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SIMULATION OF TECHNOLOGICAL PROCESSES USING KNOWLEDGE-BASED SEQUENCES

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ABSTRACT

Quick simulation of all viable execution approaches (also known as variants) for a given technological process is very important to the automation of construction processes, particularly in real time decision-making situations. The article deals with two methods of simulating technological processes using knowledge-based sequences. The formation of execution approaches in the first method is based on the "mirror changes" simulation method. The formation of execution approaches in the second method is based on the "larger nominal" simulation method.

KEYWORDS

Sequences simulation, civil engineering, knowledge-based method

1. SITUATION ANALYSIS

Rapid development of computational technologies in recent years has accelerated the use of simulation methods for two principal reasons. First, rapid development of computational technologies has enabled its users to simulate and evaluate many viable approaches to system functioning within a relatively short period of time. This opens new opportunities for the automation of technological processes.

Second, there is now a real need to evaluate technological solutions from many different angles. Considering the financial aspects alone is usually not sufficient when assessing different solutions [1], [5]. In this article, different approaches that can complete a certain technological process are also referred to as variants.

Sequences of technological processes can be simulated using different methods, of which the most popular are the random simulation and the knowledge-based methods.

Random simulation methods are preferable in situations where there is no need for an in-depth analysis of all viable approaches (also known as variants), but some practically achievable solution must be found in a short period of time.

Knowledge-based methods are generally used in situations where the main objective is to find the most rational solution to a given problem. Such methods are particularly useful in situations where the various approaches to the end result must be assessed using not one, but various ratios [5].

Some knowledge-based simulation methods are directly related to the ratio being used to assess different approaches (also known as variants), or to a system of such ratios. Other knowledge-based methods are not dependent on these ratios [2–4]. The methods of this kind can be used for various systems of assessment ratios. Moreover, the methods of this type allow us to determine certain assessment ratios (the values of these ratios are not known before the simulation process). This article presents two simulation methods of this kind.

2. "MIRROR CHANGES" METHOD USED TO SIMULATE SEQUENCES OF TECHNOLOGICAL PROCESSES

If the complex technological process consists of l processes or operations, the sequence variants of this process performance may be presented as a set of natural numbers

$$B = \{ 1, 2, 3, \ \ldots \ , \ j, \ \ldots \ l \}, \qquad (1)$$

where j is the order number of processes in a complex technological process.

Each natural number in this sequence corresponds to a real technological process. The performance sequence of these processes depends on the sequence character and terms. In order to describe all the variants of technological processes and to number adequately each variant, it is convenient to apply a variant matrix, which consists of different possible states of set B.

$$R = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1j} & \cdots & b_{1l} \\ b_{21} & b_{22} & \cdots & b_{2j} & \cdots & b_{2l} \\ \cdots & & & & & \\ b_{i1} & b_{i2} & \cdots & b_{ij} & \cdots & b_{il} \\ \cdots & & & & & \\ b_{m1} & b_{m2} & \cdots & b_{mj} & \cdots & b_{ml} \end{bmatrix}, \qquad (2)$$

where R is the variant matrix of possible sequences of technological processes, j is the technological process order number $j = 1,l$; i is the variant number, $i = 1,m$; m is the total number of possible variants.

It is possible to describe the method for simulation of possible sequence variants of technological processes by the following recurrence formulas.

$$\begin{cases} B^{(i+1)} = \left\{ b_1^{(i+1)}, b_2^{(i+1)} .. b_j^{(i+1)} ..., b_{l-1}^{(i+1)}, b_l^{(i+1)} \right\} \\ S^{(i+1)} = \left\{ s_1^{(i+1)}, s_2^{(i+1)} .. s_j^{(i+1)} ... {}_{l-1}^{(i+1)}, s_l^{(i+1)} \right\} \end{cases}$$

, where

$$\begin{cases} \left[\left(b_j^{(i)} = j \right) \& \left(s_j^{(i)} = 0 \right) \& \left(h^{(i)} = 0 \right) \right], \\ where (j = 1,2,3,...,l), when \, (i = 1); \\ \begin{bmatrix} \left(b_j^{(i+1)} = b_k^{(i)} \right) \& \left(s_z^{(i+1)} = s_z^{(i)} + 1 \right) \& \\ \& \left(s_t^{(i+1)} = 0 \right) \& \left(s_c^{(i+1)} = s_c^{(i)} \right) \end{bmatrix}, \\ where (j = 1,2,3,...,l) \, \& \\ \& \, [(h^{(i+1)} = \min\limits_{s_z^{(i)} < h^{(i+1)}} \{1,2,3,...,l\}) \, \& \, (z = h^{(i+1)})] \, \& \\ \& \, (k = 1,2,3,...,l - z - 1, l, l - 1, l - 2,..., l - z) \\ \& \, (t = 1,2,..., z - l) \, \& \, (c = z + 1, z + 2,..., l), \\ when (1 < i < l!). \end{cases} \qquad (3)$$

The set $B^{(i+1)}$ is the performance variant of a complex technological process, $i+1$ is the number of variant, $S^{(i+1)}$ is a characteristic of state of system being simulated in the $(i+1)$-th variant, $b_j^{(i)}$ is the j-th technological process (according to the order) in the i-th variant, $s_j^{(i)}$ is a conditional unit, characterizing the i-th variant of the complex technological process.

After simulation all the substitutions of technological processes the total number of variants will be equal to $m = l\,!$.

3. "MIRROR CHANGES" METHOD EXAMPLES

Let's assume that a complex technological process consists of 3 constituent processes. In this case, sequences of technological processes variant matrix R simulated by "Mirror changes" method will be:

$$R = \begin{bmatrix} 1 & 2 & 3 \\ 1 & 3 & 2 \\ 2 & 3 & 1 \\ 2 & 1 & 3 \\ 3 & 1 & 2 \\ 3 & 2 & 1 \end{bmatrix}$$

Total number of variants is $m = l\,! = 3\,! = 6$.

4. "LARGER NOMINAL" METHOD USED TO SIMULATE SEQUENCES OF TECHNOLOGICAL PROCESSES

If the first variant of complex technological process can be presented as a set of natural numbers:

$$B^{(1)} = \{1,2,...,j,...,l-1,l\} \tag{4}$$

where l *is* the number of technological processes in the complex technological process.

The second and another "larger nominal" sequence simulation is possible to describe by the following recurrence formula:

$$B^{(i+1)} = \{b_1^{(i+1)}, b_2^{(i+1)}, ..., b_j^{(i+1)}, ..., b_l^{(i+1)}, b_l^{(i+1)}\}, \tag{5}$$

when

$$\sum_{j=1}^{l} b_j^{(i)} \cdot 10^{l-j+1} < \sum_{j=1}^{l} b_j^{(i=1)} \cdot 10^{l-j+1} < \sum_{j=1}^{l} b_j^{(i+2)} \cdot 10^{l-j+1}$$

$B^{(i+1)}$ is the performance variant of complex technological process, $i+1$ is the number of the variant, $b_j^{(i+1)}$ is the j-th technological process (according to the order) in the $i+1$ variant.

5. "LARGER NOMINAL" METHOD EXAMPLE

Let's assume that a complex technological process consists of 4 processes. In this case, sequences of technological processes variant matrix R simulated by "Larger nominal" method will be:

$$R = \begin{bmatrix} 1 & 2 & 3 & 4 \\ 1 & 2 & 4 & 3 \\ 1 & 3 & 2 & 4 \\ 1 & 3 & 4 & 2 \\ . & . & . & \\ 4 & 2 & 3 & 1 \\ 4 & 3 & 1 & 2 \\ 4 & 3 & 2 & 1 \end{bmatrix}$$

Total number of variants is $m = l! = 4\,! = 24$.

6. EVALUATION OF TIME NEEDED FOR CALCULATIONS

Three methods were used to simulate sequences of technological processes: the method of "Mirror changes", the "Larger nominal" method, and the random variant simulation method. Parameters of the computer that was used for these calculations are as follows: Intel Pentium 4, CPU 2,8 GHz, 1,00 GB of RAM. All calculations were done using Visual Basic (VBA) program. The goal of the calculations was to simulate all possible non-repeating sequences of technological processes. All simulated variants were saved into the computer hard disk. The total time needed to simulate sequences of technological processes is presented in **Table 1**.

According to the data in **Table 1**, the "Mirror changes" method gives the best time results. The results of the "Larger nominal" method are very similar to the results of the "Mirror changes" method. The random variant simulation method has the worst time results. The results show that, using the random variant method, an increase in the number of technological processes may quickly

Table 1. Time needed for variant sequence simulation in seconds

The number of technological processes / the number of variants of sequences	"Mirror changes" method	"Larger nominal" method	Random variant simulation method
10 / 3628800	$2{,}83 \cdot 10^{-5}$	$3{,}52 \cdot 10^{-5}$	-
9 / 362880	$2{,}48 \cdot 10^{-5}$	$2{,}75 \cdot 10^{-5}$	-
8 / 40320	$0{,}248 \cdot 10^{-5}$	$0{,}248 \cdot 10^{-5}$	-
7 /5040	$<0{,}24 \cdot 10^{-5}$	$<0{,}24 \cdot 10^{-5}$	0,036
6 / 720	-	-	0,0166
5 / 120	-	-	0,008

increase the time needed to process each additional variant (total time needed to process one variant may quickly approach one second). Therefore, the random variant method is not very useful in practice

7. RESTRICTIONS INFLUENCE INTO SEQUENCES OF TECHNOLOGICAL PROCESSES

When the number of processes is small in a complex technological process, the number of performance sequences is also small. But when the complex process consists of a hundred and more component processes, the number of possible variants of performance sequences may be very large. For instance, the possible number of such variants in a case of 150 processes can reach $5{,}713383956446 \times 10^{262}$. It is quite understandable that simulating such a large number of variants will take an enormous time even when using the latest calculation techniques.

Usually, natural complex technological processes are restricted in respect to the sequence of the individual tasks. Taking into account this fact allows us to significantly reduce the number of simulated variants and thus shorten the time needed to perform the calculations [2].

Let us assume that there exists a restriction on a real-life complex technological process. This restriction does not allow us to complete one technological process before another technological process. In this situation, the total number of variants will be reduced by 50%. If sequences of variants of technological processes are simulated using the methods described in this article, the impossible variants can be forecasted and rejected in variant groups. Once the rejection of the impossible variants is complete, only the possible variants are to be simulated.

8. SIMULATION OF POSSIBLE VARIANTS WITH "MIRROR CHANGES" METHOD TAKING INTO ACCOUNT THE PROCESS SEQUENCE RESTRICTIONS

Let us assume that in a real complex process there exist two interconnected technological processes b_p and b_g. The indices p and g are the order numbers of technological processes in a complex process. In this case the technological process b_g cannot be performed later than b_p $(g<p)$. Thus, the impossible sequence of technological processes in the set B of the complex process will be:

$$B^{(i-1)} = \left\{b_1^{(i-1)}, b_2^{(i-1)}, \ldots, b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_g^{(i-1)}, b_{g+1}^{(i-1)}, \ldots, b_l^{(i-1)}\right\}. \quad (6)$$

In order to simulate a new sequence of the technological process performance and to reject the impossible variants of its performance, we introduce some changes in the set B (6). We carry out the first change of this set by the formula:

$$B^{(i)} = \{b_1^{(i)}, b_2^{(i)}, ..., b_l^{(i)}\} = \{b_1^{(i-1)}, b_2^{(i-1)}, ... b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_l^{(i-1)}, b_{l-1}^{(i-1)}, ... b_{g+1}^{(i-1)}, b_g^{(i-1)}\} \quad (7)$$

Using vector S of the state of the system to be simulated, we find minimal value of j satisfying the condition:

$s_j - j < 0$, where $j = \min(p, p+1, \ldots, l)$.

Taking into account the j index value, we perform the next change of the set B according to the formula

$$B^{(i+1)} = \{b_1^{(i+1)}, b_2^{(i+1)}, ..., b_l^{(i+1)}\} =$$

$$= \{b_1^{(i)}, b_2^{(i)}, ..., b_{j-1}^{(i)}, b_l^{(i)}, b_{l-1}^{(i)}, ..., b_{j+1}^{(i)}, b_j^{(i)}\} \quad (8)$$

The set B described by formula (8) will satisfy the condition $g<p$ in respect of b_p and b_g elements of set.

Other variants of the complex technological process performance sequences are simulated according to the same methods described by recurrence formulas (3) up to the next variant connected with restrictions. Then changes analogous to those described by formulas (6-8) are performed.

When the complex technological process is restricted by some $g<p$ type limitations of the performance sequence, the real number of possible performance variants of the complex process can be determined by empirical formulas:

$$\begin{cases} m_{\max} = l!/x, \\ m_{\min} = l! - 0.5 \cdot x \cdot l!. \end{cases} \quad (9)$$

where x is summary amount of $g<p$ type restrictions.

Sometimes discussing real technological processes we face processes connected with $g \neq p+1$ restriction. In such a case the technological process b_g cannot follow immediately the technological process b_p.

As an example, we can take the concrete pouring process in the complex construction technology. After the concrete pouring is done, the shuttering is removed, but the operations of removing shuttering cannot be carried out on the same site immediately after concrete is poured because a certain amount of time is needed for the concrete to harden. In this case is necessary to plane performing of other tasks until the concrete hardens.

In some cases, it is not possible to perform building operations simultaneously by two tower cranes operating side by side where operation zones of the cranes are somewhat interconnected because the rules of safe work would be violated. In such a situation, until one crane finishes operations at the point of possible approach, the other crane is to move to a safe zone.

When simulating possible sequences of complex technological process according to the methods described by the recurrence formulas (3), the decline of variants connected by these limitations is performed in the same way as in the case of $g<p$ restrictions.

If we describe a technically impossible variant of complex technological process by the formula (6), the first rearrangement can be performed according to the formula:

$$B^{(i)} = \{b_1^{(i)}, b_2^{(i)}, ..., b_l^{(i)}\} =$$

$$= \{b_1^{(i-1)}, b_2^{(i-1)}, ... b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_g^{(i-1)}, b_l^{(i-1)}, b_{l-1}^{(i-1)}, ... b_{g+2}^{(i-1)}, b_{g+1}^{(i-1)}\} \quad (9)$$

Minimal value of j variable is to be found according to the assumption:

$$s_j - j < 0, \text{ where } j = g, p, p+1, \ldots, l. \quad (10)$$

According to the formula already described (8), the last rearrangement of the set $B^{(i)}$ is performed which satisfies the conditions required by the limitation $g \neq p+1$.

9. CONCLUSIONS

1. Gathered information about the computing time of the developed products shows that knowledge-based methods are more effective then random simulation methods. This is particularly true when it is necessary to evaluate all sets of variants of possible sequences of technological processes. The simulation time needed for the knowledge-based methods can be significantly shorter than the time needed for the random variant simulation methods.

2. The comparison of the “mirror changes” and the “larger nominal” methods reveals that the “mirror changes” method is not more effective than the “larger nominal” method.

3. “Mirror changes” method is faster, especially for the long time calculations where the number of technological variants is large. This method collects information about how many variants have been already simulated and how much time is needed to calculate the remaining variants.

4. The methodology used in this article allows the user to evaluate the sequences of technological processes taking into account certain restrictions. This enables the user to save time when simulating sequences of variants. “Mirror changes” method allows to evaluate two types of restrictions: restriction $g \neq p+1$, when technological process b_g cannot follow immediately after the technological process b_p, and restriction $(g<p)$, when technological process b_g cannot be performed later than b_p .

5. Each evaluated restriction $g \neq p+1$, when technological process b_g cannot follow immediately after the technological process $b_{p,}$ allows the user of this method to save up to $100/l$ percent of the time needed for one restriction.

6. Each evaluated restriction $(g<p)$, when technological process b_g cannot be performed later than b_p, allows to user of this method to save up to 50 percent of the time needed for one restriction.

7. In this article, the shortest calculation time is obtained using the “Mirror changes” method. The total time needed to calculate a full set of possible variants for a 10 processes simulation on an Intel Pentium 4 CPU 2,8 GHz and 1,00 GB of RAM computer is equal to $2{,}83 \cdot 10^{-5}$s per one variant.

REFERENCES

[1] Koop G. (2000). Analysis of Economic Data; West Sussex: John Wiley & Sons.

[2] Tamosaitis R. (2001). Simulation of Technological Processes of Civil Engineering Companies. Informatica, Vol.12, No.1, 585-592

[3] Tamosaitis R. (2002). Calendar plans simulation in construction, Vilnius: Technika.

[4] Tamošaitis R. (2004). Virtual time norms and new vista of calander planes simulation. // 8th International conference Modern building materials, structures and techniques (E.K.Zavadskas, P.Vainiūnas, F.M Mazzolani (Ed.)), Vilnius Gediminas Technical university press “Technika”, Vilnius, Lithuania, 283-289.

[5] Zavadskas E. K., Kaklauskas A. (1999) A new Method of Complex Evaluation of Projects Based on Multiple Criteria Analysis and the Principle of Proportionality. 5th Internationale Conference "Integrating Fedinology and Human Decisions: Global Bridges into the 21 th Century". Decision Science Institute, 1999 Athens. Proceedings, Vol. 2. Edited by Dimitris K. Despotis, Constantin Zoporinidis, Athens - Greece. 2051-2053.