MODELLING THE BUILDING PROCESS USING SOFTWARE, CASE STUDY

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Abstract. *The execution phase of a construction project is often associated with interruptions of the construction process, which were not included in the original time schedule of the construction works. These interruptions may be caused by the links between the course of construction and operation and activity of the investor, where certain structures cannot be commenced according to their original schedules, or, for example, they are interruptions caused by weather conditions, when the temperature of the outdoor environment drops below + 5 ° C and most of the required technological processes cannot be performed. Also, during the construction, the necessity of performing additional works arises with a time requirement for their execution. The contractor is then obliged to prove to the investor the amount of time necessary to complete the contract, based on the unbuilt volume. The CONTEC automated building preparation system provides the possibility to accurately calculate the time required to complete building work, based on standard hours, the number of work crews employed, as well as based on technological links*

Keywords

Building, claim, investor, construction management, technologies, malfunctions.

1. Introduction

The entire current construction process of an investment building project must be state-of-the-art, taking advantage of available information technologies and software support. The current qualitative changes in the preparation, management and execution of building projects consist in modeling the building project using modern information technologies. One option is to use construction technology network diagrams (CTND) for modeling the construction process. This method allows you to create and use so-called type network diagrams. These are predefined construction models for various types of buildings in the form of computer files, which are constantly updated with objectified data from construction work. This is a network diagram for modelling the preparation and construction of buildings, based on Baukasten Netzplanung (MNP – Modular Network Planning). The building technology network diagram method builds on classic network analysis methods and uses a node-defined network diagram (activity-on-node diagram).

A CTND is a construction model and includes all necessary data for managing construction processes, and even for balancing resources in time, especially if specification based on bills of quantity, budgets or production calculations is possible. A CTND enables a construction company to put together a technological construction plan for pre-production preparations, bid processing, preparing and coordinating the production operation preparations, compile operational plans, obtain an overview of the necessary technological resources, that is, the determinative need for materials, machines, equipment and labor, classified according to decisive trades, and economic resources, meaning an overview of financing the construction and of invoicing based on the company's accounting administration.

The theory of network diagrams is not an entirely new theory. The principle of network analysis was already being used during WWII, for planning war operations, such as the Allied invasion of Europe in 1944, and again in 1960s for the planning the Apollo space program, etc. [8]. This method has also proved useful in fields other than construction. A turning point in the use and development of the network analysis method came with the development of computer technology, when working with data and information entry, and its regular updating, became more user friendly. This was reflected in the development and further active application of the network analysis method in construction. The building technology network diagram theory falls into the category of network analysis, which uses node-defined network diagrams (activity-on-node diagrams). The node-defined network diagram used in the CTND method is, compared with the MNP method, which uses 4 basic types of MNP links, complemented with another 4 links [9, 10]. This issue is cited in foreign literature, for example [26]. The methods described work with the already functioning software programs MS Project or Primavera. The method of creating a critical path, the CPM, in MS project software is described in the literature[12][13][14][14] Methods of planning the construction process using the technological possibilities of Primavera software are described in the literature [15][16][22][25]

The aim of this paper is to present the use of software in the management of a building project, taking into consideration weather and other effects on the course of the building and determining the realistic construction deadlines for the purposes of construction management and negotiating with the investor using the CONTEC automated system of construction preparation. The model of the construction process is prepared as a valued construction technology network diagram, which contains all the links resulting from the spatial and technological structure of the process of implementation of the project in question. The time structure of this process is based on a calculated model of the construction process. In this way, the technologically justified construction period respecting extra works of 2016 and the limitation of the possibility of construction in the winter period 2016-2017.

Because the background materials available included the construction execution documentation, bill of quantities and budget, with items in some categories properly numbered according to the Classification of Building Structures and Works, the database of normative process data and type network diagrams was used for the first draft of the construction process model, with everything at July 2016 – 2017 price levels. This first proposal was specified according to the design documentation, bill of quantities and budget, which are part of the documenttation. The periods of activities were calculated according to the standard times listed in the CONTEC system database. In the first stage of the work, we assembled component models of the construction process, that is, construction technology network diagrams, for the course of construction of individual structures that are part of the building

For the first proposed plan of the construction process, type network diagrams of similar structures were used. These type network diagrams have been re-worked according to the conditions of the brief, where the volumes of their activities were first modeled from the determined number of dedicated purpose units (m^3 of built-up area, m^2 of reinforced surfaces). For this these type network diagrams were modified using the main coefficients of the work queue, the values of which are shown in table. 1 (1st coefficient applies to the bottom structure, 2nd coefficient for the gross upper structure and gross interior work, and 3rd is for the finishing works), which express the spatial structure of the construction process for the buildings.

The magnitude of these coefficients is given by the ratio of the minimum workspace size for the crew, or the engagement, to the total working space on the building. This is how the minimum required working queue was set for work crews, which was used to optimize component network diagrams from the perspective of maximum use of work space on a building, which is part of the analysis and synthesis of the spatial structure of building processes.

2. Assumptions and construction progress model creation

The basic documents for the preparation of construction, which resulted from the model, were processed at the information level of construction components, with corresponding technological structure of the component construction processes (work crews). Further, the measurements of activities for all structures were specified by taking the data from the bills of quantities, whose items were numbered according to the Classification of Building Structures and Works.

During the automated transfer and summing up of assessment of items on the bill of quantities and their aggregation into component construction processes, that is, assignment to work crews, the technological division of work was respected. After specification and a certain fine-tuning of timing, during which the shortest technologically possible construction deadlines were set for individual structures that are part of the project, and the determinant procedural time periods for certain works, a construction network diagram was drawn up as the initial model of execution of the construction. This included all structures with inter-structure links, which respects, in particular, the smooth continuity of performance of the managing processes and minimizing of negative impacts of construction activity on the environment surrounding the construction site. The first link is the construction technology link, which allows us to smoothly mesh the processes from a spatial perspective. This link arises from the condition of freeing up the necessary work queues by the preceding construction process, to allow the subsequent process to start being worked on.

Table 1: Overview of main coefficients for the work queue for buildings

Building no.	Building name	Main work queu qoeficient [%]		
		No 1	No 2	No 3
1	SO 01 West wing	50	20	10
2	SO 01a Construction work of current building	50	25	13
3	SO 02 Relaying and connection medicinal gas	10	10	10
4	SO 03 Relaying of public lighting	25	25	25
5	SO 04 Sewerage connection	10	10	10
6	SO 05 Roads	25	25	25
7	SO 06 Gardens work	20	20	20

The link is not determined by its time value, but by the coefficient of the work queue. In view of the amount of work and construction period, the time unit for the network diagram was chosen to be 1 week. Documents were processed in calendar date form. In the calculation, a six-day work week was considered, with Saturdays being working days, and 1 work shift of 8.5 hours per shift is counted on. Work in extended shifts can be used during construction of the building as a reserve to speed up some of works. An exception is the internal surfaces finishing process, which is planned to be carried out in two-shift operation. The start of the construction was determined by the actual commencement of construction works on August 18, 2016. After the aggregation of budget items into component construction processes according to the technological division of labor, the price data for the construction project from the budget were numbered automatically for the activities for which it was possible. Prices of other activities (heavy current, weak current, HVAC, medicinal gases, M + R) were adjusted according to total budget prices.

The concept of the basic construction process was determined with regard to the maximum possibility of carrying out all types of work by specialized crews as well as with respect to the location of the individual buildings of the construction project, with the aim of achieving the shortest technologically justified construction times and the minimal negative impact of the construction activity on the environment, while maintaining the highest quality of construction works. From this perspective, the initially proposed construction process using the created model was optimized. After the creation of the initial model of construction according to the original contractual budget, additional works and cancelled works according to the change sheets 1 - 5 were included in the volumes of partial construction processes on buildings SO01 and SO01a. This led to a certain prolongation of some processes (deepened excavations, modification subsoil and foundation joint modification, padding of foundations, micro piles, foundations etc.). This extension, of course, also resulted in an extension of the overall construction period to a certain extent, as described in the accompanying letters to the individual change sheets. Extensions due to extra works led to the implementation of insulation and base layers of the underlying structure for building SO01, which was decisive for the total construction period, being delayed until December 2017.

However, on this building, the implementation of a monolithic load-bearing construction was dependent on the completion of these processes and could have commenced on the 2nd underground floor in January 2017 – in the technological stage of the bottom structure. Under ideal weather conditions, each partial construction process in this technological stage would not last for more than 3 weeks. Due to the weather conditions, when a relatively thick snow cover (up to 20 cm) fell, and the temperatures plunging into severely negative values, it was practically impossible to continue the construction works of concreting the supporting structure on the 2nd underground floor. In the model, this workload limitation is marked by halving of the workload (2023 - 2123) of the bottom structure (using the stress coefficient norms). This results in the prolongation of these activities in the construction execution model to double the amount of time, which is indicated in the timetable.

The completion of the concreting of the load-bearing structure then works out to 18 March 2017, which is realistic with respect to the current weather conditions. After that, the subsequent construction of the supporting structures of the other floors (1: PP - 3rd NP) planned, which are already in the technological stage of the rough top structure. In the presented model, the progress of this technological stage is divided into individual floors. Based on the amount of work, time norms and the number of workers employed, the construction time of the rough building works out to 1 floor every 3 weeks – see schedule and time-space chart. The completion of execution of the rough upper structure then works out to June 30, 2017. This will be followed by other stage processes according to the original construction process model, of course based on the completion of the execution of the rough upper structure. Under the assumption of full employment of labor, the necessary quantities of material and minimum changes in the design documentation that would result in extra work, completion and handover of the building by September 30, 2017 would be realistic.

3. Definition of the construction technological network diagram method

This chapter will introduce the basic principles of the Construction Technology Network Diagram (CTND) method, types of links in the CTND method and the time analysis of the network diagram in the CTND method

3.1. Basic Principle of the CTND Method

The Construction Technology Network Diagram (CTND), developed for use in CONTEC system [1], [2], is based on the Modular Network Planning (MNP) method. It enables modeling of the process of execution of structures for building and other processes in the technological structure of partial construction processes (work crews), stage processes and construction processes. A partial (building) process is the production process, the product of which is a construction or building component. The stage process is the manufacturing process, the product of which is a technological stage, as a relatively integral part of a building that consists of constructions that it is necessary or expedient to produce together. The building process is the manufacturing process the product of which is a building. Processes that are aggregated from partial construction processes, i.e., stage building, have, in addition to their time, usually indicated as t_i, or the so-called development time, which is indicated as T'. The stage process, which consists of partial construction processes, is shown in the space-time chart in Fig. 1.The development time T', see Fig. 1, is the time interval between the beginning of the first partial or component process and the beginning of the last partial or component process in the respective stage process.

For example, the stage process of earthworks may include the following sub-processes: preparatory and associated works, overburden of topsoil, machine excavations, manual excavations, soil removal and subsoil modification of foundation join. All of these so-called partial processes, which are performed by individual working crews, belong to the technological stage of earthworks and are carried out in this stage process. The situation is illustrated for the stage process in Fig. 1, numbers 1-6 are indicated by the aforementioned sub-processes, further indicating the period of the stage process, T'_i, during the development of this stage process.

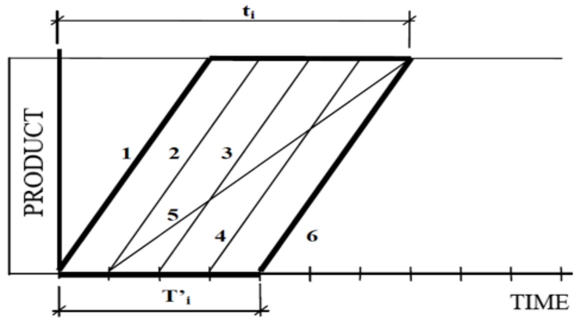


Fig. 1 Development time of the process T'

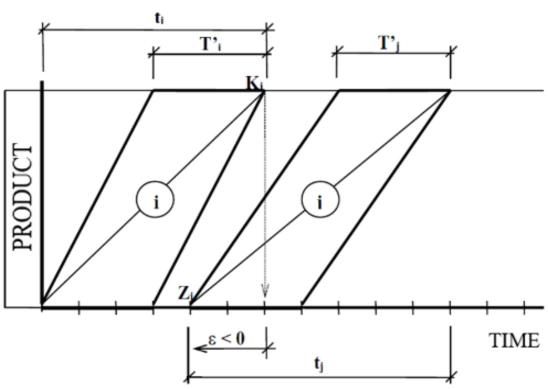


Fig. 2 Link K - Z (end - start) with development periods

The node-defined network diagram used in the CTND method is, compared with the MNP method, which uses 4 basic types of MNP links, i.e. the end-to-start, start-to-start, critical harmonization, and end-to-end, with a determined time value of the relevant link ε as well as a defined time interval expressed in number of time units, see [1], complemented with another 4 links. The fifth type of link is the so-called construction technology link, which allows to optimally mesh processes from a spatial point of view and ensures the freedom of the minimum working queue.

The sixth type of link is a flow link, which ensures the continuity of workflows of current processes on different products. The seventh and eighth types of linkage are a partial start – start (ZZ) and the link partial end – end (KK) that allow the beginning of the next process to continue upon the completed part of the product of the preceding process or the beginning of the preceding process to the part of the finished product of the subsequent process, or to the fact that part of the process under review will be terminated at the end of the previous process, or vice versa, that part of the preceding process will be terminated after the end of the monitored process.

3.2. Basic Principle of the CTND Method

The CONTEC Construction Technology Network Diagram (CTND) method was developed for automated, current calculation of technological analyses and network diagrams, by which errors can be avoided, arising from a separated calculation of both documents (failure to respect construction technological links, errors in data conversion, administrative demands for data transfer, etc.) [1], [2].The CTND Method uses a node-defined network diagram and allows for respect for the various types of linkages between activities, including the expression of optimal use of the minimum work queue of processes and the links resulting from the flow of construction method. The CTND method introduces 8 types of bonds into the calculation, that are shown on time-space charts when linking or joining adjacent stage processes i and j. These processes have a total duration (time) ti and tj and the development time T'_i and T'_j.

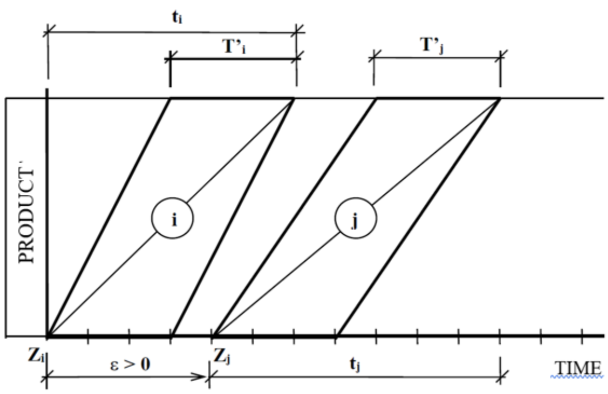
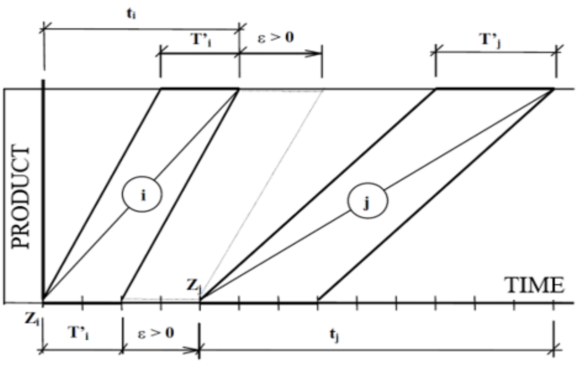


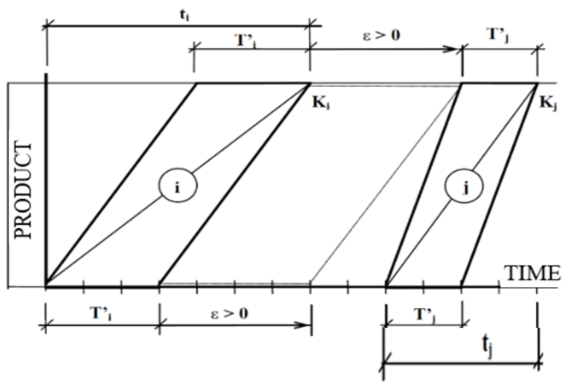
Fig. 3 Link S – S (start – start) with development period

The time value of the relevant link is indicated as ε. Fig.

2 shows the link of the first type end-start (E-S) with a time value ε, which in this case has a negative value. On Fig. 3 we see the link of the 2nd type of link start - start (S-S) with indication of its time value ε, into which the development time of the process, into which T'_i must also be incorporated. In Fig. 4, a critical harmonization (KP) type 3 link is plotted, considering the times of development of linked process in two cases that may occur here. Although the process stages are linked, the technological link actually exists between the last partial process (i.e., the last work crew) of the preceding stage process i and the first partial process (the first work crew) of the subsequent stage j process.



a) $t_i - T'_i \leq t_j - T'_j$
Fig. 4 Link CH (critical harmonization) with development periods



b) $t_i - T'_i > t_j - T'_j$
Fig. 4 Link CH (critical harmonization) with development periods

In Fig. 4, a critical harmonization (KP) type 3 link is plotted, considering the times of development of linked process in two cases that may occur here. Although the process stages are linked, the technological link actually exists between the last partial process (i.e., the last work crew) of the preceding stage process i and the first partial process (the first work crew) of the subsequent stage j process.

Fig. 4a shows the case where in the next stage process, j, the first partial process is slower than the last partial process in the previous stage, i. Fig. 4b illustrates a situation in which in the next stage process, j, the first partial process is faster than the last partial process in the previous stage process i. The dotted rhomboid determines the time value of the bond ε, which must be observed at all points of the process, ia. bonds are not covered by the development times T'_i and T'_j. It can be seen from the Figures that in the case of Fig. 4a, the harmonization of the two partial processes at their beginnings is decisive, and the linking of the critical harmonization is actually transformed into a start – start (S-S) type link. However, if the following partial process is faster, see Fig. 4b, the harmonization of the two partial processes at their ends is decisive, as the next partial process overtakes the last partial process from the previous stage. Therefore, the critical harmonization will, in this case, convert the end-to-end (E-E) type. Critical harmonization linkage is therefore a combination of S-S and E-E links. In both cases, the harmonization of the relevant sub-processes is decisive, and not the development time of the adjacent stage processes. Fig. 5 shows the end-to-end (E-E) type 4 link, the time-value of which ε includes the development period of the j processes T'_j.

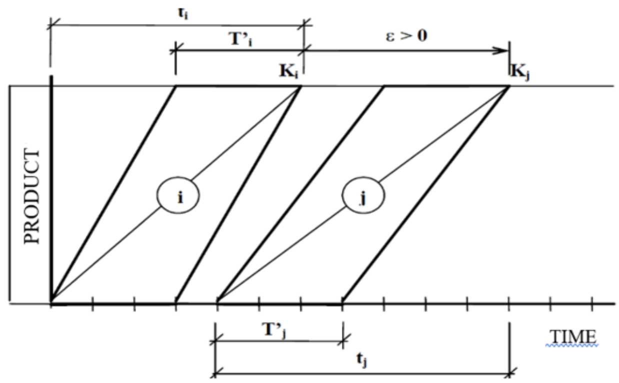


Fig. 5 Link K- K (end – end) with development period

For the optimum meshing of two processes from the perspective of maximum use of the work queue, a so-called type 5 construction-technology link (CTL) was introduced. This link follows from the condition of releasing the minimum work queue (minimum working space) through the i-team process, so that the subsequent j-team process could start work on it. This link is not determined by its time value, but by the coefficient of the work queue f_{ij}, which expresses the ratio of the minimum working queue to the total, i.e. the size of the engagement to the total working space for a particular process, see [1]. Fig. 6 shows an eight-story office building. If, for example, rough installation works are to be done here, the heating technicians need a minimum work spaces on two floors for a successful workflow, which is a minimum work queue for this process, marked M. The total work space in this building is 8 floors and is marked C. The work queue coefficient f_{ij} determines the formula (1) and is usually given as a percentage. This coefficient gives the minimum amount of production (building) that must be completed in the preceding process i to enable the subsequent process j to commence on this part of the production (building) while avoiding the two processes (work crews) interfering with each other, that is, so that both processes are carried out in a good quality, safe, cost-effective and efficient way. The coefficient f_{ij} is the basic indicator that characterizes the minimum workspace size necessary for a particular process, and is the binding of two processes from a spatial perspective. It follows from the spatial structure of the meshed construction processes.

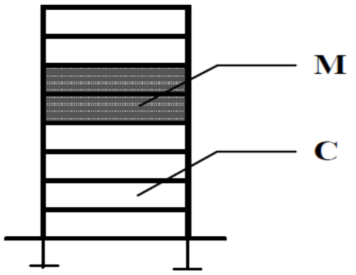


Fig. 6 Minimum and Overall Work Queue

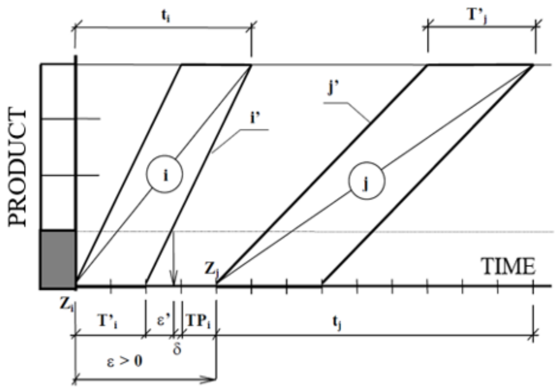
$$F_{ij} = (M / C).\ 100\ [\%] \qquad (1)$$

The principle of meshing the following 2 stage processes i and j is shown in Fig 7 where T'_i and T'_j indicate the period of development of the stage processes i and j, that is, the period that passes from the beginning of the first partial process to the start of the last partial process in the given stage process. Further in the figure and in the formulas t_i, t_j it indicates the time for the stage processes i and j, ε indicates the time value of the relevant link, T_{pi} the technological break, that must follow process i, f_{ij} indicates the coefficient of the work queue, expressing the ratio of the minimum work queue to the overall work queue. The value δ rounds the value of the link ε to whole units of time. From the meshed processes shown in Fig. 7, it follows that critical harmonization between stage processes i and j depends on the critical harmonization of the last partial process i' in the stage process i and the first partial process j in the stage process j. the period of t'_i of partial process i' is calculated according to formula (1), period t'_j of the partial process j' is calculated according to formula (2).

$$t'_i = t_i - T'_i \ \text{[time unit]} \qquad (2)$$

$$t'_j = t_j - T'_j \ \text{[time unit]} \qquad (3)$$

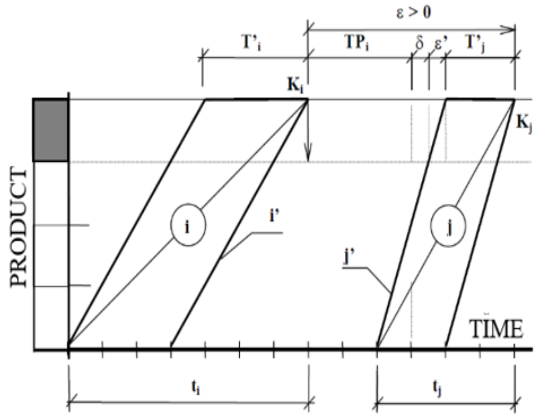
ε' indicates the time value of the link between partial processes i' and j', which can be calculated using the work queue coefficient f_{ij}.



a) $(t_i - T'_i) \leq (t_j - T'_j)$

Fig. 7 Construction technological link

The principle of meshing the following 2 stage processes i and j is shown in Fig 7, as has been already stated, whereas T'i and T'j indicate the period of development The construction technological link is then automatically de facto converted either into the link type start – start, or on the link end – end, according to the following conditions: , see also Fig. 7:



b) $(t_i - T'_i) > (t_j - T'_j)$

Fig. 7 Construction technological link

a) If $t'_i \leq t'_j$, then $(t_i - T'_i) \leq t_j - T'_j$), and since $\varepsilon' = t'_i \cdot f_{ij}$, then the start-start type link is decisive (S-S) with a time value ε according to formula (4):

$$\varepsilon = (t_i - T'_i).\ f_{ij} + T'_i + TP_i + \delta \ \text{[time unit]} \qquad (4)$$

b) If $t'_i > t'_j$, then $(t_i - T'_i) > t_j - T'_j$), and since $\varepsilon' = t'_j \cdot f_{ij}$, then the end-end type link is decisive (E-E) with a time value ε according to formula (5):

$$\varepsilon = (t_i - T'_j).\ f_{ij} + T'_j + TP_i + \delta \ \text{[time unit]} \qquad (5)$$

It can be seen from the formulas (4) and (5) that thanks to the assignment of the coefficients of the working queue, it is the possible to easily calculate the time value, ε, of the start-start links or end-to-end links, to which the construction technology link is converted and thus does not need to be entered as was the case for the first four types of links taken from the MNP method. The intro- duction of construction technology linking makes it very easy to create a network diagram, especially on a computer. However, the creation of a network diagram using construction-technological links, however, requires structural engineering experience and knowledge to determine the required size of the work queue needed for the various processes from the building plans, i.e. the determination of the spatial structure of building processes. For example, when creating a network diagram of an office building, the 1st major coefficient can indicate a situation where the minimum work queue is the space of 1 section (for foundations, earthworks, (work on the roof), the second the main coefficient determines the minimum working queue for the rough top structure and gross internal work - usually 2 floors per section, and the third main coefficient determines the work queue in another case, for example, for finishing works. So, the type model network diagram can be easily automatically modified according to the spatial composition of a particular building.

Thus, the construction technology link therefor simplifies, for one, the input of the network diagram (the user does not have to worry about the total process times or their beginnings and endings to enter the time value of the links) and further, it allows the creation of type network diagrams that are modifiable according to the spatial structure of a particular building u.

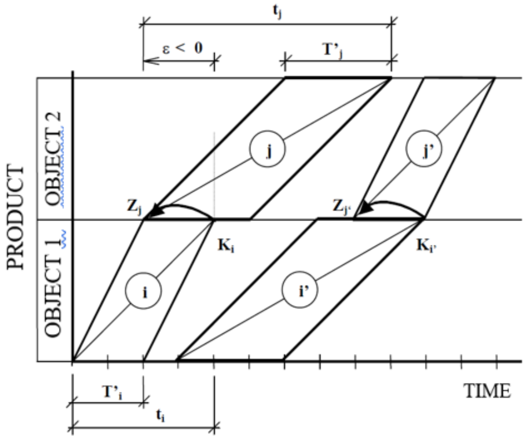


Fig. 8 Flow links (PRV)

Type network charts express the construction process and the continuity of individual processes for different types of buildings or structures or other projects that are at least partially repeatable. For the ease of entering the flow of partial or stage processes, a so-called current (PRV) type 6 link was established in the method of the building technological network diagram, which results from the condition of the flow of the current processes performed on different products. There is no need to enter either a time value or a work queue factor for this type of link. This situation is illustrated by Fig. 8.

Flow operation performs a stage process i on building u 1 and continues to building u 2 continuously by process j. The process i takes a time of t_i and has a development time T'_i, and process j takes a time period of t_j and has a development time T'_j, which is greater than the development period T'_i. It should be noted that the first partial construction process of the stage process i and the first partial process in stage j is performed by the same work crew. The link between the processes is a flow link, which is automatically converted to the end-to-start type link, the time value ε of which is equal to the lesser time of development from both stage processes and calculated according formula (6). As can be seen from the formula, the result is always a non-positive number. In this case, the first partial process is executed continuously, without interruption.

ε = max [- T(i)^',- Tj^'] [time unit] (6)

A similar situation occurs when joining the stage process i', which works on the first building u, and stage process j', whose development time is smaller and is performed on the second building u. As can be seen from Fig. 8, in this case the last partial process in both stage processes is executed continuously. However, formula (6) applies similarly. If the partial processes were linked, the development time of T' would be zero, and would practically refer to the network diagram link of the critical path method (CPM), i.e. the immediate start of the next process after the preceding process. The seventh type of links introduced in the construction network technology method is the type 7 – the partial start link start-start (P-S-S), see Fig. 9. Its principle consists in completing a certain part from the beginning of the previous process so that the following process can begin, or, on the contrary, completing a certain part from the beginning of the next process so that the preceding process can begin.

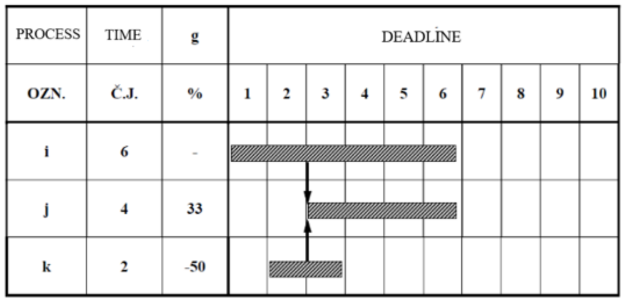


Fig. 9 Partial links start – start (P-S-S)

It is, therefore, similar to a start – start link, except that the time-value ε of the link in the time units is not given in the partial linkage of S-S, but the coefficient of the partial bond S-S in %. If this coefficient is non-negative, it indicates the percentage of completion (percentage of time period) of the preceding process to which the observed process is linked, which determines the point at which the observed process can begin, see Fig. 9. The last, eighth, type of link introduced in the construction technology network method is type 8 - partial end - end link (PE-E). Its principle lies in the fact that part of the monitored process will be terminated after the end of the preceding process or in the fact that part of the preceding process will be terminated after the end of the process. It is therefore similar to the end-to-end type link, with the difference that for the partial end to end link, the time-value of the link ε is not given in the time units, but the coefficient of partial link KK g in % see Fig. 10.

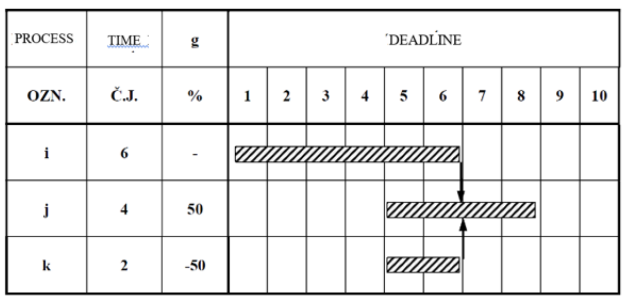


Fig. 10 Partial links end - end (P-E-E)

In addition to these types of links, the CTNG, like the MNP method, allows for the introduction of external forced deadlines, both externally forced start of i-th activity, ZN_i, as well as externally forced end of i-th activity, KN_i. The user must be aware that if the user enters a deadline of forced start for a process, the dead line takes precedence over the beginning of the process calculated from the links in the network diagram.

3.3. Time Analysis of the Network Graph in the CTNG Method

In the construction technology network diagram method, (CTNG) the time analysis is subject to similar principles as with the use of the classic method of network analysis. Moving forward, the times of the earliest possible starts and the ends of activities are calculated. The earliest possible start of i-th activity ZM_i is set as the maximum of eight partial, earliest possible starts of i-th activity $ZM_i^{(k)}$. Only immediately preceding activities are conside- red, with which the i-th activity is linked with a type k [1] [2] link.

$$ZM_i = \max \left[ZM_i^{(k)}, k \in (1.8) ZN_i\right] \text{ [time unit]} \quad (7)$$

If the index p (or n) is the time data related to the activities immediately preceding (or subsequent) activity i then $ZM_i^{(k)}$ can be calculated from formula (7), [1] where t denotes the time of the activity, ε_k the time value of the link for the kth type of link, T' time of development, T_p technological break, f working queue coefficient, g partial link factor, ε indicates increment for rounding the term to the whole time unit. The term of the earliest possible end of KM_i is then calculated from the formula (8)

$$KM_i = ZM_i + t_i \text{ [time unit]} \quad (8)$$

After that, the deadlines for the beginnings and endings of activities are counted as a maximum. The latest permissible end of i-th activity KP_i is calculated by the same logical reasoning as the earliest possible beginning, i.e. from the formula (9),

$$KP_i = \min[KP_i^{(k)}, k \in (1..8) KN_i] \text{ [time unit]} \quad (9)$$

where $KP_i^{(k)}$ is the partial, latest possible end i-th activity, taking into consideration the immediately following activities with which the i-th activity is linked, only through the k-th type, and KN_i indicates an externally forced end. That is why we get the following formulas [2]. The deadline of the latest possible start of the i-th activity ZP is calculated according to the formula (10).

$$ZP_i = KP_i - t_i \text{ [time unit]} \quad (10)$$

The latest permissible end of the last activity, from which the calculation of the network diagram starts, using a backward process, is calculated according to the formula (11) when an external forced end of the project KN is considered.

$$KP = \min[\max(KM); KN] \text{ [time unit]} \quad (11)$$

Even in the CTND method, reserves can be calculated. The overall reserve of the i-th activity RC is calculated as the difference between the latest acceptable and earliest possible time location of the activity, or (12)

$$RC_i = ZP_i - ZM_i = KP_i - KM_i \text{ [time unit]} \quad (12)$$

Due to externally forced deadlines, the total RC reserve can have RC values greater than, equal to or even, less than 0. If it is RC <0, it means that by adhering to the periods of activities that have been calculated, or assigned, the external forced term cannot be fulfilled This is therefore a delay in the respective activity. The critical path is defined in the CTND method as a sequence of activities that determines the earliest possible completion of the project.

4. Basic Results Arising from the Construction Execution Model

According to the contract for work concluded between the investor and contractor, signed on August 5, 2016, the construction period should have been 8 months, with the commencement on August 18, 2016, and the contractual end of the construction should be March 18, 2017. After the calculation of the refined construction network diagram created according to Chapter 2, the time sequence of the beginning and end of construction of the buildings and the construction, which is presented in the schedule and time-space chart of the construction, was determined. Assuming deployed resources (workers), the total construction period is 59 weeks, i.e. 13 months, including the final inspection. The model of the construction process does not take into consideration any interruptions of construction activity in the Christmas period.

4.1. Main Causes of Delay in Implementation

- delayed start of construction compared to the original plan due to delay in the conclusion of the contract for work, which caused the execution of the first two technological stages to be delayed in the seasons compared to the original balance sheets and plans of the contractor,
- additional works in the autumn of 2016, which postponed the launching the casting of the supporting structure of the 2nd underground floor until the beginning of 2017,
- weather conditions prevalent in construction location from the beginning of 2017 until practically to 15 February 2017; due to the frosts of the snow cover it was impossible to carry out concrete works during this period.

The construction period resulting from the refined model of the construction process is now technologically feasible. The average number of workers on the construction site ranges between 25 and 30 in the initial period, but at the peak in July and August 2017, it reaches 132 workers in one shift. This is due to the fact that the relatively large work space available for building SO01 and SO01a is capable of deploying so many workers to speed up the construction period.

5. Comments on Individual Documents

Technological analysis - (normal) contains a list of all processes in the technological sequence according to the indices and in the technological structure of the partial construction processes (work crews). It is a fundamental document for building management. According to the determined volumes of works, the labor demand of individual processes was calculated. Based on the crew composition, the shift time pool, the number of concurrent crews, the shift change rate, and the stress factors, the process time is calculated. The possible start and end dates of all processes and the total reserve are listed herein. The volume of the sub-building process is the sum of the coefficients of the volume of the budget item and of the adjustment quantity of the budget item, see Fig. 11 [3].

Critical activity are written red, delayed blue

Index Etap Item	Tittle of aktivity Tittle of aktivity VKVF	M.u Contractor M.U.	Volume [M.u.] Quantity	R.price [TKc] Price	Norm t. Cor. % Koef.	Labour. norm.Nh Labourisnes
3322	JÁDROVÉ VRTY 1.NP	M	46	61.36	4.240	197
0	SO01 Záp.křídlo				129	
977151124	Jádrové vrty diamantovými korunkami	M	30.75	46.74	1.000	0.00
977151119	Jádrové vrty diamantovými korunkami	M	15.62	14.62	1.000	0.00
3337	ZÁMEČNÍCI KONSTR PR 1.NP	KG	321	27.67	0.050	16
3	SO01 Záp.křídlo				21	
767995101	Výroba a montáž kov. atypických kon	KG	137.50	13.43	1.000	0.00
767995101	Výroba a montáž kov. atypických kon	KG	112.50	10.99	1.000	0.00
762086111	Montáž KDK hmotnosti prvku do 5 kg	KG	70.69	2.63	1.000	0.00
130104200	úhelník ocelový rovnostranný. v jak	T	0.08	0.62	0.000	0.00
3347	NÁTĚRY OCEL KONSTRU 1.NP	M2	9	0.35	0.260	2
3	SO01 Záp.křídlo				2	
783121190	Nátěry syntetické OK střední "D" ba	M2	8.66	0.35	1.000	0.00
3359	LEHKÉ ŘADOVÉ LEŠENÍ 1.NP	M2	1170	55.39	0.270	316
3	SO01 Záp.křídlo				92	
941111122	Montáž lešení řadového trubkového l	M2	585.07	11.06	1.000	0.00
941111222	Příplatek k lešení řadovému trubkov	M2	64357.73	34.75	0.000	0.00
941111822	Demontáž lešení řadového trubkového	M2	585.07	9.58	1.000	0.00
3379	PŘESUN HMOT TE 3 1.NP	KČ	143963	143.96	0.002	253
3	SO01 Záp.křídlo				124	
998767203	Přesun hmot pro zámečnické konstr..	%	134.27	0.22	0.000	0.00
998011003	Přesun hmot pro budovy zděné v do 2	T	2874.88	143.74	0.000	0.00
3399	LEŠENÍ TRUBKOVÉ 2.NP	M	12	29.00	0.050	1
3	SO01 Záp.křídlo				2	
949411822	Demontáž schodišťových věží trubkov	M	3.79	1.53	0.000	0.00
949411812	Demontáž schodišťových věží trubkov	M	3.79	1.53	0.000	0.00
949411221	Příplatek k schodišťovým věžím trub	M	227.25	7.98	0.000	0.00
949411211	Příplatek k schodišťovým věžím trub	M	227.25	7.98	0.000	0.00
949411122	Montáž schodišťových věží trubkovýc	M	3.79	1.69	1.000	0.00
949411112	Montáž schodišťových věží trubkovýc	M	3.79	1.69	1.000	0.00
949311812	Demontáž lešení trubkového do šache	M	4.32	1.17	0.000	0.00
949311211	Příplatek k lešení trubkovému do ša	M	259.50	4.09	0.000	0.00
949311112	Montáž lešení trubkového do šachet	M	4.32	1.35	1.000	0.00
3433	ZDI NOSNÉ 2.NP	M3	315	966.05	2.180	688
3	SO01 Záp.křídlo				112	
341361821	Výztuž stěn betonářskou ocelí 10 50	T	7.51	129.79	0.000	0.00
341321601	Stěny nosné ze ŽB tř. C 30/37 odoln	M3	38.22	83.49	1.000	0.00
317998102	Tepelná izolace betonových konstruk	M2	4.93	0.89	0.100	0.00
317998101	Tepelná izolace betonových konstruk	M2	79.64	9.63	0.060	0.00
317168138	Překlad keramický vysoký v 23.8 cm	KS	3.00	1.87	0.050	0.00
317168136	Překlad keramický vysoký v 23.8 cm	KS	5.00	2.71	0.042	0.00
317168135	Překlad keramický vysoký v 23.8 cm	KS	1.00	0.44	0.037	0.00
317168133	Překlad keramický vysoký v 23.8 cm	KS	34.25	10.38	0.029	0.00

Fig. 11 Example of CONTEC Technological Analysis

Time schedule –This is another management document based on the technological standard and contains a graphical representation of the course of all processes. Critical path processes are indicated in red, processes with a time reserve are in green, and the time reserve is indicated by a single line (also in green). For critical processes, the earliest possible and latest possible completion times are the same, and for processes with a time reserve, the end of the time reserve indicates the latest possible completion date for the activity. The timing schedule can be displayed in a relative or calendar format. In our case, the calendar format was used for all documents. If in the course of construction, a network diagram was updated, the date of this update was indicated by an axis formed by a thick red line. Besides The technological structure of partial building activities, the time chart presented here also indicates with blue and red arrows, the main (determining) links between activities arising from the network diagram.

The links between critical activities are shown in red, and the blue indicates links between all other works. The main links of the activities, which both have a non-zero period, are shown in unbroken lines with arrows, pointing from the preceding to the following activity. If the main link is shown with a dashed line, that means that in the actual network diagram, the following activity is tied to one of the other activities with a zero period This "zero" activity is not, however, visible in the schedule. That is why this line points back up to one of the activities with a non-zero duration, on which the zero activity is dependent through its main link. See Fig. 12 [4] Fig. 13[4] shows the time graph by structures.

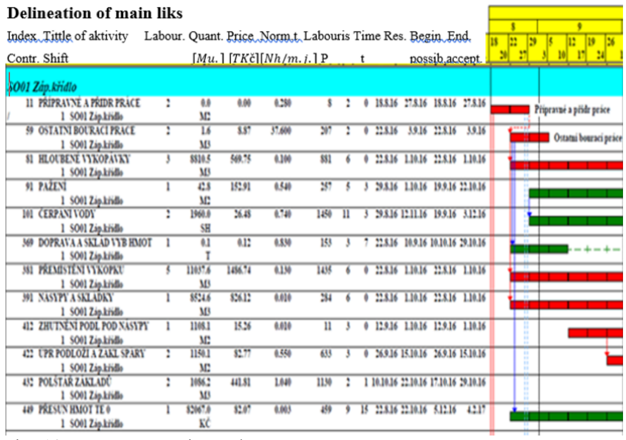


Fig. 12 – CONTEC Time Chart

The sample documents also contain all data from the calculated network diagram, i.e. the duration of the activities, the development time, the total and the free reserves of the activities, as well as all deadlines that were calculated using the equations of paragraph 3, i.e. earliest possible completion times, latest possible completion times and even completion times dictated by outside forces. The primary link that determines the date of the relevant activity is marked by an x.

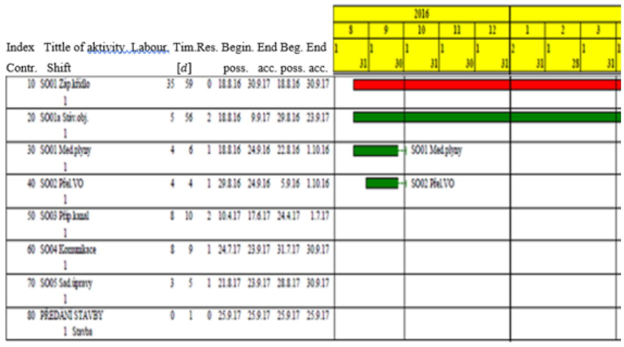


Fig. 13 Contec Construction Time Chart by Structure

The Time-space chart - was also elaborated at the level of partial construction processes (trades). It illustrates the time and spatial structure of the entire construction process, as well as the implementation and direction of construction processes. On it can be seen the spatial distribution of the building SO01 into the individual floors and work crews working on them at the given dates. All activities are carried out in the earliest possible completion times. Activities on the critical path are indicated in red, and the activities with a time reserve, which, however is not marked in this document, are in green. See Fig. 14 [5]

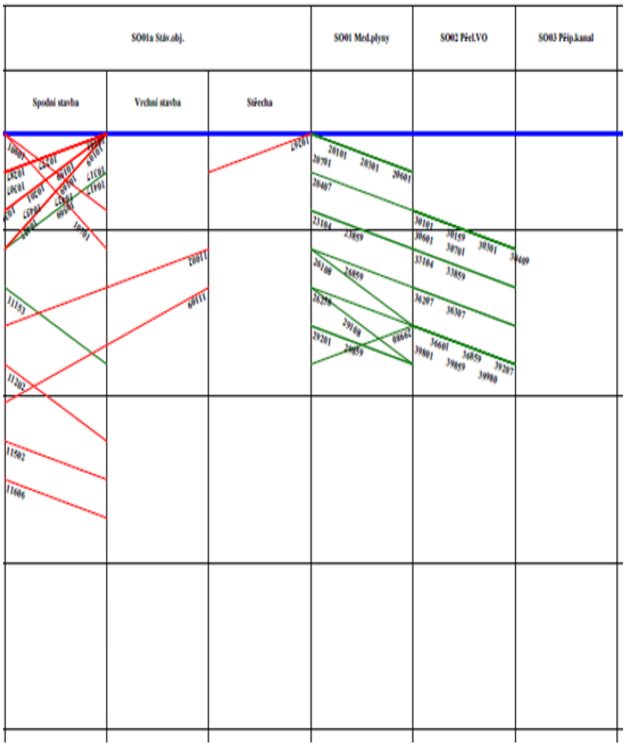


Fig. 14 CONTEC Time-space chart

Resource requirements charts - this document expresses the human resources required to meet individual partial deadlines and the final construction deadline. The document can be printed in the original time unit, that is weeks, or in months, quarters or even in individual years see Fig. 15 [6]

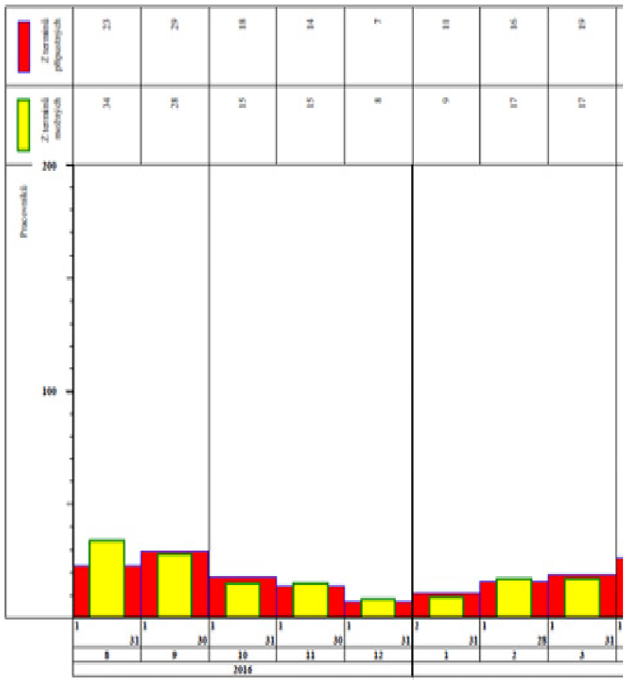


Fig. 15 Resource Requirements Chart

In our case, we chose the monthly balance in calendar format for deadlines. Yellow indicates the values resulting from the earliest possible dates. Red indicates values resulting from the latest possible deadlines. A graph of labor required was drawn from a detailed construction network technology diagram for the construction of the entire project.

6. Conclusion

Using the CONTEC [7] system, it is possible to precisely define the period required for the completion of a work based on the remaining unbuilt volumes at any given time in the construction process. During construction, it is absolutely necessary to observe the calculated deadlines of each critical activity in a given time period. The CONTEC system alerts the contractor to the timeliness of ordering the material required to perform the works of the individual items of the building process at certain times.

From an economic point of view, it is possible to check whether the economic result achieved in the given period corresponds to the planned result or whether the management of the construction by means of the pre-invoicing only provides a simulation of the economic result. In the case of the construction of the Hospital in Ostrava, it was possible, using the CONTEC system, to convince the investor of the unrealistic nature of his ideas about the completion of the building in connection with the resulting extra work and the climatic conditions under which the above-mentioned works were carried out.

There is a large body of literature from abroad that deals with other methods that have been developed to monitor the economic and timing progress of construction. In most cases, the proposed solutions have been adapted to the technical capabilities of existing software systems (e.g. MS Project, Primavera) The method introduced by Mr. Połoński deals with the creation of time and therefore financial reserves necessary in the event of interruption of construction [11][12],which are subsequently released in case of expected or unexpected problems during construction.

The above mentioned solution was successfully applied at construction sites in Poland. Founder of this theory[13] Mr. Goldratt mainly focuses on meeting critical milestones of the construction work and describing the method used to determine the time reserve. In the associated literature, it is known as Critical Chain Scheduling and Buffer Management CC/BM [14]. The confusing method allows setting costs that exceed set limits at any moment in time using a mathematical [15]

Using MS-Excel and MS-Project it is possible to create graphs showing budget costs of planned construction works in both optimistic and pessimistic variations. (optimistic / pessimistic Actual Cost of Work Perfor med - ACWPopt / ACWPpes, optimistic / pessimistic Budget Cost of Work Performed - BCWPopt / BCWPpes.). Based on the materials thus prepared, it is possible to plan construction “cash flow” more precisely.[21]

The following model differs from the previous ones by its ability to modify the construction process parameters according to the available information to obtain a satisfactory result. [17] The programming target model presented is able to optimize the total cost of the project, the completion date including any cost reductions. It also considers indirect costs in the form of contractual fines and the budget in terms of direct construction costs.

The efficiency of the model is ensured by optimizing LINGO-8 in MS-Excel. An example of application of the PERT method (Program Evaluation and Review Technique) in combination with CPM (Critical Path Method) is applied in managing the construction of a petrochemical plant in Thailand,[19] where construction time has been reduced from 356 days to 312 days and thus providing a demonstrable cost reduction.

The MS-Project software was used in the Czech Republic to manage the construction of the Radlas 16 housing cooperative, which is located in Brno-Zábrdovice. Time analysis, resource analysis, budgeting and risk analysis were processed. In the case of time analysis, it was mainly the analysis of specific activities, the use of the Gantt diagram, the network diagram and the CPM method (Critical Path Method). Furthermore, resource analysis was performed, where the focus was primarily on assigning resources to individual activities and securing resource overloads.

Most larger construction entities in the Czech Republic use this software to manage their controlling process. Primavera P6 software can easily compare the planned progression of construction works with the actual progress.[16] Basic process steps include collecting, recording, monitoring and checking information related to the actual execution of the construction work. Based on these input data, the causes delivery deadline delays can be determined. The basic benefits of this software include the ability to split large projects into smaller parts, allowing them to be better controlled. Using this software reduces risks during project planning, management and completion.

There is an improvement in the communication process between the participants in the building process using notes made directly to the schedule, which are accessible to all partners. Another indisputable advantage of this software is the estimation of unplanned resources and order needs. The literature [22], describes the use of Primavera P3 software on construction sites in Bahrain.

Based on research performed, it was concluded that using engineering software has a positive impact on the length of performance of construction and therefore also on the economics of the building process. From the perspective of quality and performance, the CONTEC computer system is comparable with the other computer systems listed. Its indisputable advantage over other computer systems is the ability to calculate a construction job in a bidding process without a detailed bill of quantities, based solely on the built-up space or characteristic indicators of the building.

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