

# Numerical modeling of technological volume between adjacent construction processes

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**Abstract.** One of the approaches to improving the reliability of organizational and technological solutions in building the objects of different purpose is the estimation of interrelation between technological processes. To measure the quality of the estimation, one needs its quantitative measurement. Therefore, the authors set the aim to express the estimation of interrelation between technological processes through the quantitative characteristics. The researchers propose a method for determining the value of the minimum volume, characterizing the quantitative assessment of the relationship of technological processes, developed by using the method of the analysis of hierarchies. The criteria and factors influencing the determination of minimum volume are identified. The composition of the specialists of building production, attracted for determining the minimum volume, is recommended. The practical implementation of the developed method for the determination of the minimum volume value is demonstrated. The formal evaluation of the relationship between technological processes, obtained by means of the developed calculation methods of quantitative assessment, allows solving the problem of determining the maximum alignment processes for the adoption of organizational and technological solutions in object building.

## 1. Introduction

The building industry has always been faced with the problem of improving the reliability of organizational and technological solutions in the construction of objects for different purposes. Making organizational and technological decisions based on the estimation of the connections of technological processes is one of the ways of addressing this.

It has been long accepted that organizational reliability of the decisions made in the construction are based on the technology of designing buildings and structures.

Currently, the basis for the formation of organizational and technological solutions continues to be an approach based on the principles of system engineering construction [1,2]. In the context of this direction, domestic specialists have developed various ways to improve the reliability of organizational and technological solutions. They include methods for reducing organizational and technological processes in groups undistinguished in terms of reliability [3], the use of the method of reliable coordination system [4], "project approach", taking into account the market basis of construction design [5], methods for improving reliability taking into account the risk in the design of the organization, technology and construction management in conditions of uncertainty [5], the



development of construction organization projects by creating an optimal management plan for the construction company [6]. Methods based on the strategy of buffer management [7], the creation of an integrated metric for quantifying the stability of interdependent systems [8], ensuring the sustainability of processes in construction [9-11], the management of construction processes using methods of analysis and evaluation of programs, statistical tests [12-16], methodological foundations of the design of organizational and technological processes are identified from foreign studies, providing system engineering coordination of functional subsystems and information-analytical tasks in information-computing sphere [17].

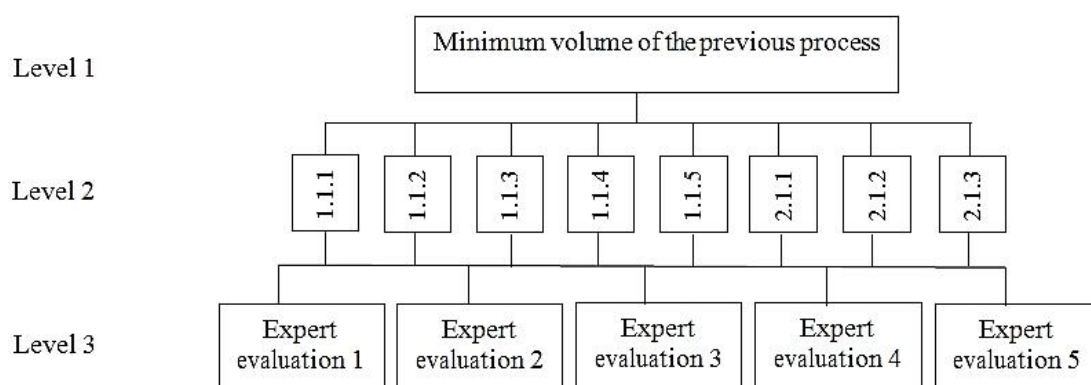
As for quantitative estimation of technological connections between building processes, the need for such assessment is traced in the analysis of the process of improving network models from simple deterministic to deterministic generalized temporal types, when the adequacy of the model to the real conditions you specify additional relations between processes, allowing to describe in a model the requirements of a maximum allowable combination of works by fixing the state's leading contractors, opening the front of the subcontractors.

Theoretical research in the field of determining the quantitative relations between interrelated works has been developed in [18-20]. The result of research in these works is to identify the quantitative characteristics of the assessment of the technological relationship of related works. This parameter is a minimum, technologically necessary volume that allows you to plan and organize the implementation of subsequent work. This assessment has the property of determinism throughout the construction period and determines the duration of the temporary area of work. The importance of the use of this magnitude to ensure the sustainability of the organizational and technological solutions determined the necessity of development of methods of its calculation.

## 2. Developing a method of quantitative evaluation of connected technological processes

In order to identify a minimum volume to characterize a qualitative evaluate of connected technological processes, a method of hierarchy analysis [21] is used that establishes a relation between a volume and other affecting factors. The development of the methods takes several stages.

*Stage 1.* This stage involves decomposition of the task into more simple components and their hierarchical presentation. As a result, there is a hierarchy that includes the top (aim), intermediate levels (criteria specifying the aim), lower level (a set of alternatives to be estimated in respect to the second level criteria and a solution option for the main task to be chosen) (Figure 1).



**Figure 1.** Decomposition of identifying a minimum volume into a hierarchy.

For Level 2 there are eight criteria that a minimum volume of the previous process depends on (Table 1). These criteria are divided into two factors: technological and organizational [22].

**Table 1.** Criteria used to identify a minimum volume of the previous process for a time slot for that to follow.

Factor	Criteria of level 2
Technological	1.1.1 Maintenance of work sites 1.1.2 Constantly running production 1.1.3 Labour intensity 1.1.4 Technological operation 1.1.5 Health and safety
Organizational	2.1.1 Resource base 2.1.2 Spaces for workers, equipment and mechanisms 2.1.3 Spaces for the materials

It is suggested that the following experts directly involved in the construction process are included in the group: 1<sup>st</sup> expert is the head of the construction site; 2<sup>nd</sup> expert is the construction work supervisor at a particular site; 3<sup>rd</sup> expert is a specialist in a particular type of works; 4<sup>th</sup> expert is a foreman of the brigade in charge of the previous work; 5<sup>th</sup> expert is a foreman of the brigade in charge of the works to follow.

There can also be specialists included in the expert group who are in some way involved in the construction process: planning department economist (expert 6), construction material department staff (expert 7), accounting staff (expert 8), the designer of the structure (expert 9 if it is individually supervised during the construction). It should be noted that the involvement of the above specialists in the group will cause disruptions to decision-making on one hand and on the other hand allow a problem at hand to be tackled with in a much more effective way. A group estimation can be relied on provided all the experts are equally committed to finding the solution.

*Stage 2.* There are a lot of matrices designed for a paired comparison of each of the lower levels with a matrix for each element of the adjacent upper level. The elements of each level are compared in pairs in terms of how they influence the adjacent upper level.

Paired comparisons here mean one element is dominated by another. The scale presented in Table 2 is used [21].

**Table 2.** Scale of estimates.

Relative humidity	Definition	Explanations
1	Equal humidity	Equal contribution towards achieving the aim
3	One is reasonably superior to another	Experiences and assumptions make one activity slightly superior to another
5	Significant or great superiority	Experiences and assumptions make one activity greatly superior to another
7	Great superiority	One kind of activity is made so superior that it becomes practically significant
9	Very great superiority	There is significant evidence showing one kind of activity being greatly superior to
2, 4, 6, 8	Intermediate solutions between two corresponding assumptions	Used as a compromise

It is recommended that relative humidity is compared starting with the upper left elements of the matrix. If the elements on the left are more significant than those above, a positive whole number

(from 1 to 9) is written in the grid, otherwise it is an inverse number (fraction). Relative humidity of any of the elements compared with itself is 1 and therefore the diagonal of the matrix (elements from the left upper corner to the bottom right one) only include unities. The symmetrical grids are filled in with the inverse values.

Stage 3. A group of matrices of paired comparisons make up a set of local priorities that describe a relative influence on a number of elements on the adjacent upper level. Each certain priority is calculated. In order to do that, a number of Eigen vectors is calculated for each matrix and the result is then standardized to a unit to estimate a priority vector for each line of the matrix.

In order to calculate a priority vector, an algorithm is used which is in Table 3 (using the example of a matrix with four compared elements).

**Table 3.** Calculation order for a priority vector.

Matrix					Calculation of an Eigen vector using the lines	Priority vector estimate
A1	A2	A3	A4			
A <sub>1</sub>	a <sub>11</sub>	a <sub>12</sub>	a <sub>13</sub>	a <sub>14</sub>	$\sqrt[4]{a_{11}a_{12}a_{13}a_{14}} = a$	$\frac{a}{a+b+c+d} = x_1$
A <sub>2</sub>	a <sub>21</sub>	a <sub>22</sub>	a <sub>23</sub>	a <sub>24</sub>	$\sqrt[4]{a_{21}a_{22}a_{23}a_{24}} = b$	$\frac{b}{a+b+c+d} = x_2$
A <sub>3</sub>	a <sub>31</sub>	a <sub>32</sub>	a <sub>33</sub>	a <sub>34</sub>	$\sqrt[4]{a_{31}a_{32}a_{33}a_{34}} = c$	$\frac{c}{a+b+c+d} = x_3$
A <sub>4</sub>	a <sub>41</sub>	a <sub>42</sub>	a <sub>43</sub>	a <sub>44</sub>	$\sqrt[4]{a_{41}a_{42}a_{43}a_{44}} = d$	$\frac{d}{a+b+c+d} = x_4$

Stage 4. It is determined how a hierarchy is arranged. Deviations are identified using arrangement index AI. The formula is used to calculate AI

$$AI = \frac{-n}{n-1}$$

where  $\lambda$  is the largest comparison matrix;  $n$  is a number of compared elements.

In order to obtain  $\lambda$  each column of the matrix should be first summed and the sum of the first column is multiplied by a priority vector in the first line of the matrix, the sum of the second column by the second one, etc. Then the numbers are summed. If AI is divided into a number corresponding with a matrix of the same order (Table 4 [21]), we get an arrangement ratio AR. This should be no more than 20 % of  $\lambda$ .

**Table 4.** Random arrangement of the matrix.

Size of the matrix	1	2	3	4	5	6	7	8	9	10
Random arrangement	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If the result is not what it is expected to be, a hierarchy is reviewed and the aims are made more structured.

Stage 5. The priorities are synthesized using the synthesis principle. Local priorities are again multiplied by a priority of a corresponding criterion of the upper level and summed according to each element according to the criteria influenced by the element. This gives a general or global priority of each element of level 2 which is then used to weigh the local priorities of the elements compared in respect to it as a criterion and those on the lower level.

### 3. Example of practical applications for the method of quantitative estimation of the connection of technological processes

In order to show a quantitative estimation of the connection of technological processes, let us consider a certain task. A minimum volume  $V_{min}$  of a technological process of laying a brick wall to start plastering it. For example, those were the expert estimates:

- expert N 1 — 10 % of the total amount of laying the wall;
- expert N 2 — 15 % of the total amount of laying the wall;
- expert N 3 — 7 % of the total amount of laying the wall;
- expert N 4 — 12 % of the total amount of laying the wall;
- expert N 5 — 17 % of the total amount of laying the wall.

Table 5 shows a matrix of paired comparisons for level 2, priority vectors, Eigen values  $\lambda_{max}$ , arrangement index, arrangement ratio.

**Table 5.** Calculating  $V_{min}$ : matrix of paired comparisons for level 2.

Level 2 criterion	1.1.1	1.1.2	1.1.3	1.1.4	1.1.5	2.1.1	2.1.2	2.1.3	Priority vector
1.1.1	1	5	3	7	6	6	1/3	1/4	0.173
1.1.2	1/5	1	1/3	5	3	3	1/5	1/7	0.054
1.1.3	1/3	3	1	6	3	4	6	1/5	0.188
1.1.4	1/7	1/5	1/6	1	1/3	1/4	1/7	1/8	0.018
1.1.5	1/6	1/3	1/3	31	1/2	1/5	1/5	1/6	0.031
2.1.1	1/6	1/3	1/4	4	2	1	1/5	1/6	0.036
2.1.2	3	5	1/6	7	5	5	1	1/2	0.167
2.1.3	4	7	5	8	6	6	2	1	0.333
									$\lambda_{max} = 9.669$
									AI=0.238
									AR=0.169

Paired comparisons are then introduced for the third level of the hierarchy showing a comparative expert estimate in respect to each criterion of the second level. The results are illustrated in eight matrices of paired comparisons using one of Level 2 criteria. As an example, a matrix of paired comparisons for the criterion 1.1.1 is introduced (Table 6).

**Table 6.** Matrix of paired comparisons for the criterion 1.1.1 of level 2.

Criterion 1.1.1	Expert1	Expert 2	Expert 3	Expert 4	Expert 5	Priority vector
Expert 1	1	6	8	1/4	1/5	0.17
Expert 2	1/6	1	7	1/6	7	0.34
Expert 3	1/8	1/7	1	5	3	0.22
Expert 4	4	6	1/5	1	1/4	0.15
Expert 5	5	1/7	1/3	4	1	0.14
						$\lambda_{max} = 13.1$
						AI = 2.025
						AR = 1.81

At the next stage using the synthesis principle, general priorities of the estimates of each expert according to the algorithm of stage 5 (Table 7).

For example, for expert 1 we have:

$$0,173 \cdot 0,17 + \frac{1}{4} + 0,333 \cdot 0,21 = 0,3$$

**Table 7.** Table of the general priorities of the expert estimates.

Expert estimate	1.1.1 (0.173)	1.1.2 (0.054)	1.1.3 (0.188)	1.1.4 (0.018)	1.1.5 (0.031)	2.1.1 (0.036)	2.1.2 (0.167)	2.1.3 (0.333)	General priorities
N 1	0.17	0.23	0.06	0.24	0.74	0.26	0.65	0.21	0.3
N 2	0.34	0.75	0.41	0.03	0.33	0.18	0.01	0.21	0.28
N 3	0.22	0.05	0.27	0.56	0.07	0.02	0.29	0.25	0.26
N 4	0.15	0.71	0.19	0.31	0.86	0.01	0.71	0.15	0.32
N 5	0.14	0.65	0.43	0.47	0.14	0.56	0.62	0.14	0.35

A criterion with the highest priority (0.35) is chosen and the initial value is calculated, i.e. a minimum volume  $V_{\min}$  of a technological process of laying a brick wall to start plastering it.

#### 4. Conclusions

Research of the organization of building construction allowed us to identify a pattern of using estimates of the connection of technological processes in dealing with improving the reliability of organization and technology solutions in the construction of structures of different purposes. A method is presented for identifying a quantitative estimate of the connection of technological processes, which is a minimum technologically necessary volume of a previous process which allows one to plan and organize the way a technologically connected process is performed. A method of hierarchy analysis has been used for the first time to calculate a quantitative estimate of the connection of technological processes which allows one to consider all the technological and organizational factors and this describe the connection of the processes.

The developed method allows timely estimates of the connection of technological processes to deal with organizational and technological solutions while setting up the dates for works to be carried out, scheduling construction works in technological records, etc. without it being too labour-intensive considering certain conditions in a construction site and involving experts chosen using the method suggested.

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