The scheduling of construction work under the assumption of brigade multitasking

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Abstract

In this article the method of minimization of downtime in scheduling construction works is presented. Essentially, the method is based on the assumption of brigade multitasking. This phenomenon is currently being noticed at Polish construction sites. The goal of the author was to develop a method based on mathematic removal of downtime which would let take advantage of the brigade multitasking at the stage of processing the scheduling of construction works. In this article the description of the method is presented, as well as an example of its application.

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1. Introduction

The scheduling of the construction works constitutes an essential issue which influences the success of the realization of the investment process. Different methods of construction and analysis of network models in

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construction undertakings are being applied. One of the criteria of evaluating the schedules is the minimization of the downtime in brigade works, as they result in additional and unnecessary costs. In such a case the optimization technique to be applied most commonly is differentiating the size of the brigades in time. Increasing the employment usually results in reducing the duration of the construction works while reduction in employment prolongs it [3]. All the changes should be introduced with bearing in mind the technological rules of construction processes. In order to ensure the continuity of the scheduling the model which includes the apparent processes, solved thanks to the evolutionary algorithms, can also be applied [2]. The multi-optionality in construction works can be applied as well [1].

When developing the new method it was assumed that none of the above mentioned popular techniques was to be used. It is supposed that the technology of running the particular processes cannot be changed. Neither increasing nor reducing the employment is possible. It is possible when all the employed resources of the contractor are assigned to one undertaking and there is no possibility of optimizing by assigning the resources to different construction sites at the same time. In order to be able to illustrate the new method better the exemplary scheduling shown in the first figure will be used.

The goal of the article is to present the method of optimizing the construction scheduling which is based on the assumption of brigade multitasking. According to the long experience of the author the situations in which workers of one speciality support the workers of another speciality is quite often. It seems obvious that when implementing the tasks of just one speciality it is difficult to achieve full efficiency. Therefore, the efficiency rates are to be introduced – their value can vary between 0 and 1. The possibility of choosing the value 0 is significant, because it enables stopping the particular works implemented by the particular brigades.

The method was developed on the basis of the previous articles of the author in which he focused on the methods of optimizing the scheduling prepared on the basis of the stream method [4]. In this article the possibility of applying the method in any construction scheduling is presented.

For the optimizing of scheduling the slack concept, determined on the basis of the CPM method, is applied. It is assumed that it is possible to take advantage of the slack of one brigade in order to shorten the working time of the brigade performing antecedent tasks. The presented calculation model is iterative. Each change consisting in shortening the working time of a particular brigade results in additional work of another brigade. This change results in new task emerging in the network model, which leads to the necessity of reanalysing of the model.

The previous articles of the author proved the legitimacy of such research. The results obtained showed that there was a possibility to make use of the brigades implementing the succeeding tasks in order to reduce the working time of the brigades implementing the antecedent tasks. At this stage of research the possibility of the antecedent brigades supporting the processes implemented by the succeeding brigades was not taken into consideration.

Fig. 1. Base schedule of the undertaking.
2. Description of the model of downtime liquidation

2.1. Algorithm of the model

The model presented in the article is iterative. The algorithm of the method of minimizing downtime in the works of construction brigades is shown in the figure below.

Fig. 2. Algorithm of the newly developed method of schedule equalization.
2.2 Description of the algorithm flowchart

In order to apply the presented method of minimizing the downtime at work of the brigades it is crucial to elaborate a network model of the undertaking in the first place.

Then, it is necessary to introduce the efficiency ratios. For the purpose of the method they are introduced into the matrix of the efficiency ratios defined below.

\[
EC = \begin{bmatrix}
ec_{1,1} & \cdots & ec_{i,i} \\
\vdots & \ddots & \vdots \\
ec_{p,1} & \cdots & ec_{p,l}
\end{bmatrix}; p = 1, ..., m; l = 1, ..., m
\]  

(1)

\(ec_{p,l}\) – stands for p brigade efficiency after having implemented the tasks of i process
\(p\) – stands for the number of the process assisted,
\(l\) – stands for the number of the (assisting) brigade,
\(m\) – stands for the total number of brigades.

The next step is the choice of the rule of downtime liquidation. The author of the present article suggests using one of the rules described below:

- First rule "R1" – If it is possible to use more than one assisting brigade at the same time, the one which has the biggest value of the efficiency ratio should be chosen.

- Second rule "R2" – If it is possible to use more than one assisting brigade at the same time, all of them should be used. The order of engaging the brigades depends on the values of the efficiency rates, according to the rules – from the largest to the smallest value. If more than one brigade has the same value of the efficiency ratio, the one which is the first in the sequence in the network model is to be chosen.

After having chosen the rule the "i" value has to be set as the numerator - "i" meaning the number of the following iteration, starting from 1. After having set the numerator of the iteration, the network model should be analysed according to the CPM method. The value of the total slack should be determined. Having identified the tasks on the critical path, one should determine the activities of which the analysis of the possibility of downtime minimization will be carried out. In every subsequent iteration the possibility of reducing time of subsequent activity will be analysed. The reduction of the duration of the critical activity will mean an additional task in the work of the assisting brigade. The extent of reduction should be determined on the following basis:

\[
ec_{p,l} = 1 \rightarrow t_{i} := t_{i} - \left[ \frac{|D_i|}{2} \cdot ec_{p,l} \right] \wedge \left( ec_{p,l} \neq 1 \rightarrow t_{i} := t_{i} - \left[ \frac{|A_i|}{2} \cdot ec_{p,l} \right] \right)
\]  

(2)

\(|D_i|\) – stands for the cardinality of the \(D_i\) set. The content of the set is the intersection set of the two sets – the set of the duration of the task counted in days and the set of days the assisting brigade stoppage,

\(|A_i|\) – stands for the cardinality of the \(A_i\) set, which is the set of the duration of the critical task chosen in the previous step of the algorithm, counted in days.

\(t_{i}\) – stands for the duration of the chosen critical task.

If the case is that it is possible to reduce the duration of the task, the additional task for the assisting brigade will appear. The duration of this task is to be determined on the following basis:
\[
\begin{align*}
ec_{p,j} = 1 & \rightarrow ADt_i := \left\lfloor \frac{|D_i|}{2} \right\rfloor \\
ec_{p,j} \neq 1 & \rightarrow ADt_i = \left\lfloor \frac{|D_i|}{2} \right\rfloor
\end{align*}
\]

\(ADt_i\) – stands for the duration of the additional task which is to be put into the network model instead of the time of stoppage which has been used.

If the reduction of duration has occurred, the update of the duration and the time of the network model is to be done. It is crucial to move to the stoppage condition. If the reduction has not occurred, it is crucial to move directly to the stoppage condition.

It is crucial to check whether the last task of the critical path has been analysed. If the condition is fulfilled, the work of the model is to be ended. If not, it is necessary to go back to the point of setting another value for the ”i” iteration numerator.

3. Example

In the first step the matrix of the efficiency ratio should be determined. It was assumed that the workers responsible for building the walls and ceilings are equally efficient. The workers responsible for installing windows achieved 50% of the efficiency of the workers responsible for the work on the frame stage.

The plasterers achieved 80% of the efficiency of the bricklayers.

\[
EC = \begin{bmatrix}
1 & 1 & 0,5 & 0,8 \\
0 & 1 & 0,5 & 0,8 \\
0 & 0 & 1 & 0,5 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

(4)

In the figure below the scheduling after optimization carried out on the basis of the first rule is presented. The final schedule was achieved after the eighth iteration.

In the figure below the scheduling after optimization done on the basis of the second rule is presented. The final schedule was achieved after the eighth iteration.
The results of the effectiveness of the model are presented in the table below – it contains total duration time of the project and downtime duration time for the three following schedules presented: basic, optimized on the basis of the first rule and optimized on the basis of the second one.

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Total time (days)</th>
<th>Slack time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>56</td>
<td>39</td>
</tr>
<tr>
<td>Optimal with first rule</td>
<td>52</td>
<td>23</td>
</tr>
<tr>
<td>Optimal with second rule</td>
<td>50</td>
<td>17</td>
</tr>
</tbody>
</table>

The main goal of the model presented is minimizing the downtime in work of the brigades. The reduction in total working time is the following: 7% with the first rule and 11% with the second rule. Minimizing the downtime in work of the brigades achieved the following results: 41% with the first rule and 56% for the second rule.

4. Summary

In this article the author focused on processing a new model of liquidation of downtime in work of the brigades at construction sites. According to the assumptions made neither increasing or reducing employment was possible. It was also impossible to modify the tasks implemented. The goal of the newly developed model was the analysis of the possibilities of making use of the brigades at downtime. The assumption regarding the multitasking of the brigades allows to optimize the construction schedules. In the example shown the downtime were reduced by nearly 50%. In addition, the duration of the whole undertaking was reduced by ca. 10%. In this article the author focused on the reduction of duration of the critical tasks only. The satisfactory results of the calculation achieved confirm that the research related to the presented topic should be continued.

References