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## THE APPLICATION OF TIME COUPLING METHODS IN THE ENGINEERING OF CONSTRUCTION PROJECTS

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### ZASTOSOWANIE METOD SPRZĘŻEŃ CZASOWYCH W INŻYNIERII PRZEDSIĘWZIĘĆ

#### **Abstract**

This paper summarises methods of scheduling construction processes with the use of artificial intelligence methods. Rules used for the calculation are characterised taking into account the implementation of priorities and resource constraints.

**Keywords:** scheduling, time coupling method, artificial intelligence

#### **Streszczenie**

W artykule przedstawiono metody harmonogramowanie procesów budowlanych z wykorzystaniem metod sztucznej inteligencji. Scharakteryzowano zasady stosowania obliczeń z uwzględnieniem priorytetów wykonawczych i ograniczeń zasobów.

**Słowa kluczowe:** harmonogramowanie, metody sprzężeń czasowych, sztuczna inteligencja

## 1. Introduction

Time coupling methods (TCM) allow the performing of schedules which take into account the technological and organisational limitations. These methods include: TCM I – continuity of work on the working plots of land; TCM II – continuity of work of the construction brigades; TCM III – minimising the duration of the project implementation; TCM IV, V & VI – continuity of the construction processes with the use of catty-cornered couplings, reverse catty-cornered couplings, sites of works and implementation resources. TCM is based on algorithmic notation which enables the automation of calculations and the introduction of numerous limitations. Traditional methods of scheduling do not provide the possibility to automatically prioritise tasks. In these methods, tasks are prioritised intuitively based on engineering knowledge. The research is focused on modelling construction projects, taking into account the tools of artificial intelligence as an optimisation calculation device. The research covers issues such as perfecting time coupling methods using metaheuristic algorithms, optimisation of duration, and cost correlation with the use of artificial intelligence methods (evolutionary algorithms, Tabu Search etc.), scheduling of construction projects with fuzzy duration of completing the tasks, planning construction projects with the dependencies between the duration, cost and resources, using genetic algorithms and a hybrid evolutionary algorithm. TCM was devised and developed by Professors V. Afanasjew, (1980, 1985, 1988, 1994), J. Mrozowicz (1982, 1997), and Z. Hejducki (2000, 2004, 2004). Specific methods of flow nature are involved in TCM application. The continuation of developing these methods has been undertaken. Issues pertaining to the scheduling of construction processes with the use of artificial intelligence methods are displayed in Fig. 1.

## 2. Systematising Time Coupling Methods TCM I, TCM II, TCM III, TCM IV, TCM V, TCM VI

While covering *subject matter 1*, TCM methods from I to VI were systematised. Various applications of each of the six time coupling methods were explained in a simple manner in publications [3–5, 19–21]. Previous scientific on TCM were denied wide recognition because of their extremely complicated mathematical notation. The methods were described according to the nomenclature and symbols used in international literature. The most important premisses of particular methods were presented for comparative purposes and schedules for every method were developed using the same database – this made presenting the research results possible in foreign journals. The most remarkable achievement of this stage was the publishing of a monograph [5] entitled *Time Couplings Methods: Construction Scheduling and Time/Cost Optimization*.

The effects of covering *Subject matter 1* include systematising the TCM methods, introducing international symbols, and indicating directions for the further development of TCM.

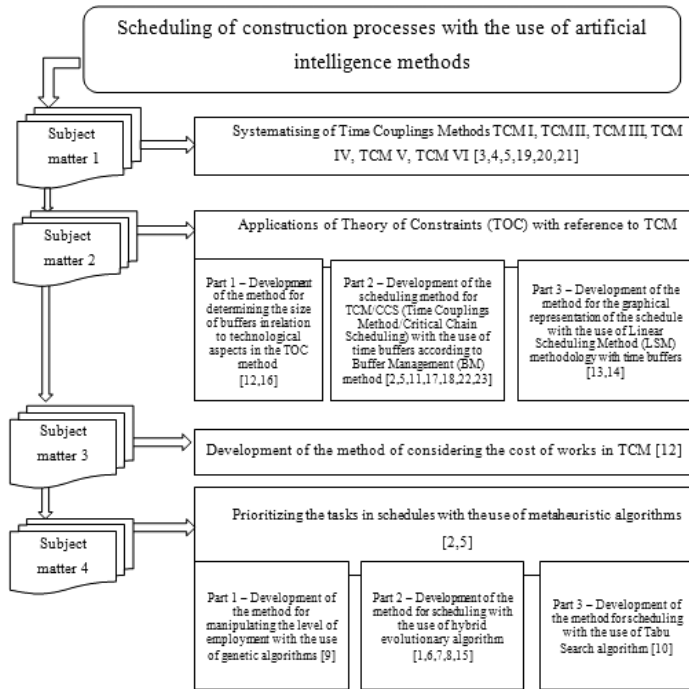


Fig. 1. Scheduling construction processes with the use of artificial intelligence methods

### 3. Applications of Theory of Constraints (TOC) with reference to TCM

*Subject matter 2* consists of introducing the premisses of Goldratt's theory of constraints (TOC) into the time coupling method (TCM) – the research results are presented in publications [2, 5, 11, 13, 14, 17, 18, 22, 23]. In TOC, project buffers (PB) and feeding buffers (FB) are introduced into the schedule in order to secure a contractor and project manager from the delay in the date of completing the works. In theory, the size of the time buffers constitute 25% of an allotted critical path. In papers [12, 16], the influence of choosing a critical path and also the influence of the system of project and feeding buffers on the overall duration of the project was analysed. The performed analysis and calculations indicate that shortening the duration of particular processes by 25% does not result in shortening the overall duration of the whole project by the same value. The duration of completing the whole project depends on the choice of the particular elements in the critical chain. While analysing graphical models (cycle graphs built in accordance with the methodology of linear scheduling model [LSM]) – it can be observed that adopting the critical chain which is closest to the right edge of the graph results in the most substantial shortening of the duration of the project. Furthermore, in cycle graphs it is necessary to treat feeding buffers (FB) as separate processes – this is due to the need to preserve the continuity of work of the construction teams and to avoid financial losses connected with unnecessary stoppages. The method of calculating the size of time buffers, different from the value proposed by Goldratt (25%), was introduced. The newly proposed

solution takes into consideration aspects such as the level of risk in completing a particular process, as well as technological limitations resulting from techniques of manufacturing. The proposed solution also takes into consideration opportunities to accelerate the process completion and the necessity to preserve technological breaks. The elements of scientific novelty in this doesn't work, consider using something like 'characteristics of' *Subject matter 2* are as follows:

- ▶ introducing TOC into the TCM method;
- ▶ determining the method of producing cycle graphs according to LSM in the TOC/TCM method and introducing international symbols;
- ▶ developing the methodology for calculations in TOC/TCM in accordance with Goldratt's premisses and considering the risk factors and technological factors of the influence, such as changes in the size of feeding buffers and a project buffer
- ▶ performing the analysis of choosing the critical path from the available critical chains in the aspect of minimising the duration of completing the project.

#### **4. Development of the method of considering the cost of works in TCM**

In *subject matter 3*, the second criterion of optimisation, namely the cost minimisation, is introduced into TCM [12]. Methodology for calculating the correlation between cost and duration in the TOC/TCM method while planning and completing construction projects is proposed. The developed method assumes three stages of creating schedules. The first stage is the output schedule, which is formed in a traditional way. The schedule of the second stage considers estimation of the risk connected with the duration and cost of completing the works. It is assumed that the risk can be estimated using all the available methods, including the Delphi method, fuzzy sets, automatic neural networks, the Monte Carlo method (Risk 4.0), and the method of construction risk assessment (MOCRA) etc. As a result of the conducted analysis, the level of risk for particular processes is estimated and the second schedule is created – usually with a longer project duration – which considers the risk connected with the duration and cost of completing the project. The third stage assumes the reduction of risk by introducing levelling factors, such as insurance, changes in the logistics system, in the involvement of resources, work organisation etc., as well as introducing feeding buffers and a project buffer, adequate for the opportunity to reduce the works. As the result of the changes made individually for every process, the third schedule is created and modified by reducing the influence of risk factors and by introducing time buffers. The correlation between the duration and cost of the project is estimated again, whereas the extra time and financial resources are left as security for completing the task. The schedules of the particular stages are presented in the following way – the 1<sup>st</sup> stage for the investor, the 2<sup>nd</sup> stage for the contractor and the 3<sup>rd</sup> stage for project manager.

The elements of scientific novelty in *subject matter 3* are as follows:

- ▶ developing the concept of introducing two criteria for optimisation of the duration and cost into the TCM method;

- ▶ developing the methodology of the 3-stage scheduling, considering risk factors and reducing the risks through technological and organisational changes and by introducing the TOC/TCM method;
- ▶ displaying the functional correlation between the size of buffers and the value of variance of the process duration with the value of variance resulting from the risk analysis.

## 5. Prioritising the tasks in schedules with the use of metaheuristic algorithms

In *Subject matter 4*, resources were introduced into the TCM method as the third criterion of optimisation. The methodology was developed to apply metaheuristic algorithms in order to prioritise the tasks in TCM, whilst considering duration, cost and use of resources [2, 5, 9]. There is a premise adopted in which a schedule is the equivalent of a chromosome. New modified schedules are obtained by mutation, crossing and selection. Limitations, which ensure the logical construction of the estimated schedule and correct decoding of chromosomes, are introduced. Hard limitations, namely those which can never be omitted, are connected with the order of completing the tasks – these are taken into account in the objective function. For instance, the objective function was determined so as to get a regular level of employment of the construction site employees. Genetic algorithms, hybrid evolutionary algorithms and the Tabu Search algorithm were used for calculations.

In *Part 1 of Subject matter 4*, traditional evolutionary algorithms were used for calculations because of their high usefulness for finding the range containing the optimal goal function value. The calculations result in an approximation of the value (a so-called suboptimal solution).

In *Part 2 of Subject matter 4*, hybrid evolutionary algorithms (memetic algorithms) were used for calculations [1, 6, 7, 8, 15]. The activity of an algorithm starts with creating the initial population, which might be created in a random manner. The best member of the initial population is assumed to be the suboptimal solution. A new population is generated in the following manner – a set of local minima is established and certain elements are determined, considering these population members which appear on the same positions in local minima, forming a set of determined elements and positions. Every permutation of a new population has certain elements at the determined positions. Permutations of finite sets can be identified with set population members of a set in a certain order. The algorithms finishes after generating a predetermined number of generations – usually, this is between 10,000 and 100,000. The calculations are considered to be correct when, after increasing the number of generations by, for instance 1000, a better result was not obtained. The results of numerical experiments connected with using a hybrid evolutionary algorithm for scheduling the construction project are presented in the papers. Optimal planning of the course of construction works are taken into account while adopting a criterion for measuring the regularity in the demand for resources, i.e. the level of employment of workers. Moreover, the limitations connected with applying the methodology of the critical chain (CSS/BM) were accepted. A classical genetic algorithm and a modified hybrid evolutionary algorithm were used for optimisation calculations.

Applying the Tabu Search (TS) procedure constitutes *Part 3 of Subject matter 4* [10]. This procedure was used for obtaining optimal solutions or solutions not far from being optimal. The basic idea of the algorithm is searching the space including all the possible solutions, using a sequence of movements. In the sequence of movements, there are movements which are not allowed – these are called tabu movements. The algorithm avoids oscillating around the local minimum as it is storing the information about the already checked solutions in the form of the tabu list (TL). Fuzzy numbers, used for the calculations, were generated from the average time in such a way that a time shorter than the average time by 16.6% was adopted as the minimum, whereas a time longer than the average by 33.3% was adopted as the maximum. The aim of the calculations was not to determine the value of fuzzy numbers of the duration of processes, but to check the possibility of using the Tabu Search algorithm for searching for the optimal solution – the minimum duration of the construction project. The obtained results were compared with the calculations made using the TS method and deterministic data. The average approximation errors of algorithms [%] were used for measuring the accuracy of calculations. The average approximation errors were 18.4% for the deterministic TS and 7.5% for the fuzzy TS. Thus, it might be assumed that when the priority of tasks is determined by using an algorithm with fuzzy parameters, the value of the objective function is changed to a much smaller extent while the duration of completing the tasks is disturbed.

The elements of scientific novelty in *subject matter 4* are as follows:

- ▶ development of the method of scheduling with the use of the Tabu Search algorithm;
- ▶ replacement of deterministic data with fuzzy data, according to the accepted rule, with the aim of obtaining the result with a smaller approximation error.

## 6. Summary

The research topic discussed in this paper has a specific character as it relates to the unique accomplishments of the authors. There is no possibility to cite other researchers' work. The work schedule is an essential part of the construction process, it is important to take into account the constraints of resources and working methods. Due to the algorithmic nature of the calculations, there is the possible application of many new solutions to the TCM as application of controlled buffers depending on technological and organizational conditions or using of probabilistic values of execution times of construction processes.

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