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# THE INFLUENCE OF CONSTRUCTION WORKS DISTURBANCES ON THE EVM ANALYSIS OUTCOMES - CASE STUDY

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The paper presents the problem of building disturbances, which are usually an inseparable element during the implementation of construction projects. They were classified, their causes and sides of the construction process responsible for their creation were identified on the basis of the analyzed construction investment. In addition, using the Earned Value Management method, the scale of delays arising in construction works and the related effects were determined. The important role of close cooperation and good communication between all participants of the construction process was emphasized, which would reduce the phenomenon of building disturbances, but also mitigate the negative effects of delays that have already occurred.

*Keywords*: building disturbances, delays in construction works, schedule changes, contractual penalties, EVM method

## 1. INTRODUCTION

Construction control and identification of the progress of construction works and making accurate decisions regarding changes in costs and the schedule of construction works are the subject of many studies with applications of various methods including BIM [2-4, 8, 13-15] regardless of the

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specifics of these works and the type of construction investment being implemented [7, 12]. This problem has not found a satisfactory, practically useful solution yet, especially in the area of risk of construction works [5, 6]. Unforeseen, adverse random factors causing delays and an increase in the cost of works are the subject of many disputes between participants of the construction process [16], which may lead to contractual penalties and termination of the contract. 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 [9].

Construction disturbances 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 (products). Extending the duration of the investment task leads to increase in general construction costs, equipment rental costs and may lead to the need to purchase materials at higher prices. It should also be remembered that removing the disturbance itself may also lead to an increase in financial outlays e.g. redesign of building which is constructing. Identified building disturbances may have a direct impact on the completion date of construction works in a situation when they delay works located on the critical path. It should be noted that there are also such building disturbances that do not cause extension of the investment implementation time, but only generate additional costs. With large investments, you can build various scenarios of construction works depending on the conditions, however, it is not possible to predict exactly how a building will be implemented due to the high operational risk of the construction industry. The execution of the construction works in a timely manner, while minimizing prices and maintaining proper quality of construction works requires reliable cooperation between the participants of the construction process, which requires good coordination and information flow between them. Failure of any party to comply with this obligation often leads to disputes that result in contractual penalties or withdrawal from the contract. It is not possible to completely eliminate disturbances during the execution of construction works, however, their early identification and appropriate management by all participants reduce the negative effects of this type of unforeseen random factors. Objective designation, based on scientific grounds, delays in the implementation of, in particular, construction works is of significant importance both at the stage of settlement of investment costs and in civil court proceedings, taking into account the participation of individual participants of the construction in generating these delays. A detailed analysis of the construction process was carried out at the execution stage of a selected modern cubature investment (Fig. 1) financed from budget funds.

The construction covered a plot of 15 569.04 m2 and concerned both buildings with reinforced concrete structures and land development. The main cubature object consisted of one underground floor and above-ground floors, where the height of the above-ground part did not exceed 6 m above ground level. The investment included several buildings with gable roofs and a larger block of the multifunctional hall – Fig. 1. The building divides the internal amphitheater into two independent parts – Fig. 2. The whole was connected by an underground floor covering the whole plot. The building acts as a local cultural center of an educational nature.

The analysis of the above investment was carried out together with the identification of building disturbances, including their causes and parties to the construction process responsible for their occurrence. For the purposes of financial settlement of this investment by local government units, the scale of delays arising in construction works and the effects of calculating contractual penalties were determined using Earned Value Management (EVM) method.

Contractual penalties in the amount of of some percentage of the net contractual value for each day of delay related to the delay in completion of construction works is usually caused by the Contractor of construction works.

Fig. 1. General view of the cubature investment (http://wwaa.pl).

Fig. 2. View of the internal amphitheater (photo Jakub Certowicz).

## 2. CLASSIFICATION OF BUILDING DISTURBANCES

The simplest division of building disturbances takes into account the occurrence of three groups of factors: human factors, factors related with a building contract and unforseen random ones – Fig. 3.

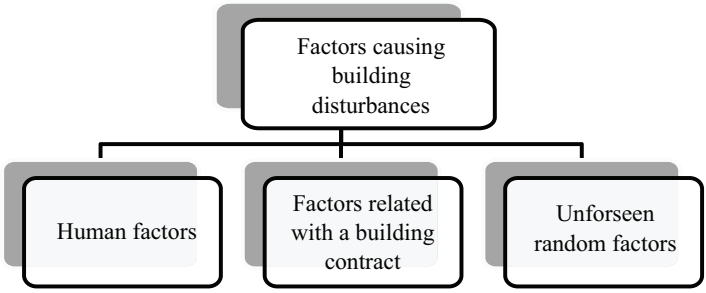


Fig. 3. Division of factors causing building disturbances at the construction stage.

Human factors are all unintentional actions taken by participants of the construction process that result in the occurrence of building disturbances. The main causes of disturbances for which the investor is responsible include: changes introduced during the implementation of the investment, interference in the competence of the construction works contractor and modifications to the arrangements, combined with a long period of decision making. Another participant in the construction process that can lead to disturbances is the designer. As a result of errors or lack of documentation, the contractor of construction works may be forced to stop them. The time needed

to redesign the building as a result of changes introduced by the investor should also be taken into account. In order to avoid losses, the contractor of construction works should have considerable experience in the implementation of a given type of investment projects. This avoids execution errors and increases the efficiency of managing by construction managers and supervising works in the aspect of control and supervision over the course of construction works - also carried out by subcontractors. An important issue for which the contractor is responsible is the availability of resources. Workforce, building materials and equipment should be provided at every stage of execution to avoid downtime as part of building disturbances.

Factors related with a building contract relate to the investor and contractor of construction works and the arrangements between them. In addition to the imprecise terms of the contract, account is also taken of the date of execution and finances. The contractor may incorrectly draw up the construction works schedule, which may result in delaying the obtaining building acceptance for use. On the other hand, the contracting authority (investor) may impose an unrealistic time to complete construction works, condemning the contractor in advance to exceed the deadline. Another source of disturbances may be the investor's failure to pay fixed amounts of money for construction works on time, which may disrupt the contractor's financial liquidity and lead to downtime e.g. lack of funds for the purchase of building materials. Similar problems may result from the contractor's unpaid timely payments to subcontractors. This will lead to a lack of work front for the contractor itself and subcontractors. Factors associated with the contract also include unusual construction and material solutions not found in widespread use. Such solutions cause not only problems in design and execution, but also in a limited opportunity to buy building materials.

The third group are unforseen random factors, mainly weather phenomena. Weather conditions can affect the implementation of construction works either directly or indirectly. The weather can prevent some works from being carried out for technological reasons e.g. preventing concreting at low outside temperatures and making layers of road surfaces during heavy rainfall. Weather conditions may also damage the equipment or previosly executed construction works which were not protected. The unforseen random factors also include: collisions, sudden changes in legal acts or random situations, e.g. theft or presence of archaeological excavations on the investment site.

Building disturbances is also classified for the party responsible for their occurrence during the construction process. Determining who is responsible for a given situation may be the basis for financial claims of the investor or contractor of construction works against other participants of the construction process. The contractor of construction works should not incur additional costs for errors or changes introduced by the investor or designer, as well as the investor should not be

responsible for disturbances caused by the contractor of construction works. Classification of building disturbances due to the party responsible for their occurrence are presented in Fig. 4.

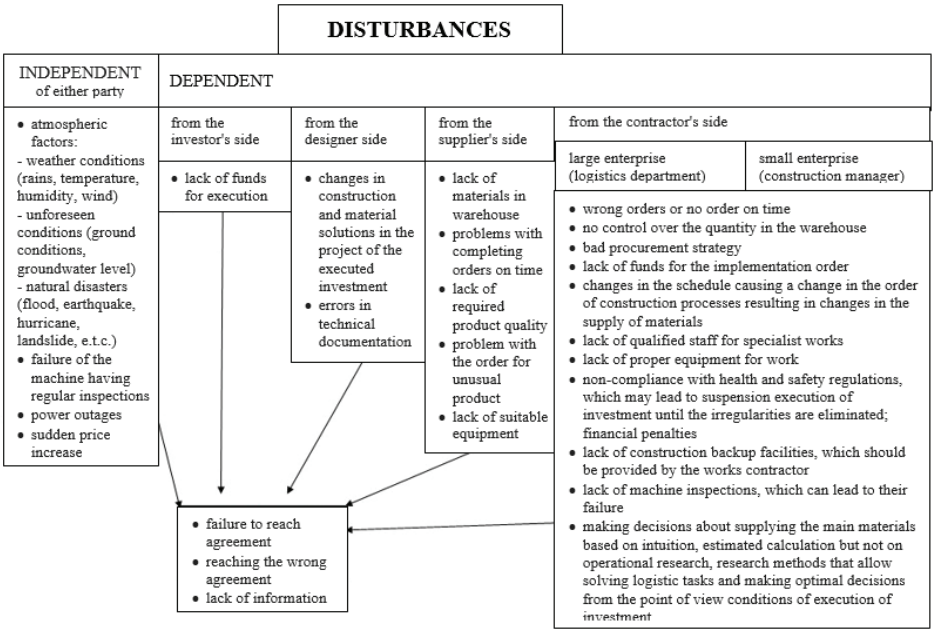


Fig. 4. Classification of building disturbances due to the party responsible for their occurrence.

## 3. IDENTIFICATION OF BUILDING DISTURBANCES ON THE ANALYZED INVESTMENT

After a detailed analysis of the construction process in question, building disturbances were identified on the investment under investigation, covering a total of **1165 days** of the implementation period.

Then the building disturbances were divided on the basis of a detailed analysis of the reasons for the occurrence of individual disturbances and the appropriate party responsible for its occurrence. The diagram below shows the division of disturbances according to party responsible for their occurrence – Fig. 5. Due to the lack of disturbances from the suppliers side, they are not indicated in the diagram below. The following results refer to the total sum of identified disturbances, i.e. 1165 days.

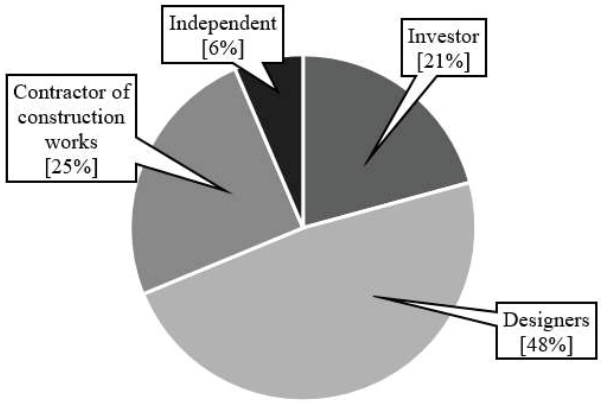


Fig. 5. Division of disturbances by parties to the construction process responsible for their occurrence.

Building disturbances, for which the Investor is responsible, constitute 21% of all disturbances occurring in the analyzed investment. They result from changes introduced during the investment, which do not result directly from design errors. The investor is also responsible for disturbances resulting from the delay in accepting solutions introduced by designers during the construction process, due to which the Contractor had limited or completely suspended construction works fronts on individual sections. This situation occurred during the acceptance of solutions regarding, among others interior finishing.

The next participants in the construction process who have a direct impact on the building disturbances are Designers in the architectural, electrical, sanitary and road specialities. Together they are responsible for 48% of disturbances that occurred at the construction site under investigation. Their role in the process of disturbing the construction of the building object concerned the redesign of its elements, which is caused by: design errors, a change in concept or a collision. Please note that Designers are not responsible for collisions with existing infrastructure components incorrectly located on maps for design purposes that also occurred in the investment. The diagram below shows the division of design disturbances according to the party responsible for their occurrence – Fig. 6. The following results refer to the total sum of identified disturbances caused by Designers, i.e. 559 days.

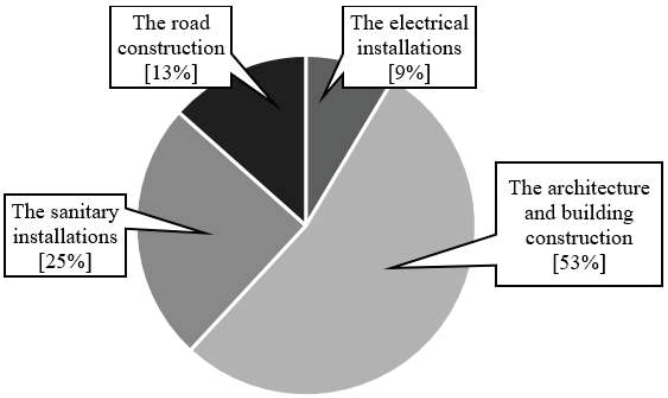


Fig. 6. Division of disturbances caused by designers, taking into account their construction specialties (road construction, electrical installations, sanitary installations, architecture and building construction).

It can be seen that it was the designer of the architectural and construction industry who, at this investment, fulfilled the function - in accordance with the design work contract - of the coordinator and Main Designer contributed most to the resulting disturbances. This was the result of a wide scale of the architectural industry with a modern architectural form compared to other industries.

The next participant in the construction process is the Contractor of construction works, whose activities also led to building disturbances representing 25% of all disturbances.

The last group of building disturbances are disturbances for which neither participant in the construction process nor the Contractor are responsible. They only account for 6% of all disturbances. They were caused mainly by atmospheric conditions (e.g. the need to lower the groundwater table), collision of newly built elements with existing ones, which were located in a different place than specified in the design documentation, and harmful unintentional actions of third parties.

To sum up, in relation to the identified building disturbances of the construction process in question, the division of these disturbances by the factors that caused them (in accordance with Fig. 1) are mostly human factors, constituting 87%, while the factors related with a building contract constitute only 3%, and unforseen random factors are 10%.

## 4. ANALYSIS OF DELAYS ARISING

The resulting delays were analyzed using the EVM method [2], [10]. The purpose of the analysis was to examine the impact of building disturbances on the investment under consideration [11]. During the construction works, many building 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 indicators of this method. The starting material for the analysis are the substantive and financial schedules created on the basis of project documentation [1]. The first one was created based on planned costs and duration of works adopted from investor's cost estimates. The second of these schedules was developed as an updated base schedule based on the identified disturbances and the construction technology adopted from the construction project and it is the schedule of completed works. The so-called „time points" of submissions for acceptance of disappearing works or works being covered (entries in the construction log made by the Construction Manager) and acceptance of part or all of the works included in the partial acceptance reports have been marked in this schedule. The identified disturbances were defined as additional tasks preceding the construction works, which were disruptived. The duration of these additional tasks is equal to the duration of building disturbances. Some of them were on the critical path, which affected the critical technological sequence of the investment. The cost of performing these schedule items is the unexpected expenses incurred by the Contractor of construction works due to the occurrence of individual disturbances. It was assumed that the occurrence of a building 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 building disturbances. 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 building disturbances identified in this study. 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. It should be emphasized here that there are significant time differences between the completion of individual tasks and the so-called time points of submissions for acceptance of disappearing works or works being covered (entries in the construction log made by the Construction Manager) and acceptance of part or all of the works included in the partial acceptance reports, which results from the above described conditions.

**Methodology of conduct:** 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. At the beginning, the duration and costs of disturbances were set to zero. Real data was only entered when the disturbance began, which reflected real conditions and their unpredictability. 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". In total, 35 controls were carried out during the investment. On the day of the control, the progress of all construction works was estimated as compared to the previous "control day". 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.

An example of an control day (control day No. 11) of the investment under analysis is presented below to better understand the methodology of conduct.

**Control day 11:**

| | SKK [PLN] | ETTC [work hours] | WWK | WWH |
|---|---|---|---|---|
| Value | **9 294 041,44** | **5058** | **0,94** | **0,78** |

In the considered period two identified disturbances appear: "Strengthening of the existing channel" and "Extension of the retention reservoir". Two disturbances significantly influenced the current status of the investment, delaying the construction of the retention tank and connections (storm water drainage, heating and water supply) – see Fig. 7.

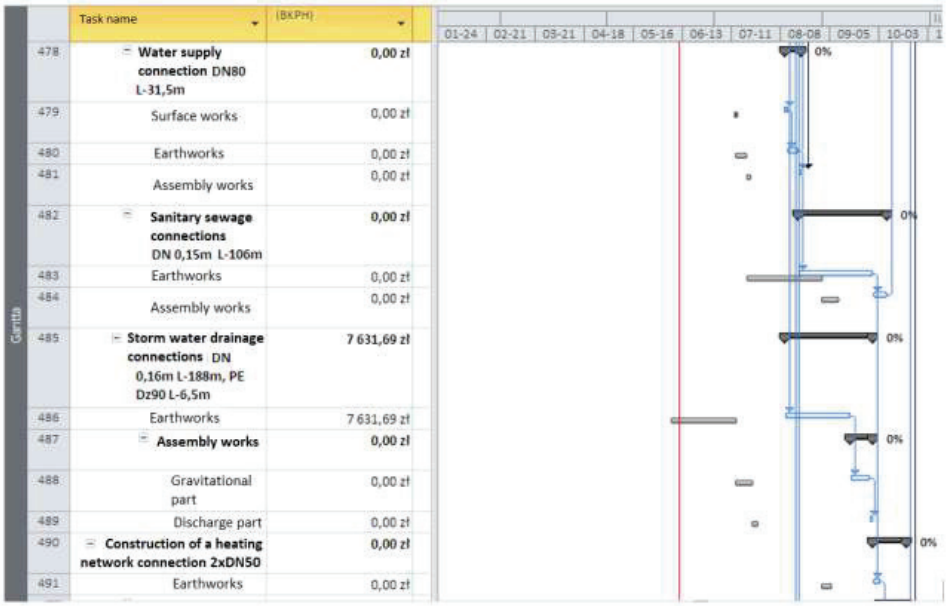


Fig. 7. Delay of tasks related to the execution of connections as a result of the disturbance *"Extension of the retention reservoir"*.

As a result of disturbances in the implementation of the task, indices regarding the EVM method have decreased. The WWH index (SPI), illustrating the progress of construction works in relation to the plan, dropped to 0.78. The WWK index (CPI) determining the current financial balance of investments has decreased to 0.94, which means that spending money is delayed. Therefore, the estimated final SKK cost increased to over 9 million PLN – see Fig. 8.


Fig. 8. Results for the control no. 11 by EVM.

The disruption of the "Enlargement of the retention reservoir" disrupted the implementation of tasks lying on the critical path, related to the retention reservoir and the estimated date of completion of works was shifted – Fig. 9.


Fig. 9. Updated completion date for construction works.

The following charts present the results of the calculations made.

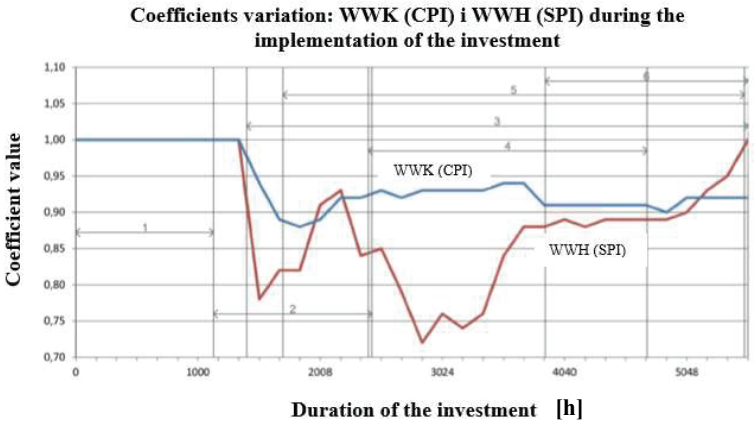


Fig. 10. Variability of CPI and SPI indices during the implementation of the investment.

The above chart (Fig. 10) presents the variability of SPI and CPI indices during the groups of construction works together with the duration of these groups of works. In the period of "1-preparatory works" there was no delay in the execution of construction works and costs. It was only during the duration of the "2-earthworks" that the SPI schedule execution index was reduced due to building disturbances mainly related to the expansion of the retention reservoir. The identified disturbances also affected the costs of this investment. In the following considered time intervals, the SPI values change very dynamically, especially during periods of works related to 3-perform the structure, 4-finishing works and 5-installation works. It is caused by many building disturbances

that occurred during the investment – see Fig. 11. It is caused by disturbances lying on the critical path as well as outside this path. In order to illustrate the course of investment, the following chart was prepared using the results of the analysis in MS Project.

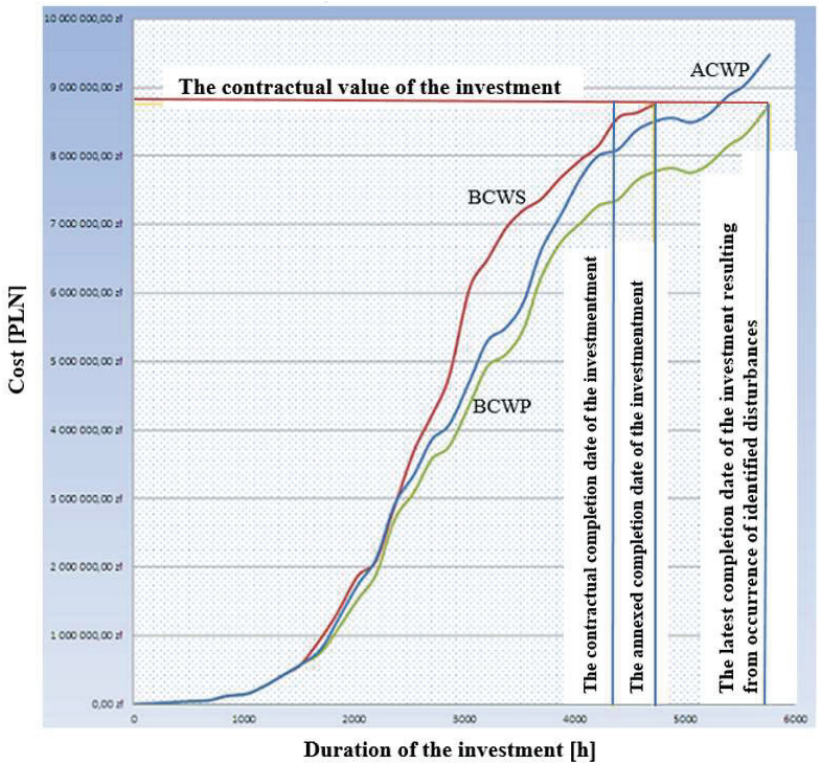


Fig. 11. Graph of the cost dependence on the duration of the investment using the EVM method.

The total disturbances time at the construction site was **1165 calendar days**, however, most of the disturbances were not on the critical path, and thus they did not significantly affect the extension of the investment completion date.

The objective extension of the construction deadline was **349 calendar days**, i.e. virtually 30% of the planned duration of the investment, including 112 calendar days of delay for which the Contractor of construction works was responsible.

## 5. CONCLUSION

Based on a detailed analysis of the construction documentation, a list of building disturbances was created that occurred during the implementation of the analyzed investment. An updated schedule (of completed works) taking into account identified building 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 building 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.

Below is a diagram illustrating the scale of disturbances lying on the critical path depending on each of the parties causing it – Fig. 12. Due to the lack of disturbances from the suppliers side, they are not indicated in the diagram below.

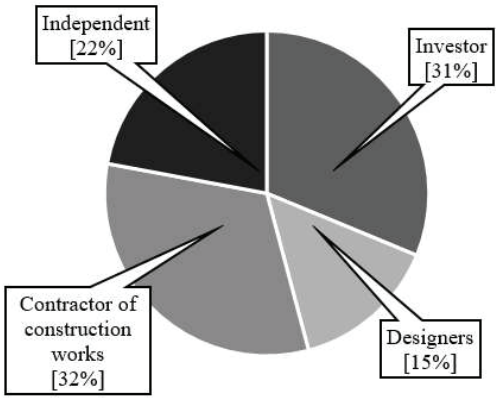


Fig.12. Juxtaposition of disturbances lying on the critical path depending on each of the parties causing them.

As can be seen, the two parties with the greatest impact on causing disturbances on the critical path, and thus the duration of the investment, are the Contractor (32%) and the Investor (31%). This final result was used by the Investor to calculate the amount of contractual penalties for the extension of construction works at the investment. It should be remembered that the Investor is the main participant in the construction process. He is obliged above all to prepare construction works - including performing formal activities necessary to commence works, as well as obtaining required

permits and notifications. The investor is also required to provide the Contractor with design documentation, transfer the construction site, coordinate and monitor the construction process, and collect the completed facility after the completion of construction works [10]. The investor is also obliged to pay a contractual remuneration. In turn, the Contractor of construction works is responsible, among others, for checking the project documentation received from the Investor, which does not mean that he is responsible for detecting "non-obvious" defects in the project, as confirmed by the Supreme Court in its judgment of March 27, 2000 (Act signature III CKN 629/98). The contractor, on the other hand, bears full code responsibility for the implementation of the subject of the investment in accordance with the construction documentation, principles of technical knowledge and applicable law. He is also responsible for securing the construction site and putting the investment into use, including notification of construction works for final acceptance. The contractor should also take into account the possibility of building disruptions and should include these risk elements in his tender offer and when preparing the schedule for the implementation of construction works, including the current one. It should be emphasized that the most important element in the implementation of construction investment is close cooperation and good communication between all participants of the construction process, which will not only reduce the phenomenon of building disturbances, but will also mitigate the negative effects of these disturbances.

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**LIST OF FIGURES AND TABLES:**

## WPŁYW ZAKŁÓCEŃ ROBÓT BUDOWLANYCH NA WYNIKI ANALIZY EVM - STUDIUM PRZYPADKU

*Słowa kluczowe*: zakłócenia budowlane, opóźnienia robót, zmiany harmonogramu, kary umowne, metoda EVM

**STRESZCZENIE:**

W artykule dokonano szczegółowej analizy procesu inwestycyjnego na etapie wykonawstwa wybranej współczesnej inwestycji kubaturowej finansowanej ze środków budżetowych. Przedstawiono również problem zakłóceń budowlanych, które są z reguły nieodłacznym elementem podczas realizacji przedsięwzięć budowlanych oraz dokonano ich klasyfikacji. Po przeprowadzeniu szczegółowej analizy przedmiotowego procesu budowlanego zidentyfikowano występujące zakłócenia budowlane na badanej inwestycji obejmujące łącznie 1165 dni realizowanego okresu wykonawstwa.

Nastepnie dokonano podziału zakłóceń budowlanych na podstawie szczegółowej analizy przyczyn powstania poszczególnych zakłóceń oraz strony odpowiednialnej za jego wystąpienie. Za pomocą metody Earned Value Management (EVM) określono skalę powstałych opóźnień w robotach budowlanych oraz skutki związane z naliczeniem kar umownych na potrzeby rozliczenia finansowego tej inwestycji przez jednostki samorządu terytorialnego. Celem analizy było zbadanie wpływu zakłóceń budowlanych na badaną inwestycję. W czasie trwania robót budowlanych wystąpiło wiele zakłóceń budowlanych, które wpłynęły negatywnie na koszt i czas realizacji tej inwestycji. Na podstawie porównania zaplanowanej realizacji inwestycji i danych skorygowanych o uwzględnienie zidentyfikowanych zakłóceń w danym punkcie kontrolnym można było oszacować przy pomocy metody EVM skorygowany koszt całkowity, zaktualizowany termin zakończenia robót budowlanych oraz ocenić aktualny stan inwestycji przy użyciu wskaźników tej metody. Opracowano harmonogramy rzeczowe (Gantta) wraz z określeniem czasów trwania poszczególnych zadań budowlanych oraz stworzono logiczną sieć zależności pomiędzy nimi. Wyznaczono zadania krytyczne i niekrytyczne analizowanych robót budowlanych:

- planowanych do realizacji (harmonogram wyjściowy),
- zrealizowanych (harmonogramy zaktualizowane wraz z identyfikacją zakłóconych zadań na ścieżce krytycznej).

Nastepnie dokonano oceny wpływu zidentyfikowanych zakłóceń budowlanych na czas realizacji robót budowlanych na przedmiotowej inwestycji, w tym na terminy rozpoczęcia oraz zakończenia poszczególnych rodzajów robót budowlanych (zadań) z wykorzystaniem metody EVM. Za pomocą wykresu przedstawiono zmienność wskaźników SPI i CPI tej metody w czasie trwania grup robót budowlanych wraz z zaznaczeniem czasu trwania tych grup robót:

1-roboty przygotowawcze, 2-roboty ziemne, 3-wykonanie konstrukcji, 4-roboty wykończeniowe, 5-roboty instalacyjne. Ponadto w celu zobrazowania przebiegu inwestycji sporządzono wykres zależności kosztu od czasu trwania inwestycji metodą EVM wykorzystując wyniki z analizy w programie MS Project. Łaczny czas zakłóceń występujących na budowie wyniósł 1165 dni kalendarzowych, jednak większość zakłóceń nie leżała na ścieżce krytycznej, a tym samym nie wpływały one w sposób istotny na wydłużenie terminu zakończenia inwestycji, co oznacza że obiektywne wydłużenie terminu końcowego budowy wyniosło 349 dni kalendarzowych czyli o 30% planowanego czasu trwania inwestycji, w tym 112 dni kalendarzowych opóźnienia za które było odpowiedzialany Wykonawca robót budowlanych. Przeprowadzona analiza pozwoliła uzyskać informację na temat wpływu poszczególnych zidentyfikowanych zakłóceń na aktualny stan robót budowlanych oraz poszczególne zadania harmonogramowe. Podstawowym celem tej analizy było wiarygodne określenie maksymalnego wydłużenia czasu trwania robót budowlanych ze względu na zidentyfikowane zakłócenia budowlane. Dwie strony mające największy wpływ na spowodowanie zakłóceń wystąpujących na ścieżce krytycznej, a tym samym na wydłużenie czasu trwania inwestycji to Wykonawca robót budowlanych (32%) i Inwestor (31%). Ten wynik końcowy posłużył Inwestorowi do wyliczenia wysokości kar umownych dla Wykonawcy z tytułu wydłużenia robót budowlanych na budowie.

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