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Research paper

Use of the EVM method for analysis of extending the construction project duration as a result of realization disturbances – case study

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Abstract: In pursuing numerous construction projects, investors and contractors regularly face construction delay problems, many of which are likely to have been avoidable. There is found that payment delays and project delays are the two most critical effects of risk factors of construction management. The paper presents the practical application of the Earned Value Management method, which was used to estimate the possible extension of the duration of construction works during which realization disturbances occurred on the example of selected construction investment. The realization disturbances are usually an inseparable element in the implementation of construction works. They are the result of, among others: additional works, changes or design defects, as well as a badly adopted logistics strategy regarding the supply of construction materials. Delays or increasing the total cost of investment is a problem often encountered in the implementation of construction investments, despite advanced construction technologies, including system technologies and proven tools supporting the management of the construction process. The EVM method is used to control investments. It allows you to control delays and acceleration of construction works as well as to estimate their cost and completion date. In the analyzed case it was used to determine the scale of delays arising in construction works and related effects with the specification of the participation of individual participants of the investment process for delays. This paper is a continuation and supplementation of the research presented in the article: "The influence of construction works disturbances on the EVM analysis outcomes – case study" [23].

Keywords: EVM method, realization disturbances, delays in construction works

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1. Introduction

The article below is a continuation and supplementation of the research conducted on the building investment, presented in the paper: "The influence of construction works disturbances on the EVM analysis outcomes – case study" in 2020 [23].

In pursuing numerous construction projects, investors and contractors regularly face construction delay problems, many of which are likely to have been avoidable [1]. There is found that payment delays and project delays are the two most critical risk factors of construction management [2]. The Earned Value Management (EVM) method plays an important role in the investment control process, in particular construction [5], [8], [11], [12], [19–21]. One of the first versions of EVM method was developed by the Defence Department (DoD) – The American National Standards Institute [3]. Since 2005, EVM has been a part of general federal project risk management. Today EVM is a mandatory requirement of the US government. EVM is also used in the private sector by companies in a variety of industries [9], [22], [24], also construction industry [4], [18].

The purpose of applying this method to the analyzed construction investment was to effectively monitor the implementation of the selected investment, taking into account the interdependent progress of the construction works, but without analyzing the costs incurred. It should be emphasized here that, compared to the traditional approach to the control of construction investments, EVM allows not only to combine the assessment of the progress of construction works with the current financial result of the investment, but also by using indices, gives the possibility to forecast future trends in the pace of construction works on individual investment tasks and costs incurred [16]. The concept of the Earned Value Management is based on the introduction to the analysis of the progress of construction works of the size specifying the so-called Scheduled cost of completed investment tasks. Earned value determines the financial outlays that the contractor of construction works would incur on the implementation of tasks completed by the date of the inspection (report on the implementation of construction works). At the same time, it also uses information on the actual costs of construction works carried out and the costs to be borne by the contractor when carrying them out in accordance with the schedule. This is the basis for calculating the Earned Value Management using the following values:

- BCWS (Budgeted Cost of Work Scheduled) – i.e. the planned cost as the sum of all costs of planned construction works in a given investment or in a given part, calculated until the date of the report,

- BCWP (Budgeted Cost of Work Performed) – i.e earned value – the cost of all progress of construction works achieved during the implementation of the investment or part thereof, calculated to the date of the report and expressed in terms of planned costs, assumed in the initial estimates. It is also called "earned value" because it shows what has been done instead of what was planned,
- ACWP (Actual Cost of Work Performed) – i.e. the actual cost of construction works – total expenses related to the investment or part of it, calculated until the date of the report; the sum of expenses incurred, regardless of what was planned or carried out.

The BCWS, BCWP and ACWP values are the basis for determining the indicators of the Earned Value Method divided into two groups:

- indices for the progress of construction works,
- indices for forecasting future costs of construction works and the pace of their implementation.

The first group consists of values that allow to determine the current pace of construction works and the current financial balance of construction in relation to completed tasks. In order to precisely determine their advancement, the EVM method provides for the calculation of the following indices:

a. CV (Cost Variance) – this is the difference between earned value and real expenses incurred in carrying out construction works:

$$CV = BCWP - ACWP \tag{1.1}$$

where:
BCWP – Budgeted Cost of Work Performed [PLN],
ACWP – Actual Cost of Work Performed [PLN];

b. SV (Scheduled Variance) – this is the difference between earned value and costs of planned construction works:

$$SV = BCWP - BCWS \tag{1.2}$$

where:
BCWP – Budgeted Cost of Work Performed [PLN],
BCWS – Budgeted Cost of Work Scheduled [PLN];

c. CPI (Cost Performance Index) – this is the cost effectiveness of construction works expressed as the quotient of earned value to the costs actually incurred until the date of the report:

$$CPI = BCWP / ACWP \tag{1.3}$$

where:
BCWP – Budgeted Cost of Work Performed [PLN],
ACWP – Actual Cost of Work Performed [PLN];

d. SPI (Schedule Performance Index) – it is the ratio of earned value to the sum of costs of all tasks that should be performed until control progress of construction works:

$$SPI = BCWP / BCWS \tag{1.4}$$

where:
BCWP – Budgeted Cost of Work Performed [PLN],
BCWS – Budgeted Cost of Work Scheduled [PLN].

The second group are indicators for forecasting the future costs of construction works and the pace of their implementation. We distinguish the following values:

a. EAC (Estimated Cost At Completion):

$$EAC = ACWP + \frac{BAC - BCWP}{PF} \tag{1.5}$$

where:
ACWP – Actual Cost of Work Performed [PLN],
BAC – Budget Cost At Completion [PLN],
BCWP – Budgeted Cost of Work Performed [PLN],
PF – the index depends on the cost of future construction works.

When estimating the cost of construction works for the entire investment based on the current financial result, attention should be paid to the lack of consideration of the implementation risk and the variable nature of construction works carried out at various stages (e.g. foundation works have a higher risk of execution due to weather conditions than finishing works inside the

building). Although forecasting of total investment expenditure is based on a linear approximation, the problem to be solved is an assessment of how further investment expenditure for the execution of construction works will be. Different scenarios are considered:

- The cost of construction works to be carried out will coincide with the initial assumptions, PF = 1, so:

(1.6) $$EAC = BAC - CV$$

where:
BAC – Budget Cost At Completion [PLN],
CV – Cost Variance.

The current trend of changes in the cost of construction works will continue until the end of construction (the cost of future construction works will be proportional to the actual index CPI):

(1.7) $$EAC = ACWP + \frac{BAC - BCWP}{CPI}$$

where:
BAC – Budget Cost At Completion [PLN],
BCWP - Budgeted Cost of Work Performed [PLN],
CPI – Cost Performance Index.

- It is assumed that the current pace of implementation and the rate of change in the cost of construction works will affect further stages of construction works. In this case, the proportionality of future construction costs is assumed to depend on the Critical Ratio CR. The variant of dependence on the Critical Ratio is given as a pessimistic estimate: PF = CR = CPI·SPI

(1.8) $$EAC = ACWP + \frac{BAC - BCWP}{CPI * SPI}$$

where:
BAC – Budget Cost At Completion [PLN],
BCWP – Budgeted Cost of Work Performed [PLN],
CPI – Cost Performance Index,
SPI – Schedule Performance Index.

b. The Estimated Cost At Completion for the various stages of implementation of the analyzed construction works assumed that the current trend in changes in the cost of construction works would continue until the end of building investment. Expert knowledge shows that the adopted variant allows to obtain the most reliable results, and its implementation is most likely.

$$\text{ETTC} = \text{ATE} + \frac{\text{OD} - (\text{ATE} * \text{SPI})}{\text{SPI}} \tag{1.9}$$

where:

ATE – time from commencement of construction works to the date of the report,

OD – planned total duration of construction works,

SPI – Schedule Performance Index.

All these values can be presented on the "time–cost" graph illustrating the assumed model of construction works.

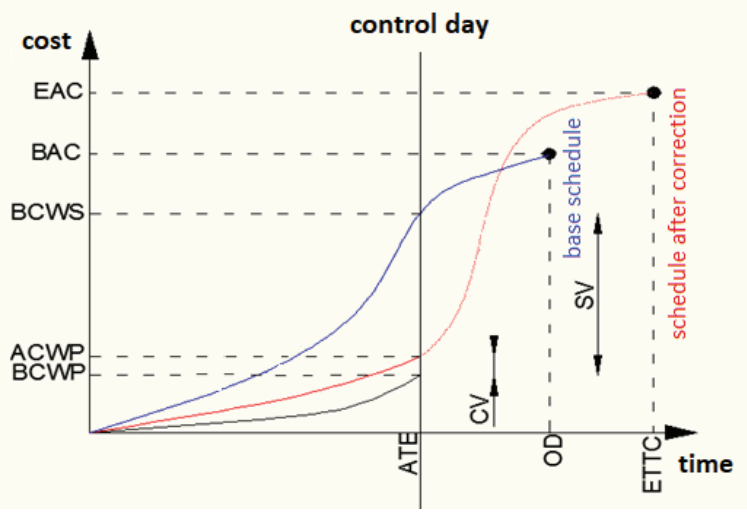


Fig. 1. Graph of the cost of investment construction works during its implementation in the Earned Value Management

In fact, the cost graph for construction works is usually in the form of an "S" curve. In the first and last phase of construction of a large investment, construction works are carried out at a low cost, but are time consuming. Then, fronts of construction works are created or works on fronts are completed and acceptance with possible removal of defects in construction works. In the middle phase, the contractor carries out construction works in quite a short time.

2. Proceeding procedure

The purpose of the analysis was to examine the impact of realization disturbances on the course of construction works of the analyzed investment, in particular in terms of assessing the extension of its implementation time and the participation of participants of the investment process in this process. During the construction works, many realization disturbances occurred, which negatively affected the cost and duration of the investment. Based on a comparison of planned investment implementation and data corrected to include identified disturbances at a given control point, it is possible to estimate using the Earned Value Management method the adjusted total cost, the updated date of completion of construction works and to assess the current state of the investment using indeces of this method.

The starting material for the analysis are the substantive and financial schedules created on the basis of project documentation [15]. The first one was created based on planned costs and duration of works adopted from cost estimates. The second one has been updated with identified realization disturbances.

The assumptions:

1. The identified disturbances were defined as additional tasks preceding the construction works, which were disruptived.
2. The duration of these additional tasks is equal to the duration of realization disturbances. Some of them were on the critical path, which affected the critical technological sequence of the investment.
3. The cost of performing these schedule items is the unexpected expenses incurred by the Investor and the Contractor of construction works due to the occurrence of individual disturbances.
4. It was assumed, due to lack of verification, that the occurrence of a realization disturbance causes downtime on the entire front related to a given construction work. This assumption is incompatible with the actual implementation of construction projects, but allows you to examine the impact of disturbances in the absence of any Contractor's initiative to mitigate the negative effects of realization disturbances.
5. It was assumed that all planned construction works were carried out in accordance with their planned duration, and the delays resulted only from the disturbances. Discontinued works during construction were also not omitted. This allowed to illustrate what maximum impact on the analyzed investment would be the identified disturbances without the influence of the

amount of means (human work, equipment and materials) engaged for specific tasks by the Contractor.

This assumption allowed answering the question of how much the implementation time would be extended as a result of occurrence of realization disturbances identified in this study.

6. The analysis did not take into account the actual dates of disturbances, but they were referred to the progress of construction works according to the schedule. This means that the occurrence of individual disturbances depends on the execution of construction works, and not the actual dates of their occurrence, which can be determined on the basis of building documentation. Only their durations have been preserved.

The analysis was carried out using the Earned Value Management method in MS Project on an updated base schedule with identified disturbances in the form of additional tasks.

The steps in the approach used:

1. At the beginning, the duration and costs of disturbances were set to zero.
2. Real data was only entered when the disturbance began, which reflected real conditions and their unpredictability.
3. It was assumed that research on the progress and costs of construction works will take place every month. Each subsequent research will take place in so-called "control day". On the day of the control, the progress of all construction works was estimated as compared to the previous "control day".
4. The determined progress (defined as % of the completion of the entire scheduling task) was compared with the planned progress on a given calendar day taken from the base (starting) schedule.
5. A large number of results will allow the creation charts reflecting the use of costs and execution of the construction schedule at various stages of implementation of the analyzed investment. The results that were read for each study were:
   SPI (WWH) – Schedule Performance Index,
   CPI (WWK) – Cost Performance Index,
   EAC (SKK) – Estimated Cost At Completion [PLN],
   ETTC – Estimated Time At Completion.
   Different names of particular values appearing in MS Project are given in brackets.

The first three values can be read from the method result table, and the projected completion date should be “manually” read as the end date of the last critical task. MS Project does not have an algorithm for determining the Estimated Time At Completion by the EVM method, taking into account their current delay due to the program being used for various types of investments, not only building investment, and thus the inability to link costs with time. However, this value can be calculated using the classic formula of the Earned Value Management, which has been done. The results of calculations of the Estimated Time At Completion of construction works present the individual stages of their implementation in which the disterbences occurred. They should draw the contractor's attention to the possible risk of not completing the construction works of the investment on time and which should contribute to the construction works contractor's reaction.

6. The last stage of the analysis was the so-called condensation of the above values obtained in the analysis. The presentation of results using charts and tables allows for clear presentation of the results of the analysis and preparation of final conclusions.

3. Test conduct

The actual analysis of the execution of construction works was carried out on a monthly basis, while for the purposes of the study, the following results were presented in 6-month periods.

1. Control day:

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	8747995,92	4683	0	0

where:

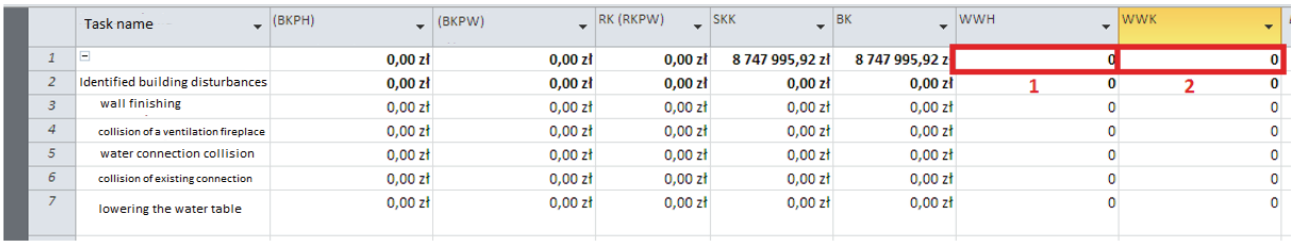
SKK (EAC) – Estimated Cost At Completion [PLN],

ETTC – Estimated Time At Completion [work hours],

WWH (SPI) – Schedule Performance Index,

WWK (CPI) – Cost Performance Index,

Before commencing construction works, a study was carried out to verify the correctness of the data entered. As expected, the Cost Performance Index and Schedule Performance Index were zero. This means that no works have been carried out until this day (WWH = 0) and no costs have been incurred (WWK = 0). The Estimated Cost At Completion (SKK) is equal to value the Budgeted Cost of Work Scheduled (BK).



	Task name	(BKPH)	(BKPW)	RK (RKPW)	SKK	BK	WWH	WWK
1		0,00 zł	0,00 zł	0,00 zł	8 747 995,92 zł	8 747 995,92 z	0	0
2	Identified building disturbances	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	1 0	2 0
3	wall finishing	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
4	collision of a ventilation fireplace	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
5	water connection collision	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
6	collision of existing connection	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
7	lowering the water table	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0

Fig. 2. Results for the control no. 1 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

The deadline for completion of construction works was defined as the date of completion of the last task on the critical path.

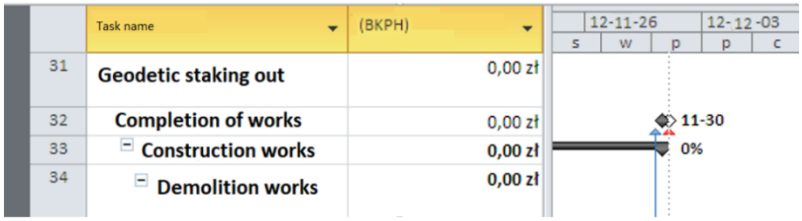


Fig. 3. Deadline for completion of construction works after control no.1 (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

7. Control day: (*on the day of the control, the progress of all construction works was estimated as compared to the previous* "*control day*")

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	8 747 995,92	4683	1	1

The construction investment is still in the final stages of preparatory works. Although the pace of construction is still quite low, it should be expected that at the end of the winter period (and at the same time the demolition works are completed), the daily throughput of work hours on the analyzed investment will increase substantially.

Still, as a result of the investment task without any realization disturbances, the earned value is equal to the planned value and actual costs, which is "good news" for both the contractor and the investor.

	Task name	(BKPH)	(BKPW)	RK (RKPW)	SKK	BK	WWH	WWK
1	**building investment**	153 249,13 zł	153 249,13 zł	153 249,13 zł	8 747 995,92 zł	8 747 995,92 zł	1	1
2	**identified building disturbances during construction**	2 0,00 zł	1 0,00 zł	3 0,00 zł	0,00 zł	0,00 zł	0	0
3	linear drainage	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
4	dance hall - rebuild of ventilation ducts	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
5	finishing the walls and roofs of the facade with the Siberian larch	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0

Fig. 4. Results for the control no. 7 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

The absence of identified realization disturbances means that the construction works should be completed in accordance with the assumptions, i.e. on the date of completion of the works specified in Annex No. 1 to the construction works contract.

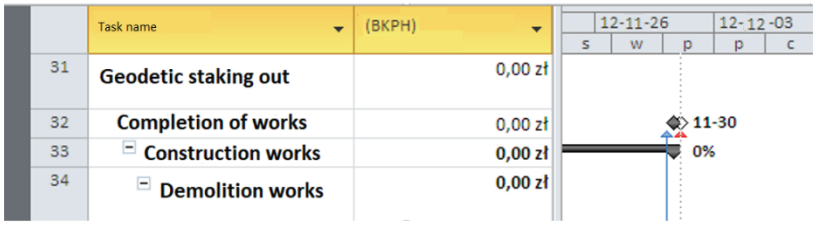


Fig. 5. Deadline for completion of construction works after control no.7 (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

13. Control day: (*on the day of the control, the progress of all construction works was estimated as compared to the previous* "*control day*")

Realization disturbance: Lowering the ground water table with wellpoints for the implementation of the retention tank (the disturbance lasted 5 calendar days).

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	9 974 709,76	5082	0,88	0,82

The appearance of another disturbance did not cause major changes in the Earned Value Management method indices. This was due to the short duration of the disturbance (5 calendar days) in relation to the contractual duration of the construction works and the absence of additional costs identified. The contractor for construction works incurred financial expenses for the rental of

wellpoints, but he should take into account such situations due to the high operational risk of the construction industry. The low value of WWK = 0,88 increases the value of the estimated final cost of construction works for the entire investment SKK = 9 974 709,76 PLN.

	Task name	(BKPH)	(BKPW)	RK (RKPW)	SKK	BK	WWH	WWK
1	**building investment**	**1 870 518,64 zł**	**1 527 180,34 zł**	**1 741 333,77 z**	**9 974 709,76 zł**	**8 747 995,92 zł**	**0,82**	**0,88**
2	**identified building disturbances during construction**	**0,00 zł**	**0,00 zł**	**214 153,42 zł**	**2 225 127,17 zł**	**0,00 zł**	**0**	**1 0**
3	linear drainage	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
4	dance hall - rebuild of ventilation ducts	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
5	finishing the walls and roofs of the facade with the Siberian larch	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0

Fig. 6. Results for the control no. 13 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

The disturbance "*Lowering the ground water table with wellpoints for the implementation of the retention tank*" delays construction works related to the construction of the retention tank, which are on the critical path this investment. This, in turn, delays the planned investment completion date by 75 calendar days.

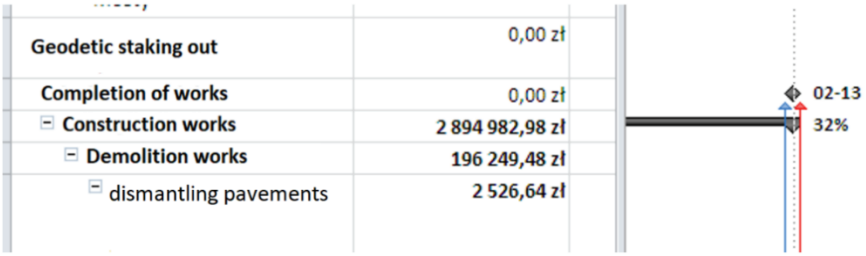


Fig. 7. Deadline for completion of construction works after control no.13 (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

19. Control day: *(on the day of the control, the progress of all construction works was estimated as compared to the previous "control day")*

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	9 421 988,51	5082	0,93	0,72

Despite the absence of any disturbance, the value of WWH fell to 0,72. The reason for this was the need to move the masonry works outside the winter period. According to the initial construction

schedule, the masonry works were to be carried out in a heated facility under construction, however, the identified disturbances caused their shift to a period of temperatures above zero Celsius degrees. The WWK index remained stable at 0,93. Even non-performance of masonry works did not change the value of the WWK index, as the costs of construction works incurred so far were much higher than the cost estimate of masonry works.

	Task name	(BKPH)	(BKPW)	RK (RKPW)	SKK	BK	WWH	WWK
1	**building investment**	6 077 104,26 zł	4 380 098,56 zł	4 717 564,88 zł	9 421 988,51 zł	8 747 995,92 zł	0,72	0,93
2	**identified building disturbances during construction**	0,00 zł	0,00 zł	3 337 466,32 zł	337 466,32 zł	0,00 zł	1 0	2 0
3	finishing the walls and roofs of the facade with the Siberian larch	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
4	linear drainage	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
5	dance hall - rebuild of ventilation ducts	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
6	collision of the U26 chamber ventilation fireplace with the parking surface	0,00 zł	0,00 zł	16 015,19 zł	16 015,19 zł	0,00 zł	0	0

Fig. 8. Results for the control no. 19 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

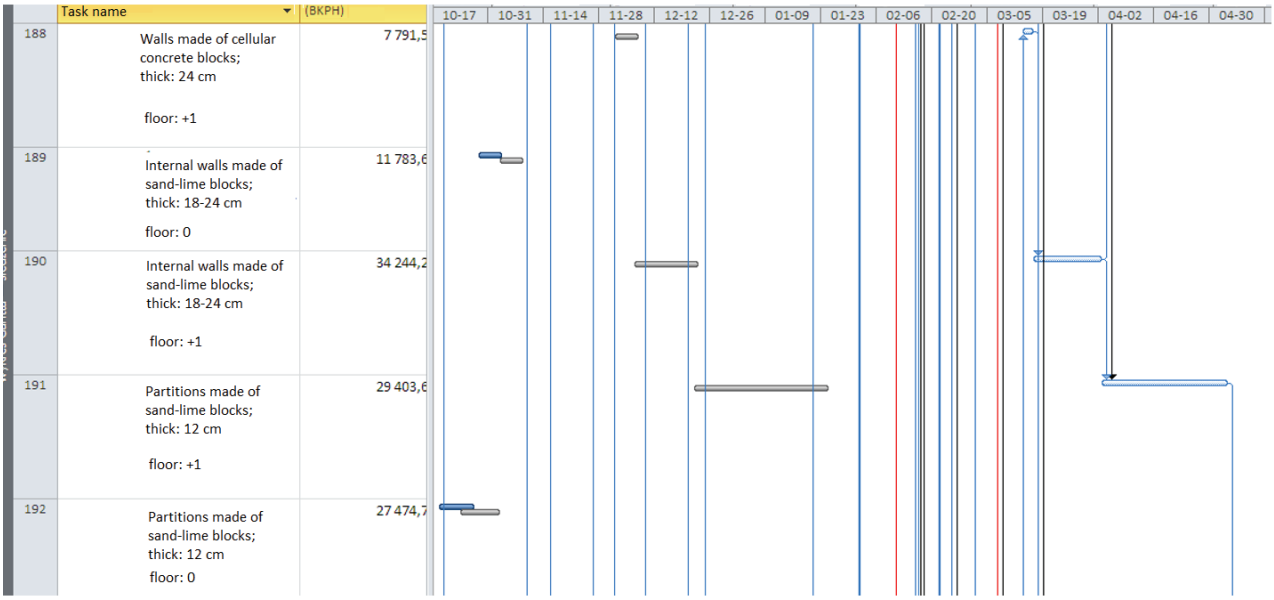


Fig. 9. Delay of masonry works due to disturbance – failure to complete the central heating network before winter

The lack of identified realization disturbances of works lying on the critical path during the considered period meant that construction works were not delayed in relation to the previous survey.

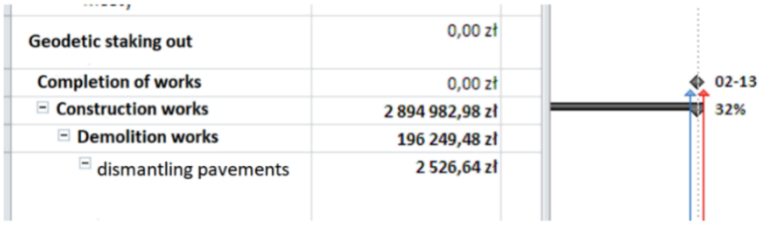


Fig. 10. Deadline for completion of construction works after control no.19 (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

25. Control day: (*on the day of the control, the progress of all construction works was estimated as compared to the previous* "*control day*")

Disturbance: expansion of video monitoring and lighting of elevator shafts (the disturbance lasted 22 calendar days).

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	9 567 565,40	5386	0,91	0,88

The appearance of the disturbance "Extension of video monitoring and lighting of elevator shafts" had a significant impact on the cost performance index WWK = 0,91. This was due to the large financial outlays that had to be incurred to perform this additional work. The WWH index systematically increased its value.

	Task name	(BKPH)	(BKPH)	RK (RKPW)	SKK	BK	WWH	WWK
1	**building investment**	7 946 711,23 zł	7 025 574,17 zł	7 683 775,91 zł	9 567 565,40 zł	8 747 995,92 z	0,88	0,91
2	**identified building disturbances during construction**	0,00 zł	0,00 zł	658 201,74 zł	730 655,63 zł	0,00 zł	1 0	2 0
3	finishing the walls and roofs of the facade with the Siberian larch	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
4	linear drainage	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0
5	dance hall - rebuild of ventilation ducts	0,00 zł	0,00 zł	5 625,46 zł	5 625,46 zł	0,00 zł	0	0
6	collision of the U26 chamber ventilation fireplace with the parking surface	0,00 zł	0,00 zł	16 015,19 zł	16 015,19 zł	0,00 zł	0	0
7	collision of the water connection with the parking surface	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0

Fig. 11. Results for the control no. 25 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

The lack of identified realization disturbances of works lying on the critical path during the considered period meant that construction works were not delayed in relation to the previous survey.

Fig. 12. Deadline for completion of construction works after control no.25

31. Control day: (*on the day of the control, the progress of all construction works was estimated as compared to the previous* "*control day*")

Disturbance: arrangements for glazed exterior walls (disturbance lasted 118 calendar days).

	SKK [PLN]	ETTC [work hours]	WWK	WWH
Value of construction works	9 571 829,73	5794	0,9	0,89

The identified disturbance at this stage of the construction works of a given investment does not affect the indices of the Earned Value Management method.

	Task name	(BKPH)	(BKPW)	RK (RKPW)	SKK	BK	WWH	WWK	Do
1	**building investment**	**8 747 995,92 zł**	**7 758 572,69 zł**	**8 489 228,56 zł**	**9 571 829,73 zł**	**8 747 995,92 zł**	**0,89**	**0,91**	
2	**identified building disturbances during construction**	**0,00 zł**	**0,00 zł**	**730 655,63 zł**	**730 655,63 zł**	**0,00 zł**	**0**	**0**	
3	finishing the walls and roofs of the facade with the Siberian larch	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0	
4	linear drainage	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0	
5	dance hall - rebuild of ventilation ducts	0,00 zł	0,00 zł	5 625,46 zł	5 625,46 zł	0,00 zł	0	0	
6	collision of the U26 chamber ventilation fireplace with the parking surface	0,00 zł	0,00 zł	16 015,19 zł	16 015,19 zł	0,00 zł	0	0	
7	collision of the water connection with the parking surface	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0,00 zł	0	0	

Fig. 13. Results for the control no. 31 by EVM (the symbol "zł" of the monetary unit is identical to Polish złoty "PLN")

The lack of identified realization disturbances of works lying on the critical path during the considered period meant that construction works were not delayed in relation to the previous survey.

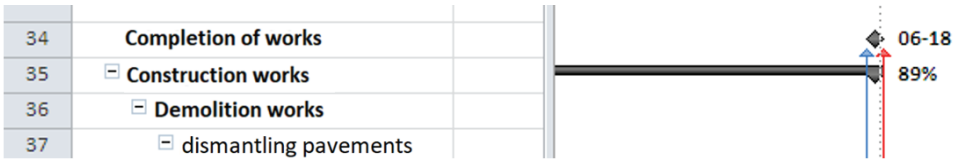


Fig. 14. Deadline for completion of construction works after control no. 31

4. Analysis of the test results

Table 1 on the next page summarizes the results obtained in all control days of executing construction works. The indices showing the current state of construction works were compared: Cost Performance Index (CPI), Schedule Performance Index (SPI) and forecasts based on the current state of construction works: Estimated Cost At Completion (EAC), Estimated Time At Completion (ETTC). Using the formulas of the classic Earned Value Management method, the Estimated Time At Completion on the subject investment was calculated on the basis of data taken from the analysis of the progress of construction works in MS Project, i.e. the Budgeted Cost of Work Performed (BCWP) and Actual Cost of Work Performed (ACWP).

Based on the table on the previous page, the following conclusions can be made:

- MS Project does not allow full forecasting of the duration of construction works on a given investment based on the so-called current trend. It is possible to determine the duration of construction works after updating them with identified realization disturbances. The classic Earned Value Management method allows to estimate the Estimated Time At Completion by treating cost as an analogy of time. The results obtained for individual control days using the classical EVM method are similar to the expected duration of the investment in question extended by the disturbances of construction works on the critical path. It proves that the schedule of construction works carried out together with the identification of tasks on the critical path has been correctly prepared.
- After exceeding the contractual "annexed" deadline for the execution of construction works, the ETTC value estimated using the classical EVM method begins to decrease, despite the still extending time of their implementation. This is due to the completion at this stage of many construction works, which affects the value of the SPI index.
- The Estimated Cost At Completion is expressed as a percentage, where 100% is the so-called initial budget of the investment - the value of contractual works, and the increase in costs results from the occurrence of additional works.

In order to achieve precision in the implementation of construction projects, it becomes necessary and unavoidable to incorporate the method into BIM technology as an integrated building information management [19, 20], supplemented with the EVM method used to control the time and cost of individual works and the entire investment. The BIM-EVM system thus generated as a digital record of the physical and functional properties of a building, serving as a source of knowledge and all data about the object, including delays in time and an increase in the cost of the facility, fully available to investment process participants will provide a reliable basis for making decisions during the life cycle, from the first concept to the demolition of the building.

Table 1: The results obtained in all control days (the symbol “zł” of the monetary unit is identical to Polish złoty “PLN”)

Test	1	2	3	4	5	6	7	8	9
	10.08.2010 r.	10.09.2010 r.	10.10.2010 r.	10.11.2010 r.	10.12.2010 r.	10.01.2011 r.	10.02.2011 r.	10.03.2011 r.	10.04.2011 r.
Budget Cost At Completion (BAC) [zł]								8747995,92	
Budgeted Cost of Work Scheduled (BCWS) [zł]	0,00 zł	13 455,31 zł	28 636,23 zł	44 405,42 zł	57 278,81 zł	121 789,04 zł	153 249,13 zł	264 956,61 zł	424 768,80 zł
Budgeted Cost of Work Performed (BCWP) [zł]	0,00 zł	13 455,31 zł	28 636,23 zł	44 405,42 zł	57 278,81 zł	121 789,04 zł	153 249,13 zł	264 956,61 zł	424 768,80 zł
Actual Cost of Work Performed (ACWP)[zł]	0,00 zł	13 455,31 zł	28 636,23 zł	44 405,42 zł	57 278,81 zł	121 789,04 zł	153 249,13 zł	264 956,61 zł	424 768,80 zł
Estimated Cost At Completion SKK(EAC)[zł]	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%	100,00%
Schedule Performance Index WWH (SPI)	0	1,00	1	1	1	1	1	1	1,00
Cost Performance Index WWK (CPI)	0	1,00	1	1	1	1	1	1	1
Estimated Time At Completion (ETTC)-MS Project[work hours]	4683	4683	4683	4683	4683	4683	4683	4683	4683
Estimated Time At Completion (ETTC)- Classical Earned Value Management method[work hours]		4683	4683	4683	4683	4683	4683	4683	4683
Time from commencement of construction works to the date of the report (ATE) [work hours]	0	176	336	512	680	840	1024	1184	1352

10	11	12	13	14	15	16	17	18	19	20	21	22	23
10.05.2011 r.	10.06.2011 r.	10.07.2011 r.	10.08.2011 r.	10.09.2011 r.	10.10.2011 r.	11.2011 r.	10.12.2011 r.	10.01.2012 r.	10.02.2012 r.	10.03.2012 r.	10.04.2012 r.	10.05.2012 r.	10.06.2012 r.
577 331,44 zł	958 646,62 zł	1 334 975,11 zł	1 870 518,64 zł	2 096 850,93 zł	2 894 982,98 zł	2 011,94 zł	4 213 687,17 zł	4 795 591,71 zł	6 077 104,26 zł	6 485 001,67 zł	6 944 387,45 zł	7 210 463,36 zł	7 372 127,77 zł
577 331,44 zł	752 434,48 zł	1 090 604,53 zł	1 527 189,34 zł	1 901 985,44 zł	2 698 285,41 zł	8 228,85 zł	3 576 165,15 zł	3 769 685,84 zł	4 380 098,56 zł	4 926 623,32 zł	5 107 018,76 zł	5 472 157,41 zł	6 229 369,70 zł
577 331,44 zł	799 401,06 zł	1 222 355,78 zł	1 741 333,77 zł	2 127 112,61 zł	2 923 412,58 zł	3 408,08 zł	3 860 633,28 zł	4 084 354,03 zł	4 717 564,88 zł	5 298 858,37 zł	5 494 028,42 zł	5 866 449,66 zł	6 624 493,25 zł
100,00%	106,24%	112,08%	114,02%	111,84%	108,34%	08,24%	107,95%	108,35%	107,70%	107,56%	107,58%	107,21%	106,34%
1,00	0,78	0,82	0,82	0,91	0,93	0,84	0,85	0,79	0,72	0,76	0,74	0,76	0,84
1,00	0,94	0,89	0,88	0,89	0,92	0,92	0,93	0,92	0,93	0,93	0,93	0,93	0,94
4683	5058	5058	5082	5082	5082	5082	5082	5082	5082	5370	5370	5386	5386
4683	5966	5732	5736	5163	5024	5596	5518	5957	6497	6164	6368	6171	5542
1512	1696	1848	2032	2200	2368	2544	2704	2864	3048	3208	3376	3536	3696

24	25	26	27	28	29	30	31	32	33	34	35
10.07.2012 r.	10.08.2012 r.	10.09.2012 r.	10.10.2012 r.	10.11.2012 r.	10.12.2012 r.	10.01.2013 r.	10.02.2013 r.	10.03.2013 r.	10.04.2013 r.	10.05.2013 r.	19.06.2013
8747995,92											
7 682 847,49 zł	7 946 711,23 zł	8 152 885,33 zł	8 557 910,59 zł	8 630 608,24 zł	8 747 995,92 zł	8 747 995,92 zł	8 747 995,92 zł	8 747 995,92 zł	8 747 995,92 zł	8 747 995,92 zł	8 747 995,92 zł
6 737 183,61 zł	7 025 574,17 zł	7 274 568,44 zł	7 363 381,74 zł	7 641 438,98 zł	7 774 977,38 zł	7 826 034,06 zł	7 758 572,69 zł	7 880 936,10 zł	8 146 832,78 zł	8 319 893,39 zł	8 747 995,92 zł
7 132 307,16 zł	7 683 775,91 zł	8 005 224,07 zł	8 094 037,37 zł	8 372 094,61 zł	8 505 633,01 zł	8 556 690,20 zł	8 489 228,56 zł	8 611 591,73 zł	8 877 488,41 zł	9 050 549,02 zł	9 478 651,55 zł
105,86%	109,37%	110,04%	109,92%	109,56%	109,40%	109,34%	109,42%	109,27%	108,97%	108,78%	108,35%
0,88	0,88	0,89	0,86	0,89	0,89	0,89	0,89	0,90	0,93	0,95	1,00
0,94	0,91	0,91	0,91	0,91	0,91	0,91	0,91	0,92	0,92	0,92	0,92
5386	5386	5386	5386	5386	5794	5794	5794	5794	5794	5794	5794
5340	5297	5248	5443	5289	5269	5235	5280	5198	5029	4924	4683
3872	4056	4216	4392	4560	4728	4888	5056	5216	5392	5552	5768

5. Conclusions

The analysis of the impact of realization disturbances on the course of construction works using the Earned Value Management method was aimed at determining the maximum delay in completion of construction works after taking into account the identified disturbances. The basis for this analysis was the starting construction schedule based on investor cost estimates received from the investor. The technological sequence and the number of construction workers assigned to a given construction work have been established so as to ensure, on the one hand, the most uniform employment at the construction site, and on the other hand, to ensure that the investment is completed by the date specified in the annex to the construction contract. When creating the base schedule for construction works, the main focus was on expert knowledge regarding the technological sequence of individual construction works. Based on a detailed analysis of the construction documentation, a list of realization disturbances was created that occurred during the implementation of the analyzed investment. An updated schedule (of completed works) taking into account identified realization disturbances was developed. The analysis allowed to obtain information on the impact of individual identified disturbances on the current status of construction works and individual scheduling tasks. The main purpose of this analysis was to determine the maximum extension of the duration of construction works due to identified realization disturbances. During this analysis, the number of employees assigned to the task was not modified and the technological line was not modified to minimize the delay in construction works.

With the data from the analysis carried out and the actual implementation of contractual construction works, it was possible to determine the amount of their delay.

1. Planned, after taking into account the annex to the contract, construction works should be completed after 843 calendar days.
2. Based on the Earned Value Management method analysis, taking into account the impact of identified realization disturbances, construction work should be completed 200 calendar days later than planned. The following factors had an impact on the amount of extension of the investment implementation:
    - Disturbance: Dance Hall – ventilation duct housing (duration of disturbance is 4 calendar days),
    - Disturbance: lowering the ground water table with wellpoints for the implementation of a retention tank (duration of disturbance is 5 calendar days),

- Disturbance: disassembly and assembly of mechanical ventilation elements in a new place in the performance hall (duration of disturbance is 3 calendar days),
- Disturbance: collision of mechanical ventilation with the warehouse door (building E) and the exit door of building E (duration of disturbance is 48 calendar days),
- Disturbance: expansion of the retention tank (duration of disturbance is 71 calendar days)
- the remaining value of postponing the completion date of the investment results from the inability to continue construction works in the winter, which is caused by the extension of the duration of disturbanced tasks lying on the critical path.

3. The actual deadline for the completion of construction works by the contractor of construction works was determined on the basis of entries in the construction log, taking into account the results of the case law of common civil courts. The delay in the contractual annexed date of completion of construction works was 349 calendar days.

The reasons for the difference between the actual project duration increase and the estimated one are the components of the formula for the Estimated Time At Completion, mainly the SPI index. This SPI index is very sensitive to any changes occurring during the implementation of the investment, e.g. completion of certain stages or work fronts. For example – After exceeding the contractual "annexed" deadline for the execution of construction works, the ETTC value begins to decrease, despite the still extending time of their implementation. This is due to the completion at this stage of many construction works, which affects the value of the SPI index.

The possibilities of practical application of the presented methodology

- Advantages:
  - This metod allows to combine a temporary assessment of the progress of works with their financial advancement against the planned values;
  - This method allows to estimate the final cost and completion date of the investment based on the trends that have emerged in the implementation of the facility so far;
  - Some indicators of the EVM method make it possible to assess the situation at a given moment of the investment, while others allow to forecast the situation at the time of completion of the investment based on the situation during the works.
- Limitations:
  - The main problem that may arise is knowledge about the necessary data, that is obligatory for the application of this method;

– Correct estimation of the advancement of the execution of works sometimes provides methodological problems;
– The method indicators, eg SPI, CPI, refer to the analysis of investments in deterministic conditions. It does not allow taking into account the probabilities, random events and risks most often associated with delay in time and increase in the cost of works.

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Wykorzystanie metody evm do analizy wydłużenia czasu trwania inwestycji budowlanej w wyniku wystąpienia zakłóceń realizacji – studium przypadku

Słowa kluczowe: metoda EVM, zakłócenia budowlane, opóźnienia robót budowlanych

Streszczenie:

Realizując liczne projekty budowlane, inwestorzy i wykonawcy regularnie spotykają się z problemami dotyczącymi opóźnienia robót budowlanych, z których wielu prawdopodobnie można byłoby uniknąć. Stwierdzono, że opóźnienia w płatnościach i w realizacji inwestycji to dwa najbardziej krytyczne skutki czynników ryzyka związane z zarządzaniem budową. W artykule przedstawiono praktyczne zastosowanie metody Earned Value Management, która posłużyła do oszacowania możliwego wydłużenia czasu trwania robót budowlanych, podczas których wystąpiły zakłócenia budowlane na przykładzie wybranej inwestycji budowlanej. Nieodłącznym elementem realizacji robót budowlanych są zwykle zakłócenia budowlane. Są wynikiem m.in.: dodatkowych prac, zmian czy wad projektowych, a także źle przyjętej strategii logistycznej w zakresie dostaw materiałów budowlanych. Opóźnienia lub wzrost całkowitego kosztu inwestycji to problem często napotykany przy realizacji inwestycji budowlanych, pomimo zaawansowanych technologii budowlanych, w tym technologii systemowych i sprawdzonych narzędzi wspomagających zarządzanie procesem budowlanym. Do kontroli inwestycji stosowana jest metoda EVM. Pozwala kontrolować opóźnienia i przyspieszenie prac budowlanych oraz oszacować ich koszt i termin zakończenia. W analizowanym przypadku posłużył on do określenia skali opóźnień powstających w robotach budowlanych i związanych z nimi skutków. Niniejszy artykuł jest kontynuacją i uzupełnieniem badań przeprowadzonych na inwestycji budowlanej, przedstawionych w pracy: „Wpływ zakłóceń robót budowlanych na wyniki analizy EVM – studium przypadku" w 2020 r. [23].

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