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MODELLING OF NETWORK SCHEDULE INCLUDING PRIORITY OF SELECTED TECHNICAL RESOURCES

MODELOWANIE HARMONOGRAMU SIECIOWEGO Z UWZGLĘDNIENIEM PRIORYTETU WYBRANYCH ŚRODKÓW TECHNICZNYCH

A b s t r a c t

The paper presents a method of network planning CPM – Critical Path Method. The author compares models of optimal solutions to design deadlines for individual works, taking various leading technical resources such as is labor and a tower crane into account.

Keywords: network programming, optimization, technical resources

S t r e s z c z e n i e

W artykule przedstawiono metodę planowania sieciowego CPM – Metodę ścieżki krytycznej. Autorka ma na celu porównanie modeli optymalnych rozwiązań zaprojektowania terminów wykonania poszczególnych prac przy uwzględnieniu różnych wiodących środków technicznych czyli robocizny i żurawia wieżowego.

Słowa kluczowe: programowanie sieciowe, optymalizacja, środki techniczne

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1. Introduction

Scheduling is one of the most difficult stages of planning construction work. Planning completion is based primarily calculating the amount of work, the determination duration of each activity as well as the acceptance of work teams and the use of appropriate equipment. The article presents the problem of prioritizing leading resource. When two alternatives of works are compared: first leading is the tower crane, the second option leading is the workers. The author has applied a two-point planning network: Critical Path Method (CPM), because it best shows technological connections, design and actually reserves time. In [1, p. 91] The authors attempt to find the best solutions for managing design and implementation, and indicating that the CPM in the Polish reality is a good method, along with other tools, which complement each other and allow for a clearer presentation of the results.

2. Network Programming

2.1. The description of investment

The subject of the study is the construction of a multi-family building complex with a basement, consisting of nine apartments. The basement consists of six garages, storerooms and utility rooms. There are three apartments on each floor. The total building area is 290,50 m², 610,00 m² floor space, the gross cubature of 3312.00 m³, with the height of each building standing at 10.8 m. For the design, the residential building was located on the actual area. In the grounds there is a water feature, therefore, it was also necessary to apply a band drainage system. The ground is composed of small and medium-sized thickened humus sand.

2.2. Works plots

The plot is divided into building sections of approximate size, on which the same combinations of processes were carried out.

The property was divided into works plots in the elevation view, separating each floor as a separate plot and in the plan view along the stairs. This was possible thanks to the repeatability of processes and approximate mirrored workload on each of the plots.

2.3. The organization of work [2]

The key step in the planning works is the choice of work organization method [2, 3]. The most popular are the following organizational methods: the method of further completion, the method of simultaneous completion and the method of even work. The first of these is a method of organization, in which all operations are carried out in sequence – one after the other on each work place. The method of simultaneous completion consists of carrying out the work simultaneously at all working areas. And the even working method is the optimal method combining features of the two previously described methods. In the present building used an individual method of work organization based on the even working method, due to work on the tower crane leading.

Work planning should begin by calculating the primary labor and equipment investment. Calculations were performed using the *Norma Pro computer program*. According to the tables of workload (based on [4]) the total number of shifts (excluding the number of employees) amounted to 1744. The tower crane amounted to 80.7 shifts. It is necessary to determine the number of working hours of both workers technical equipment. The working brigade/ crew should then be set as the number of workers assigned to the activity as well as determining the number of pieces of equipment. On the basis of the assigned brigades/ crews and pieces of equipment, it can then be determined how many shifts activity will take. This information is also supplemented by sufficient knowledge of manufacturing technology in order to begin the network planning. It is also necessary to make a graph of technological connections between operations. The network structure is as follows: preliminary works, earth works and foundation were planned in succession, then the brigade/ crew was separated into two plots from ground floor construction until final execution of the project. a screenshot of the network model shown on figure 1. and the selected fragment shown on Fig. 2.

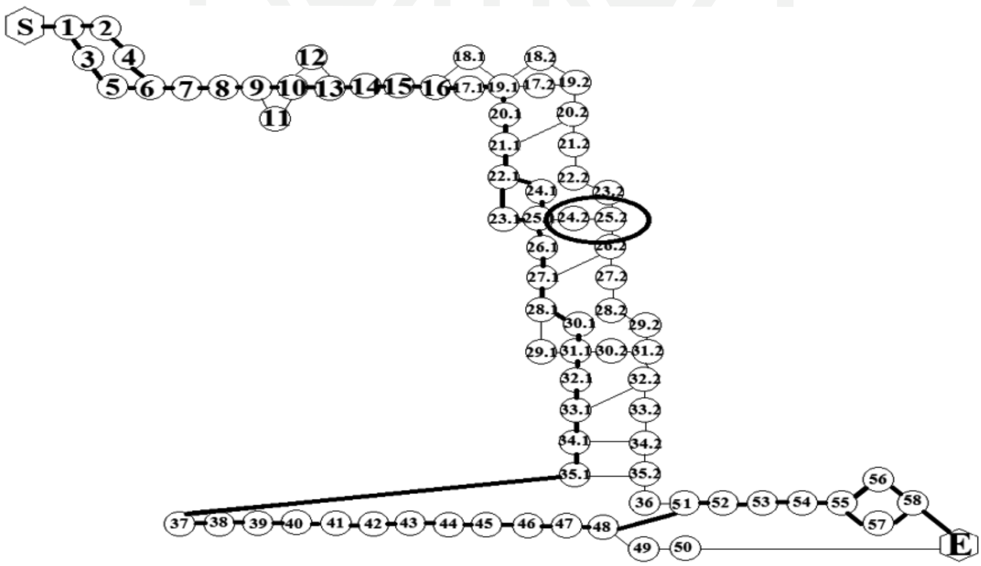

Fig. 1. Screenshot of the whole enterprise network, taking into account the priority of the tower crane with indicated fragment presented in Fig. 2 (elaborated by author)

In CPM beginning and ending working operations should be distinguished. All operations must be linked technologically, which means that every action must have its predecessor "preceding operations" and the successor "subsequent operations". Operations in the graph are marked by arrows, events by circles. The fragment of the network model shown in Fig. 2. Actual operations are marked by a solid line, and the apparent operations such as technological gaps, transition work teams are marked by a breaking line. For each event, two different times need to be distinguished: the earliest possible date of the event and the latest permissible date for the occurrence of the event. The difference between these terms is the time reserve "backlash" of the event. If the reserve is equal to zero or tends towards zero, then the event is critical. Zero time reserve should be interpreted as the operations lying on the critical path that are determined by the due date of beginning and completion of operation. It cannot be moved either forward or backward, as this would affect date of completion of all works. Operations that are not critical can be completed with the displacement equal to the time reserve and it does not affect the deadline of the works. Precise backlash is presented in section 3.1 and 3.2.

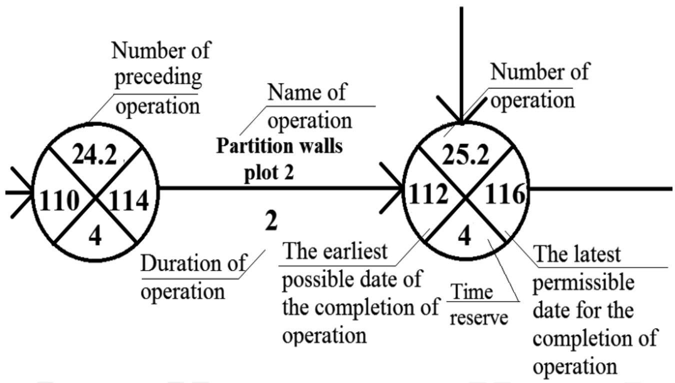

Fig. 2. Fragment the network schedule of execution objective building (elaborated by author)

2.4. Technical resources

Technical resources consist of renewable and non-renewable [3]:

- Work – the designer sets the specialized work teams or professionals of the specific field, determines the number of people needed to perform the work and creates a list of workers' labor, called the graph of employment, work is a renewable resource;
- Work equipment – necessary for the transport of materials and completion of works. Most commonly used are the following: means of transport, earth moving equipment (an excavator, a bulldozer, a grader), a concrete pump, a crane, a lift, a winch, a scaffolding etc., hardware is renewable resource;
- Work materials – materials of the required quality and quantities are calculated in excess or in estimate by KNR [4] directories. For each type of material is given a directory unit, for example for concrete [m3], steel [t], etc., materials are a non-renewable resource.

Depending on the leading technical equipment, the duration of work can vary. If for the completion of a construction project a construction team is employed and divided into brigades/teams, it is obvious that the number of employed persons must be constant. It cannot be scheduled work for one day for the 12 workers and another day for the 16 workers, because it is uneconomical and unfair to employees. Works should be planned in such way that a fixed number of workers have continuous employment without interruption (except those resulting from technological interruptions). The priority of labor is easy to plan, but difficult to reconcile with the optimal use of the equipment.

Construction materials do not affect the duration of the works, provided that they meet the quality requirements, quantities are properly estimated and they are delivered on time.

Taking construction equipment into consideration, it is always possible to determine the leading equipment. For each step, the main equipment is determined, for which the time of work becomes a determinant of the duration of the operation. The priority of the leading equipment operation can be set and it can be assumed that the operating time of a machine should be selected in such a way that the machine does not have any major downtime – in order to have the highest possible efficiency. This has its advantages – the equipment is used in maximum as much as possible, the time of its work is minimized, and the cost of operating this equipment also is reduced relatively to the schedule without considering the priority equipment. The next chapter describes the selection of technical means priority which is labor and crane work.

3. Works optimization [5]

3.1. Priority of the tower crane

The work of tower crane was analyzed. The aim of the study was to verify the use of the working time of that hardware and to plan works in such a way that the equipment is used to a maximum, to ensure the highest operating efficiency of the crane and to minimize time. The characteristic parameters required for the equipment need to be determined in order to optimally select a machine.

Regarding the selected crane, after calculating the necessary indicators and performance while working on various operations, the following parameters were provided: load capacity max is 1.8 t, overhang 22 m, height under hook 19 m.

In the case of the priority operation of the tower crane, it was necessary to establish the following work teams: preliminary and earth works: 6 workers, the foundations: 6 workers, the construction of the basement to the ceiling: 6–8 workers, the construction of the ground floor to the ceiling: 5–8 workers, construction floor to the ceiling: 5–8 workers, the construction of the second floor to the ceiling: 5–8 workers and completion: 8 workers. The number of workers has been selected in such a way that the crane was used to its maximum.

The equipment analyzed by the author will be used for the preparatory works: zero state work and assembly. Operations in which the crane was needed are summarized. The crane will be used, among other tasks, during the lifting of pallets of hollow bricks, ceiling beams, light equipment such as welding equipment and a plastering machine. In order to optimally use this equipment, the sequence of operations carried out during the construction of the building were set in such a way that works using the crane were carried out in very short intervals. This action meant that the assumptions of even work methods will not always be met. However, thanks to this, the crane will be used for a period of 30 to 171 shifts, all of the work were scheduled for 174 shifts (which is not equal to the calendar days, due to the assumption of non-working holidays). The start date of the project established on 03.01.2010 and 26.11.2010 on completion of the works, of course taking into account holidays and days free from work. Calculated deadlines for execution and reserve of time for the following: 10 shifts reserved for the ceiling over ground floor for the second plot, 4 shifts reserved for the ceiling over first floor for the second plot, 10 shifts reserved for the ceiling over second floor, and 10 shifts for sheet metal treatment.

Based on the number of working shifts adopted by the initial schedule and machine shifts set in the workload tables, the percentage of use of the tower crane was calculated. The results are shown in Fig. 3. The axis X shows only those operations that employed the analyzed technical resource, the Y axis is the percentage ratio of the possibilities for using the crane.

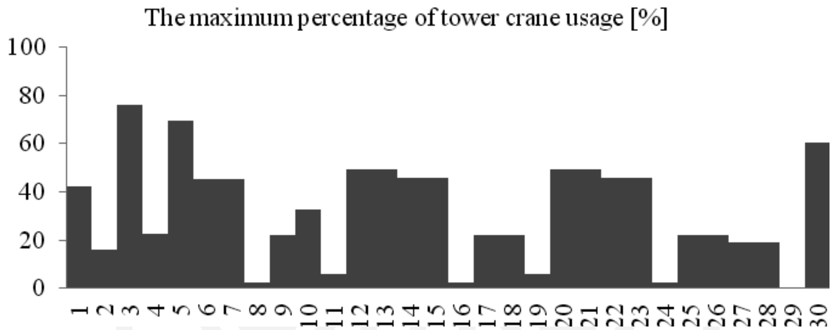

Fig. 3. The maximum percentage of tower crane usage – *y* defined for the integrated operations, *x* axis presents numbers of integrated operations (elaborated by author)

The calculation of Tangible Directory Expenditures [4] during the network model shows that in a few days, i.e. from 30 to 33 shifts, at shift 72 and from shifts 95 to 98, the crane possibilities would be exceeded. This means that the equipment would have to work more than 8 hours in a single shift on those shifts. This is not possible in the assumptions of one shift daily, therefore other methods for solving the problem were explored. One is to rent an additional crane for the duration of the non-availability, while another possibility is to change the date, during which the crane would still be available at crucial moments, while pouring the ground floor and brick work to the walls on the ground and first floors. There is also the possibility of employing additional workers, which could help speed up operations.

Eventually, the problem of deficit was solved using various methods in order to avoid the use of an additional crane. Instead of five employees pouring on the ground floor, 9 were hired, resulting in the operation being completed earlier. The partition walls on the second works on the ground floor and second floors will also be bricked sooner as a result. The partition walls on the second works plot on the first floor will, however be bricked later than assumed in the schedule, at the same time the stairs will be poured on the second floor, it is from 104 to 108 shifts.

3.2. The workers priority

In order to maximize crane efficiency during the construction, it has to be assumed that the correct number of specialized workers will be available for every shift, because every shift has a different number of workers. Thus, this solution can't be applied to the construction of one freestanding house, but rather considered for the construction of an entire housing estate. This is the best solution because of the efficient use of working time and the cost of a tower crane, but it is not so good with regard to the employment of workers chart which will not be constant, as is required for such a construction. Therefore a second schedule was established, which incorporated a fixed number of workers and a team of 8 people. Thanks to that works were scheduled for 155 shifts. The start date of the project was established for 03.01.2010 and to end on 29.10.2010, of course taking holidays and days free from work into account. This means that with such a schedule, construction of the multi-family building would take less time. The chart of employment will be constant, but the efficiency of technical resource such as the crane will not be at maximum efficiency, which means that all the possibilities will not be used. In the case of a leading work, it was necessary to maintain a constant number of jobs: preliminary and earth works: 6 workers, the foundations: 6 workers, the construction of the basement to the ceiling: 8 workers, the construction of the ground floor to the ceiling: 8 workers, construction floor to the ceiling: 8 workers, the construction of the second floor to the ceiling: 8 workers and the completion of works: 8 workers.

Calculated deadlines of execution and reserve of time. In the present case time reserve only relate to the completion works: plaster, painting, flooring for the second plot.

3.3. The selection of the optimal solution (5–7)

Optimization is a series of actions to be taken during design work, in order to reach the best solution according to the selected criteria. The purpose of optimization can be, for example, the minimization of costs, execution time, or maximizing quality or profit. The search for the optimal solution is quite a problematic task, especially considering the many factors which have to be taken into account, which in fact often translate into mutually exclusive conditions assumed in the project. In practice, this means that an optimal solution may not exist, but still, every effort has to be made to pursue it. Such an example is the case analyzed in this article, when the time-optimized operation of the crane excludes the optimal employment of workers and vice versa. Here an intermediate solution will no longer be the best and is not optimal. The author in her analysis did not take costs into account, because the simplest solution would be to plan the work in the cheapest way, and as such, was not a research problem. The aim was to analyse the comparative for the case of maximum use of the crane as well as the more obvious constant work graph, which is the basis of an even working method**.** The critical path method used in this article is very good for providing opportunities to save time. Even the author in [6] writes that this method provides good results as regards cost analysis.

4. Conclusions

Network programming aims to plan works in order to show technological relationships, the duration of these operations and their earliest and latest dates of completion. The more criteria optimization is taken into account, the harder it is to determine the best solution in this regard. Another problem may be unforeseen events, that could disrupt the planned time schedule, such as damage to equipment, not supplying materials in a timely manner, adverse weather conditions, and many others, which confronted other author's mentioned in this article.

It has been concluded that scheduling is a complex process consisting of a series necessary decisions to be made at the design stage [7]. One way to protect against failure is to present optimal solutions together with alternative solutions, but this requires additional work. a very good solution is to schedule the work in the specified and individual manner for the specific construction work. This involves among other things, the calculation of all parameters for specific equipment, in order that operating efficiency can be determined accurately. The supply of earth and materials, distance, efficiency of vehicles and proper design of the development site should also be taken into account. It is most important to ensure that the implementation of these projects and plans will take place. Unfortunately, at the moment they are not given a great importance, as is evident by the results of a survey conducted on 30 employees from different construction companies (elaborated by author): only 28% of respondents claim that they fully use time schedules in their enterprises, where 65% point as a reason for failure for meeting the deadline for completion of work as bad weather or the delayed delivery of materials.

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