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# Simulation of Technological Processes of Civil Engineering Companies

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**Abstract.** Method of simulation of technological processes of civil engineering companies allows evaluate quality of the organizational variants by multicriterial estimation methods (Zavadskas *et al.*, 1995). Simulation methods allow to design a rational work programme according to the financial, technological and organizational parameters.

It is quite understandable that simulation of work programmes of civil engineering companies will take enormous time even using the latest calculation techniques. Counters often have problems with a big amount of combinations of technological processes. Usually, real programme is restricted in respect of its performance sequences. The latter fact has been taken into account for simulation different combinations and sequences of works included in work programme. It allows to decrease the amount of calculating considerably.

**Key words:** processes, simulation, methods, computing time, multicriterial estimation.

## 1. The Concept of Simulation

Rapid development of computational technology in recent years has accelerated the application of simulation methods because of two principal reasons. First, the necessity is felt to evaluate technological solutions in different aspects because the only financial aspect is insufficient for assessing solutions (Kallberg *et al.*, 1982). Secondly, a rapidly developing computational technology allows to simulate and to evaluate many possible variants of functioning the system to be simulated in a comparatively short span of time. It opens up new vistas for practical applications of simulating (Taylor and Moore, 1980).

Every object in a work programme is like a work zone. Civil engineering companies often repeat technological processes in some work zones. For performing these processes, special teams of workers are organized and tasks are performed by flows. Rhythmical and not rhythmical flows can be used (*Code of Practice for Project Management for Construction and Development*; Lock, 1995).

The complex includes $n$ job zones. Building operations are to be performed by some flows ($m$) of special workers. Such a flow of some specialized teams can be called a complex flow. Fig. 1 is shown model organization of works.

To change sequences of technological process in job zone is difficult but usually we can simulate sequences of work zones.

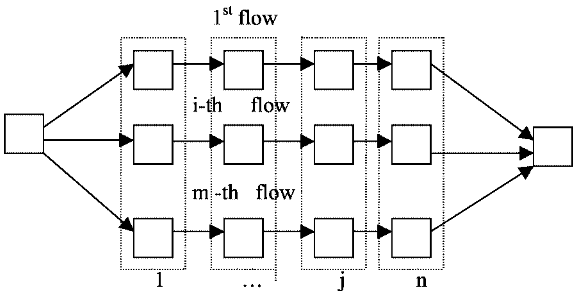


Fig. 1. Model organization of works (where $j$ is the number of job zone $(j = \overline{1,n})$, $i$ is the flow number $(i = \overline{1,m})$.

## 2. Method for Simulation the Sequence of Technological Processes

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

$$B = \{1, 2, 3, \ldots, j, \ldots l\}, \tag{1}$$

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

Each natural number in this set corresponds to a real technological process. The performance sequence of these processes depends on the sequence character of the set 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 $B$.

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

where $R$ is the variant matrix of possible sequences of technological processes, $j$ is the number of technological process order number $j = \overline{1,l}$; $i$ is the variant number, $i = \overline{1,m}$; $m$ is the common possible variant number of technological process sequence.

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

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

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

$$\begin{cases} \left[\left(b_j^{(i)}=j\right)\&\left(s_j^{(i)}=0\right)\&\left(h^{(i)}=0\right)\right], \text{ when } (j=1,2,3,\ldots,l), \text{ when } (i=1); \\ \left[\left(b_j^{(i+1)}=b_k^{(i)}\right)\&\left(s_z^{(i+1)}=s_z^{(i)}+1\right)\&\left(s_t^{(i+1)}=0\right)\&\left(s_c^{(i+1)}=s_c^{(i)}\right)\right], \text{where} \end{cases} \quad (3)$$

$$(j=1,2,3,\ldots,l)\&\left[\left(h^{(i+1)}=\min_{s_z^{(i)}<h^{(i+1)}}\{1,2,3,\ldots,l\}\right)\&(z=h^{(i+1)})\right]$$
$$\&(k=1,2,3,\ldots,l-z-1,l,l-1,l-2,\ldots,l-z)$$
$$\&(t=1,2,\ldots,z-1)\&(c=z+1,z+2,\ldots,l), \text{ when } (1<i<l!).$$

The set $B^{(i+1)}$ is the performance variant of complex technological process $i+1$, the set $S^{(i+1)}$ is a characteristic set of state of system being simulated in the $(i+1)$-th variant, the quantity $b_j^{(i)}$ 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.

Let's assume that a complex technological process consists of 3 constituent processes. In this case the matrix $R$ of possible technological sequence variants simulated after the above-mentioned methods 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 $m=l!=3!=6$.

## 3. The Influence of Restricted Sequences

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 100 and more component processes, in such a case the number of possible variants of performance sequences may be very large. For instance, the possible number of such variants in case of 150 processes can reach 5,713383956446 $\times$ $10^{262}$. It is quite understandable, that simulating such a number of variants will take enormous time even using the latest calculation techniques. Usually natural complex technological processes are restricted in respect of their performance sequences and this fact should be taken into account. It allows to decrease considerably the amount of calculating the technological operations.

Let us assume that there exists a restriction on a real complex process which does not allow to perform a technological process earlier than another process of composite technological processes finishes; in such a case the number of variants will decrease by 50%. If the sequences of a complex technological process are simulated according to the methods described by Eq. 3, these impossible variants of the complex technological process performance can be forecast and rejected in groups and only the possible variants of the complex process are to be simulated.

## 4. Simulating the Possible Variants of the Complex Technological Process Taking into Account the Restrictions on the Work Performance Sequence

Let's assume that in a real complex process there exist two interconnected technological processes $b_p$ and $b_g$. The indices *p, g* are the 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:

$$B^{(i-1)} = \left\{b_1^{(i-1)}, b_2^{(i-1)}, \dots, b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_g^{(i-1)}, b_{g+1}^{(i-1)}, \dots, b_l^{(i-1)}\right\}. \quad (4)$$

In order to simulate a new sequence of technological process performance and to reject the impossible variants of its performance, we introduce some changes in the set $B$ Eq. 4. The first change of this set we carry out by the formula:

$$\begin{aligned} B^{(i)} &= \left\{b_1^{(i)}, b_2^{(i)}, \dots, b_l^{(i)}\right\} \\ &= \left\{b_1^{(i-1)}, b_2^{(i-1)}, \dots, b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_l^{(i-1)}, b_{l-1}^{(i-1)}, \dots, b_{g+1}^{(i-1)}, b_g^{(i-1)}\right\}. \end{aligned} \quad (5)$$

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

$$s_j - j < 0, \quad \text{where} \quad j = \min(p, p+1, \dots, l). \quad (6)$$

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

$$\begin{aligned} B^{(i+1)} &= \left\{b_1^{(i+1)}, b_2^{(i+1)}, \dots, b_l^{(i+1)}\right\} \\ &= \left\{b_1^{(i)}, b_2^{(i)}, \dots, b_{j-1}^{(i)}, b_l^{(i)}, b_{l-1}^{(i)}, \dots, b_{j+1}^{(i)}, b_j^{(i)}\right\}. \end{aligned} \quad (7)$$

The set $B$ described by (7) will satisfy the condition in respect of $b_p$ and $b_g$ elements of $g < p$ set.

Other variants of the complex technological process performance sequences are simulated according to the same methods described by recurrence (3) up to the next variant connected with restrictions. Then changes analogous to those described by (4)–(7) 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

$$\begin{cases} m_{\max} = l!/x, \\ m_{\min} = l! - 0.5 \cdot x \cdot l!, \end{cases} \quad (8)$$

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

When these formulas are expressed graphically (Fig. 2), the real number of the complex technological process performance variants will be in the graph part restricted by the curve and straight line. As the graph shows, under four restrictions of the above-mentioned character, the number of possible variants of the complex technological process performance will not exceed 10% of the total number of variants disregarding the restrictions.

It is difficult to determine the real number of complex technological process performance variants because we do not know how much one limitation is connected with another one.

Let's assume that a technological process consists of 4 constituent technological processes $\{1, 2, 3, 4\}$, connected by the following limitations: the 2nd technological process cannot be performed earlier than the 3rd one and the 3rd and 4th processes not earlier than the first one.

In this case the calculated number of complex technological process performance possible variants, without taking into account the limitations, is 24, but paying regard to the limitations, is consequently $m_{\min} = 0$, $m_{\max} = 8$ . Thus, the actual number of complex technological process possible performance variants is 6.

Therefore the possible variants of the complex technological process performance sequences after evaluating $g < p$ type limitations are:

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

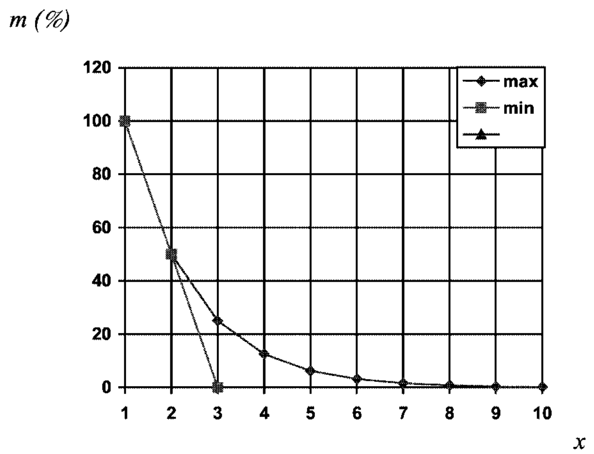


Fig. 2. Dependency of the quantity of complex technological process performance sequences on the number $x$ of $g < p$ type restrictions.

Sometimes, when 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 concreting processes in the complex construction technology. After concreting the shuttering is removed, but the operations of removing shuttering cannot be carried out on the same site immediately after concreting, because a definite span of time is needed for concrete hardening. In this case a team of workers will be forced to perform 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. Under such circumstances, 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 methods described by the recurrence (3), the decline of variants connected by these limitations is performed in the same way as in the case of $g < p$ restrictions.

If a technically impossible variant of complex technological process we describe by the (4 ), the first rearrangement is performed according to the formula:

$$\begin{aligned} B^{(i)} &= \left\{b_1^{(i)}, b_2^{(i)}, \ldots, b_l^{(i)}\right\} \\ &= \left\{b_1^{(i-1)}, b_2^{(i-1)}, \ldots, b_{p-1}^{(i-1)}, b_p^{(i-1)}, b_g^{(i-1)}, b_l^{(i-1)}, b_{l-1}^{(i-1)}, \ldots, b_{g+2}^{(i-1)}, b_{g+1}^{(i-1)}\right\}. \end{aligned} \quad (9)$$

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

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

According to the formula already described (7), the last rearrangement of the set $B^{(i)}$ is performed and thanks to it a new variant is formed which satisfies the conditions required by the limitation $g \neq p+1$.

In this case one limitation diminishes the number of variants to be simulated by $G$ value:

$$G = l!/l, \quad (11)$$

or by percentage expression:

$$G\% = 100/l. \quad (12)$$

In Fig. 3, the influence of $g \neq p+1$ type on the number of variants to be simulated is presented in a graphical form, when the complex technological process, including five technological processes, is connected by some limitations of $g \neq p+1$ type.

Let's assume that the complex technological process consists of four consistent technological processes $\{1, 2, 3, 4\}$ connected by the following restrictions. The third technological process cannot follow in succession the first technological process and the second process cannot go immediately after the 4th process.

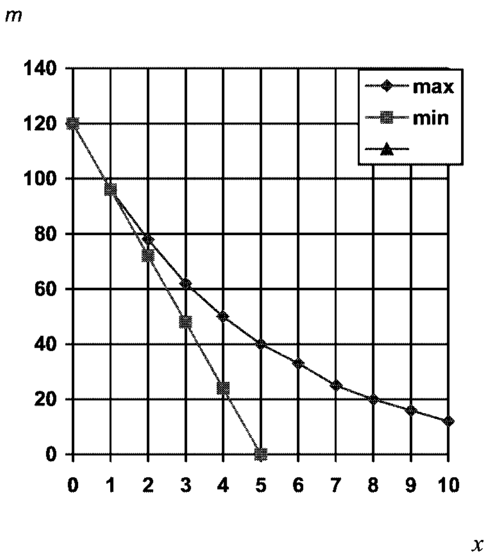


Fig. 3. Dependency of the quantity of complex technological process performance sequences on the number $x(l = 5)$ of $g \neq p + 1$ type limitations.

The calculated number of possible performance variants of a complex technological process, without evaluating limitations, is 24, whereas after evaluating the limitations $m_{min} = 12$, $m_{max} = 14$. The actual number of possible performance variants of the complex technological process is 14.

In this case, possible performance sequence variants of the complex technological process will be:

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

We can conclude from the graphs presented in Fig. 2 and Fig. 3 that the restriction $g \neq p + 1$ does not influence greatly the total variant number as that of $g < p$. Nevertheless, the decrease of variants to be simulated is considerable, when the number of restrictions is larger.

## 5. Concluding Remarks

This paper presents new methods for determining amount of combinations of processes in real work programme and method for simulation different combinations and sequences of works included in work programme. Simulation methods allow to save more then 90% computing time for simulation process.

Work programme simulation methods allow for civil engineering companies according to the financial, technological and organizational parameters to find a rational work programme and to evaluate quality of organizational variants by multicriterial estimation methods.

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## Statybos kompanijų technologinių procesų imitacinis modeliavimas

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Straipsnyje pateikiami technologinių procesų imitacinio modeliavimo metodai leidžia įvertinti praktikoje dažniausiai pasitaikančius technologinių procesų eiliškumo apribojimus ir tokiu būdu ženkliai sumažinti galimų technologinių procesų atlikimo variantų imitacinio modeliavimo trukmę. Tuo pačiu, pateikti imitacinio modeliavimo metodai sukuria galimybę technologinių procesų atlikimo variantus vertinti atsižvelgiant į vertintojui aktualius kriterijus, tokius kaip trukmė, kaina, patikimumas ir t.t., naudojant daugiatikslio vertinimo metodus.