Disturbance Analysis and Their Impact On Delays in Construction Process

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Abstract. Despite the development of: modern technologies, the software supporting the management of construction projects, popularizing of the tools for data analysis and numerous studies on factors interfering the efficient course of the construction process, the delays are still a phenomenon often present in the construction industry. Based on the literature, it should be noted that the main goal of the researchers is to try to rank the factors causing delays in the construction and their classification into groups. Frequently, the classification criterion is the participant's status in the investment process (a designer, a contractor, an investor, etc.); the general macro division into factors related to an investor/a company, a contract, the external environment or the division by resources, i.e. human factors, hardware factors and material factors. The subject of investigations of the authors of this article is to identify the types of disturbances causing delays and their classification depending on the scale and degree of influence on the further implementation of construction processes based on the implementation of a commercial and service building. Analysing the course of the implementation of the construction project, it is possible to indicate those factors that cause the necessity to engage considerable resources and change the sequence of processes to minimize the delay. Therefore, it is important to monitor the processes and control of work progress indicators, enabling early detection of delays and planning alternative solutions.

1. Introduction
Disturbances in the course of construction processes can be caused by many factors whose identification, in the planning and variants selection phase of the construction works, is difficult to clearly determine. The use of modern technologies, innovative material and construction solutions without prior knowledge/experience, change of type, scope and quantity of construction works during their implementation and the method of their stages, errors and inaccuracies in a project documentation, lack of comprehensive identification of conditions at the construction site are the basic determinants of unfavourable factors affecting delays in construction projects. The initial analysis of the aforementioned factors allows planning of remedial actions, e.g. by proposing some alternative solutions in the face of dynamically changing situation at the construction site. Each construction project requires an individual approach to planning and flexibility in managing it [1]. Therefore, such an important task is proper supervision over the course of the construction project, including ongoing monitoring of the progress of construction works, enabling early detection and assessment of the impact of factors interfering with their course on the possible delays of construction processes. Despite the extensive knowledge of contract managers and the awareness of disturbances occurrence in construction processes, the problem
of delays is still valid. The development of computer software, supporting the management of construction projects (e.g. MS Project, Primavera, Asta PowerProject) and popularization of various tools and techniques of data analysis [2-5], certainly facilitates the assessment of the impact of interference.

2. Types and causes of construction delays
Delaying the execution time of construction works is a phenomenon often occurring and readily analysed by numerous researchers [6-23]. The main task of the authors of publications is to draw attention to the need for the in-depth analysis of factors causing delays in construction works, estimation of their impact on key terms and their breakdown by selected criterion (depending on the stages or participants of the construction process). A disruption can increase the complexity of the task, cause a delay, or change the order in which tasks are performed. However, this is not always related to the increase in costs. Therefore, it is worth considering, when the disruptive factors have a key impact on the duration and cost of individual tasks. This has a direct impact on the risk assessment of construction works.

Based on our own experience, literature studies and the results of research carried out by the authors of selected publications in the identification of delays in construction processes [10-15], it is possible to indicate the basic types of delays and outline the main, most frequently mentioned, reasons for their occurrence. In the publication [24], different types of delays were classified regardless of the reasons for their occurrence (Table 1). However, the data contained in Table 2 do not fully exhaust the problem associated with their classification.

Table 1. Types of delays

| Delay type | Description | Visualisation |
|------------|-------------|--------------|
| **Base schedule** | „as planned“ | |
| **Type A** | Delaying the start date or the end date of construction works or carrying out construction works in a different order than it was planned (e.g. caused by a change in technology, material changes) | |
| **Type B** | Extended duration of construction work | |
| **Type C** | The need to carry out the additional construction works causing the postponement of the next construction work the start date | |
| **Type D** | Interruption of works due to, e.g., bad weather conditions | |
| **Type E** | Delays in construction work progress due to e.g. the contractor’s lack of experience, low labour productivity | |
Table 2. Classification of delays in construction processes due to the cause of the delay

| Category                        | Factor / Cause of delay |
|---------------------------------|-------------------------|
| Contractor of construction works | - lack of workers,      |
|                                 | - inadequate experience of the construction contractor, |
|                                 | - difficulties in financing of construction works by the contractor, |
|                                 | - ineffectiveness in planning and preparation of the construction project (including ongoing control of the schedule, control of construction works progress), |
|                                 | - low level of labour productivity, |
|                                 | - construction works failures, the need for additional construction works, |
|                                 | - assuming too short time to complete the entire construction project, |
|                                 | - errors in scheduling. |
| Investor                        | - delays in payments from the investor, |
|                                 | - introducing changes to the project by the investor. |
| Designer                        | - low quality of the project, |
|                                 | - design mistakes, |
|                                 | - lack of author's supervision. |
| External factors                | - delays in the delivery of materials, |
|                                 | - weather conditions. |

The most common types of delays are the following:
- postponing the start date or the end date of the construction work,
- the need to carry out the additional construction works,
- extending the construction work duration,
- delay as a consequence of impediments in the flow of information in the investor-designer-contractor relation or delay in the delivery of materials.

The research results for road investments are slightly different [12]. The main reasons for the time delays are the following: difficulties in the process of financing of investments, delays in payments, changes in contracts and their impact on financing, as well as contracting demand for atypical materials. In addition, the delays were identified that were related to legal procedures and difficulties in obtaining land for investment [25]. In general, project managers indicate the following reasons for the time delays: imprecisely identified conditions for the implementation of construction works, inefficient preparation and supervision of a construction project and errors in construction project documentation (including, for example, circulation of documentation and the process of transferring a replacement construction project is not always adequate to the progress of construction works).

3. Techniques for analysing delays in building processes

When preparing a schedule of construction works, the planner does not assume any disturbing factors. Therefore, schedules show little resistance to any changes in the duration of construction works causing delays in construction processes. It is noticeable that there is a lack, among the management of the construction project, of the habit of analysing the delays, using clearly defined techniques as part of the previously developed procedure. This is a consequence of limited time to make decisions and difficulties in quantifying the impact of delays on the completion dates of selected processes and the time limit of the project's directive date.

The basic technique of delay analysis can include [26-29]:
- the global impact technique – applying all delay to the schedule; the total time of extension of the construction project is the sum of all delays, however, bypassing their mutual convergence.
• the net impact technique – including, on the updated schedule, the net effect of all delays, while the time is extended by the difference between the planned and updated date of construction works performance (CPM networks are not used in this technique).
• the CPM technique matched to the schedule ("as-build") – inclusion of delays in the CPM network.
• the collapsing technique – taking into account all types of delays and their simultaneous occurrence, based on the CPM (Critical Path Method).
• the snapshot technique – dividing of the construction project into periods of delaying events and comparison for each of the periods of the planned schedule with the updated one.
• time influence technique – similar to the snapshot technique, however, the focus is on delaying events, not on periods of their occurrence.

In the literature, the new concepts are being developed related to modifications of schedules by including risk factors in them or locating time buffers constituting a kind of “security” (e.g. the MOCRA method, a critical chain according to the Theory of Constraints, innovative solutions for construction projects such as: Text Mining, Case Based Reasoning, MCDM) [30-35]. The search for methods for determining the size of buffers and their proper allocation, ensuring stability of the schedule against the negative impact of disturbing factors is an important issue. An interesting proposal for the predictive schedules, resistant to disturbances in construction processes, was proposed by Klimek M. at his work [36]. The author presented a way of predicting, at the planning stage, the possibility of interfering factors and their impact on delays in construction processes. The proactive approach proposed in the work [36] is aimed at ensuring the minimization of deviations of the actual deadlines for the implementation of processes from the dates previously planned at the stage of scheduling and adherence to the planned deadline for completion of the construction project.

The initial analysis of delays should be based on the base schedule of the construction project, and any changes (i.e. extension of the duration, additional construction works) successively included in it. Such proceedings will allow to identify any deviations in the time of the construction works from the assumed at the stage of planning the construction project as well as forecast of a realistic completion date.

4. Classification of delays on the example of the erection of a retail, service and office building facility

The authors of the article attempted to compare the base schedule (“as-planned”) with the updated schedule (“as-build”) and to identify factors disrupting the course of the construction process. This building facility combines a commercial, office and functional function. It has 4 above-ground storeys, and one underground (a garage) and a connector with an existing building. The usable space of the building is divided into two main functions: a commercial part and an office and service part located on the levels from +1 to +3. The underground part – a multi-station garage, to which leads one ramp from the front of the building. The building was designed and constructed from the reinforced monolithic concrete elements. The elevations, in the majority, were designed in the system of glass facades. Some selected parts of the elevations were finished with plaster or aluminium panels on the system support substructures. Due to the immediate vicinity of the basement walls of the new building with the existing buildings (i.e. the existing car showroom and the paint shop), it was decided to make the underground part as a wall in the palisade technology.

According to the base schedule “as-planned”, the time of completing the building facility with a total usable floor area of 4,500 m² was 9 months. The planned start date – August 2010, while the deadline for completion of construction works was scheduled for the end of April 2011, including the completion of construction works in the underground garage at the end of March 2011. Due to a number of factors disrupt the smooth course of construction processes, the deadline for completion of the
building was postponed about a month late. The procedure for classifying of the most important reasons for delays and their consequences, and in particular the analysis of their impact on the extension of the construction project duration, is presented in Figure 1 and Table 3.

**Figure 1.** The procedure of qualification of disturbances and their evaluation

Due to the requirements of the Purchaser (i.e. the permanent passage through the construction site to the paint shop building), the construction project was divided into stages. Three working plots were separated in the area of the underground car park. The third plot was carried out with a slight time lag in relation to the office building structure. The significant time delays occurred already at the stage of the earthworks, during construction of a palisade wall and a controlled drilling (Table 3, item 1). Due to the considerable depth, small width between the palisade wall and the existing foundations of the paint shop building and inadequate identification of the ground conditions in this area of the building plot (the possibility of burying large boulders, large fragments of debris in the ground, etc.), two attempts were made to make the controlled drilling. These attempts failed. The reason for the failure were the disturbances of the electromagnetic field produced by the reinforced concrete slab (which was found by making an additional control excavation) and other metal elements left (probably from the previous construction works). It was impossible to properly read the homing device. The contractor raised reservations, at the same time asking the designer to propose an alternative solution (e.g. by carrying out the pipeline in the floor pan). In the new design solution, it was proposed to carry out a sanitary sewage system by a planned underground garage, which involved breaking the palisade wall, the need to carry out some additional construction works (i.e. making two Berlin walls), at the same time changing the order of making the piles by the subcontractor.
Table 3. Classification of delays in construction processes (selected examples)

| No | General group | Type | Characteristics of the reason for the delay | Effects | Impact on subsequent tasks | Impact on the project completion date | Delay type |
|----|---------------|------|---------------------------------------------|---------|----------------------------|---------------------------------------|------------|
| 1  | "Contract"    | Implementation | It is not possible to make a control drilling due to the proximity of the foundations of the neighbouring buildings | The redesign of the sewage system, the need to break the palisade | Change in the way of further works due to the redesign of the sewerage network (additional works within the palisade resulting from the change of the network layout) | Very big Type c) |
| 2  | "Contract"    | Construction | The necessity of changing the working position of the piling machine on uneven ground | Making every third pile, the risk of making piles with a deviation | It is not possible to systematically make a cap that joins the palisade / increased number of gunning works | Very big Types b) and e) |
| 3  | "Contract"    | Construction | Shortages in the supply of elements of formwork | Downtime in reinforced concrete works | Necessity to change the order of performing monolithic and reinforced concrete works | Big Type a) |
| 4  | "Contract"    | Construction | Laying the undercoat layer of a concrete mix in inappropriate weather conditions | Incorrect binding of the concrete mix, partial casing of the surface layer | No more work is possible, including waterproofing of felt | Very big Type a) |
| 5  | "Contract"    | Designing | "No solution in the executive design of the way of drainage of rainwater from balconies | Pouring rainwater down the facade of the building | There is no possibility to perform facade treatments | Average Type a) |
| 6  | "Contract"    | Designing | There is no design solution for embedding emergency transfers on the roof of the connector | Stagnation from rainwater | Suspension of construction works related to the execution of façade treatment in the area of the connector for drilling (additional works, spare works) | Very big Type d) |
| 7  | "Contract"    | Designing | Introduction of changes in the project by the investor during implementation of, among others change of the location of the partially constructed wall g-k | Demolishing and re-walling in a new place | Additional and replacement works that move the tasks planned in the schedule | Small (depends on the type of change introduced) Type e) |

The necessity to change the working position of the piling machine and the time pressure (resulting from the making of every third pile) determined the performance of the cap connecting the palisade. This was of fundamental importance for the earthworks, which should start immediately after making the palisade with the cap, using special struts. In the face of compensation of disturbances and visible delays, the remedial actions were taken, minimizing the time deviations at the stage of the earthworks. The layout of the working plots and the stages of construction works in the palisade area are shown in Figure 2.
The construction of the reinforced concrete structure of the office building ended at the planned date, but at the expense of a temporary slowdown of the progress of construction works at the level of the underground garage (among others: in the field of shotcrete of the palisade wall and driving layer of the floor).

Due to the constant changes in the stages of construction works during construction process, the construction schedule was permanently updated. The completion of the construction schedule was a detailed schedule of the finishing construction works and a schedule of the installation works, including delivery dates for materials and building elements. An additional difficulty was:

- small construction site (the supply logistics),
- permanent investor access to existing building facilities (the so-called “active plant”, permanent passage through the construction site),
- the need to carry out reinforced concrete works in the evening, with artificial lighting of the construction site.
In response to the construction site conditions, the authors analysed in detail the delays of selected tasks and their impact on the construction project's end date (e.g. by changing the order of performing individual construction works, changing the technology of construction works, prior notification to the designer of missing details of selected construction solutions in the project documentation). The above activities allowed to minimize the delay of the entire construction project.

5. Conclusions
The disruption is the reason for the delay in the timely completion of tasks (i.e. an extension of the task duration) and the increased in investment costs. Many factors interfere with the implementation of construction processes, which are difficult to identify and evaluate during the planning phase. It is a consequence of their random occurrence. The article lists several types of delays and their classification on the example of a commercial, service and office building.

For the example cited, the most common delay is:

- extending the execution time of the construction work (e.g. extending of the time of making the palisade wall),
- postponing the start of the construction work (e.g. construction works related to shotcrete began with almost a month delay),
- the need to carry out the additional construction works (i.e. the necessity of forging the piles and alignment of the area of the cap),
- decrease in the progress of construction works or decrease in productivity (e.g. decrease in productivity due to regular adjustment of the piling machine and making of small sections of the palisade, lack of continuity in the work of the piling machine).

Due to their random nature, the disturbing factors are not usually included in the construction schedules. Therefore, the allocation of time buffers is an interesting solution of the problem. The time buffers are time reserves due to possible time delays of construction processes. Another solution is to compare the base schedule with the updated one, in which all the delays (that might occur during the construction process) will be taken into account and their analysis in accordance with one of the available techniques, e.g. the global impact technique. Alternatively, the following scenarios of construction works conditions may be developed: realistic, optimistic and pessimistic of a given construction process in order to accelerate the reaction in abnormal situations. It is also worth remembering that the scope and type of disturbing factors depends on the type, scale, individual project parameters and its complexity.

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