Journal, v.12/2003

[2] BABAR S., THAHEEM M. J., AYUB B., *Estimated cost at completion: integrating risk into EVM.* Journal of Construction Engineering and Management, v. 143Issue 3, 2017

[3] BARR Z., *Earned Value analysis: a case study.* P. M. Network, X (12), p. 31-37, May 1996

[4] CHEN Q., JIN Z., XIA B., SKITMORE M., *Time and cost performance of design build projects.* Journal of Construction Engineering and Management, ASCE, 142(2), p. 162-169, February 2016

[5] COLIN J., MARTENS A., VANHOUCKE M., WAUTERS M., *A multivariate approach for top-down project control using earned value management.* Decision Support Systems v. 79, p. 65-76, November 2015

[6] CZEMPLIK A., *Application of Earned Value Method to Progress control of construction projects.* XXIII R-S-P Seminar, Theoretical Foundation of Civil Engineering (23RSP) Procedia Engineering, v. 91(2014), p. 424-428, May 2014

[7] CZYŻEWSKI A., *Economic analysis in the implementation of investment projects.* Poznań: Publishing house of the Poznań University of Economics, 2011

 doi:10.20944/preprints201911.0188.v1

[8] De KONING P., VANHOUCKE M., *Stability of earned value management: Do project characteristics influence the stability moment of the cost and schedule performance index.* Journal of Modern Project Management, 4(1), p. 8-25, August 2016
[9] FARID F., KARSHENAS S., *Cost/Schedule control systems criteria under inflation.* Project Management Journal, XIX (5), p. 23-29, November 1998
[10] KHAMOOSHI H., ABDI A., *Project duration forecasting using Earned duration management with exponential techniques.* Journal of Management in Engineering v.33 Issue 1, 2017
[11] PRZYWARA D., *Time-cost analysis in monitoring the works of the construction schedule*. Dissertation. Opole University of Technology, Opole, 2019
[12] PRZYWARA D., RAK A., *Assessment of time and cost variances using the earned value method*. Building Materials, v. 6/2016, p. 29-31, Wrocław 2016
[13] TROCKI M., *Modern project management.* Warsaw: P.W.E., 2012
[14] VANHOUCKE M., VEREECKE A., GEMMEL P., *The project scheduling game (PSG): simulating time/cost trade-offs in projects.* Project Management Journal, v. 36(1), p. 51-59, 2005