# TECHNOLOGY AND ORGANIZATION OF CONSTRUCTION

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*Ufa State Oil Technological University*
*PhD in Engineering, Assoc. Prof. of Dept. of Technological Machines and Equipment*
*Z. R. Mukhametzyanov*
*Russia, Ufa, tel.: +7-917-780-35-05; e-mail:* zinur-1966@mail.ru
*Voronezh State University of Architecture and Civil Engineering*
*D.Sc. in Engineering, Prof., Head of Dept. of Heat and Gas Supply and Oil and Gas Business V. N. Melkumov*
*Russia, Voronezh, tel.: (473)271-53-21, e-mail: ser.chu@mail.ru*

Z. R. Mukhametzyanov, V.N. Melkumov

## CALCULATION METHOD OF QUANTITATIVE ESTIMATION OF TECHNOLOGICAL CONNECTIONS BETWEEN BUILDING PROCESSES

**Statement of the problem.** One of the approaches to improving the reliability of organizational and technological solutions in building of objects of different purpose is the estimation of interrelation between technological processes. Measuring the quality of the estimation quantitative measurement is necessary. Therefore the interrelation of technological processes through the quantitative characteristics should be estimated.

**Results.** A method of determining a minimum volume characterizing the quantitative assessment of the relationship between technological processes developed using the method of analysis of hierarchies is proposed. The criteria and factors influencing the determination of minimum volume are identified. The team of building industry specialists of building production to be employed to determine a minimum volume is recommended. The practical realization of the developed method of determining a minimum volume is shown.

**Conclusions.** A formal evaluation of a relationship between technological processes was obtained using the developed calculation methods of quantitative assessment allows one to solve the problem of determining a maximum alignment processes for the adoption of organizational and technological solutions in the construction of objects.

**Keywords:** organizational and technological solutions, construction process, quantitative estimation, method of analysis of hierarchies, technological factor, organizational factor, minimum volume.

## 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 purpos-

es. 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. The theory of organizing construction process based on this principle is complex and has been modified by V.A. Afanasiev, A.A. Afanasiev, S.N. Budnikov, I.G. Galkin, A.A. Gusakov, L.G. Dikman, L.V. Kievskiy and other scientists in this country [1—3]. As for a quantitative estimation of technological connections of construction processes, this kind of estimation becomes necessary in the analysis of the processes of improving network models from simplest determined ones to general determined temporary ones when in order to make a model more viable, additional connections of the processes are introduced to describe the requirements for a maximum acceptable combination of works by recording the current state of the current works to open up a time slot for those to follow.

The theoretical research into quantitative connections between joint works was taken to a new level by the developer of a model of objective technological connections Ye.V. Gusev. The principle of designing this construction model is based on “a qualitative and quantitative estimation of technological connections between works that are crucial to planning the volume at the start and end of the works depending on the state of the former” [4, 5].

In this approach a quantitative estimate is a minimum, technologically necessary volume that allows planning and organizing works to be further carried out. A certain method for determining this volume has not been developed yet and this is still a current issue.

**1. 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 [6] 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) (Fig.).

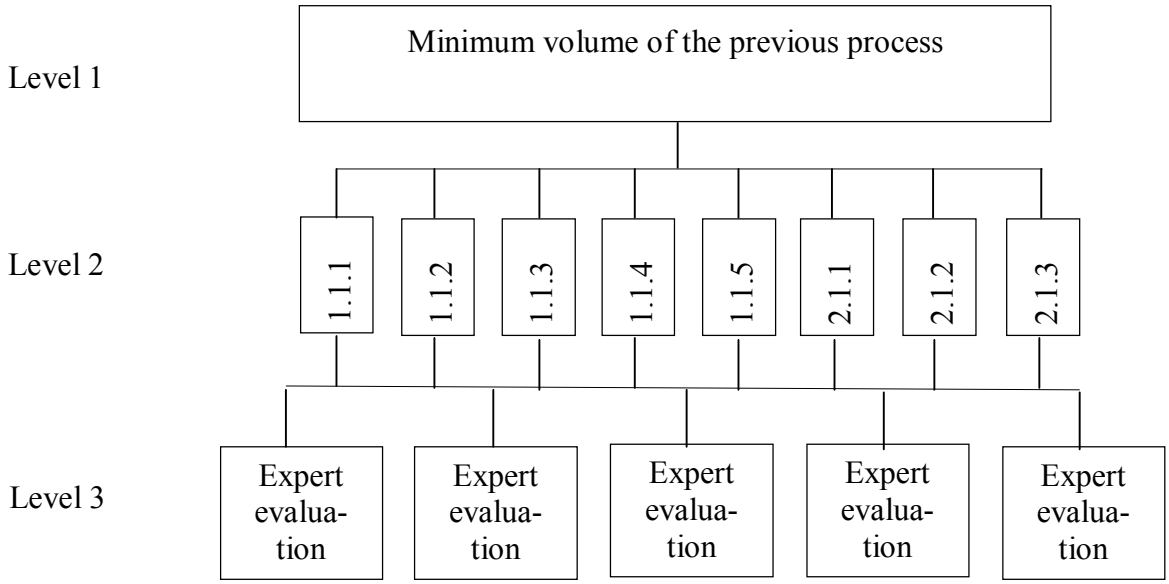


**Fig.** Decomposition of identifying a minimum volume into a hierarchy

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 [7].

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<br>1.1.2. Constantly running production<br>1.1.3. Labour intensity<br>1.1.4. Technological operation<br>1.1.5. Health and safety |
| Organizational | 2.1.1. Resource base<br>2.1.2. Spaces for workers, equipment and mechanisms<br>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: 1st expert is the head of the construction site; 2nd expert is the construction work supervisor at a particular site; 3rd expert is a specialist in a particular type of works; 4th expert is a foreman of the brigade in charge of the previous work; 5th 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 (see Fig. 2). 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 [6].

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 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 another |
| 2, 4, 6, 8 | Intermediate solutions between two corresponding assumptions | Used as a compromise |

Table 3

Calculation order for a priority vector

| Matrix | | | | | Calculation of an Eigen vector using the lines | Priority vector estimate |
|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $\sqrt[4]{a_{11}a_{12}a_{13}a_{14}} = a$ | $\frac{a}{a+b+c+d} = x_1$ |
| $A_1$ | $a_{11}$ | $a_{12}$ | $a_{13}$ | $a_{14}$ | | |
| $A_2$ | $a_{21}$ | $a_{22}$ | $a_{23}$ | $a_{24}$ | $\sqrt[4]{a_{21}a_{22}a_{23}a_{24}} = b$ | $\frac{b}{a+b+c+d} = x_2$ |
| $A_3$ | $a_{31}$ | $a_{32}$ | $a_{33}$ | $a_{34}$ | $\sqrt[4]{a_{31}a_{32}a_{33}a_{34}} = c$ | $\frac{c}{a+b+c+d} = x_3$ |
| $A_4$ | $a_{41}$ | $a_{42}$ | $a_{43}$ | $a_{44}$ | $\sqrt[4]{a_{41}a_{42}a_{43}a_{44}} = d$ | $\frac{d}{a+b+c+d} = x_4$ |

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

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

where λ is the largest comparison matrix; *n* is a number of compared elements.

In order to obtain λ 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 [6]), we get an arrangement ratio AR. This should be no more than 20 % of λ.

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.

**2. 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 |
| | | | | | | | | | $\lambda_{max} = 9.669$ |

End of Table 5

| 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 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | *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:

$$0,173 \times 0,17 + \ldots + 0,333 \times 0,21 = 0,3.$$

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.

**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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