The aggregation method of inhibiting factors in construction

A O Alekseev\(^1\), V S Gladkikh\(^1\), U V Aftahova\(^1\), A G Aftahov\(^1\), O V Takhumova\(^2\)*

\(^1\)Perm National Research Polytechnic University, 29, Komsomolsky Ave., Perm, 614990, Russia
\(^2\)Kuban State Agrarian University named after I.T. Trubilin, 13, Kalinina Street, Krasnodar, 350044, Russia

E-mail: takhumova@rambler.ru

Abstract. The article presents a new methodology for the complex assessment of factors that restrict working conditions, which is based on matrix mechanisms of complex assessment, allowing to take into account heterogeneous complexity factors. As criteria for determining the cramped working conditions, the following are used: the mass and dimensions of the inventory, their number and the complexity of work to prepare the workplace for construction and installation work. The presented approach is able to take into account any factors’ combination, which makes it possible to abandon the existing fixed number of coefficients. Illustrated examples are shown and that clearly demonstrates the methodology for assessing the complexity of construction and installation work. The proposed method can be used in the management of construction projects, to adjust the cost of work, etc. The screen forms of the software module created specifically to provide a comprehensive assessment of complexity factors are demonstrated.

1. Introduction

Construction and installation work can be performed under various conditions, including the non-standard ones, in which the work is carried out at a slower pace, or the complexity of the work increases, this may be due to the need to prepare the workplace, for example, due to poor lighting, clutter of the room with equipment or furniture, etc. Such conditions are usually called constrained, and the factors leading to delays in work are the factors that constrain working conditions.

For example, according to J. Leea, in the construction of multi-storey and low-rise buildings in Taiwan, the builders are faced with the problem of the wind influence of the upper floors, that is much higher than on the lower ones. This leads to an increase in construction time and the accidents’ likelihood. In addition, in view of the growing number of atypical high-rise buildings, it is difficult to quickly assemble the traditional existing form of shuttering, additional work appears due to the changes that occur as the number of floors increases, thereby, again, delaying the construction period and increasing its cost [1]. According to O. Oyeyipo, the construction time and, as a result, its cost is influenced by the number of stakeholders. The more complex a project is, the more it needs to be coordinated with a large number of stakeholders. This means that stakeholders expose construction projects to varying degrees of risk and uncertainty during the construction process [2]. M. Adamu believes that if the principles of “total cost, efficiency and schedule” are followed during the construction of the project, then the implementation of the project can be carried out with great risks. That cannot be said about the inclusion of the lean production principles in the construction process, thereby it is
possible to achieve a ratio of price and quality, i.e., to take into account all the factors that may affect
the construction course before the project is finally approved for work [3]. The workers of a culvert in
central Feldafing faced the constrained working conditions when they were forced to repair it. On the
one hand, public transport should have an unrestricted passage over this structure, on the other hand,
from the point of view of water management, the cross section of the canal can only be slightly reduced.
In addition, private land passes through the canal, so the owners should experience as few restrictions
as possible. All these factors undoubtedly affected the cost and time required for the repair [4]. S.
Helmstädtter believes that local conditions, environmental requirements, technical and economic aspects,
changes in logistics and regional experience should be taken into account when choosing the
construction methods and their options. This will undoubtedly leave its mark on the cost of construction
and its timing [5]. The authors agree with the opinions of experts that when planning the construction
work, it is necessary to take into account local conditions, including regional programs for the
sustainable development, which is confirmed by the studies in the field of justification of directions for
increasing the environmental sustainability of construction production [6, 7].

It is important to note that at present, both in Russia and in other countries, as a rule, in the regulatory
and technical documents and standards, a fixed list of conditions restricting working conditions is
defined, but in practice, the work can be performed with a simultaneous combination of several
complexity factors. Therefore, it is required to develop a universal methodology for the comprehensive
assessment of factors constraining working conditions. This determined the goal and objectives of this
study.

2. Methods
To take into account modern complexity factors, it is proposed to use matrix mechanisms of complex
assessment (hereinafter – MMCA). MMCA advantage among other mechanisms is that it is possible to
evaluate and compare with each other heterogeneous criteria, by transferring them from the phase space
to qualimetric (criterial), and it is also possible to take into account the nonlinear influence of factors.
With regard to the problem under consideration, it is proposed to take into account the following factors:
the mass and dimensions of the equipment required to prepare the workplace; its quantity, as well as the
complexity of the preparatory work.

For a comprehensive assessment of heterogeneous criteria, it is necessary to draw up a graph in the
form of a binary tree, which will show the sequence of particular criteria aggregation. So, it is proposed
to first roll up such criteria as the mass and dimensions of the inventory, as the most common. Then the
generalized result is rolled up with a criterion corresponding to the amount of inventory used, as a result
of which a generalized assessment is formed - the complexity of the equipment operation, which in turn
is reduced with the laboriousness of preparatory work and as a result, a single comprehensive assessment
is formed, reflecting the complexity level of preparing a workplace for construction installation work
(Figure 1).
Figure 1. Criteria tree for complex assessment of factors constraining working conditions

The nodes of the criteria tree contain the convolution matrices (Fig. 2), reflecting the rules for aggregating the particular criteria. It should be noted that when developing MMCA, as a rule, a single descriptive rank scale from 1 to 4 is used, where 1 is an assessment reflecting the worst qualitative state of the criterion, and 4 is the best. In this study, an inverse scale is adopted, but with a similar number of gradations (Table 1). Therefore, the convolution matrices will be $4 \times 4$. Each convolution matrix is a set of compound inference rules “If, then”, and takes into account the influence of each criterion, depending on the priorities set in the matrix. In the works devoted to the MMCA study [8,9] such convention is accepted that the convolution matrices’ origin is located in the lower right corner, the left criterion corresponds to the rows, and the right criterion corresponds to the columns. In this study, we will take the same matrices arrangement.

Table 1. Descriptive scales of factors constraining working conditions and their criterion presentation in a rank scale from 1 to 4

| №  | Criterion value (point) | Qualitative interpretation grade | Weight, [kg] | Dimensions, [m$^3$] | Quantity, [set.] | Labor intensity, [man-hours] |
|----|-------------------------|---------------------------------|--------------|---------------------|------------------|-----------------------------|
| 1  | 1                       | The factor that complicates the work takes place | Low          | Small               | Small            | Low                         |
| 2  | 2                       | Moderately complicating factor   | Average      | Average             | Average          | Average                     |
| 3  | 3                       | Factor that significantly (significantly) complicates the work | High         | Large               | Large            | High                        |
| 4  | 4                       | Critically Complicating Factor   | Very high    | Very big            | Very big         | Very high                   |
Note: specific values for the criteria are determined for the specific complexity conditions. A detailed example is presented in Table. 2

Composite inference rules are formed in the form of causal statements, for example, if the mass is "high" \((k_m=3)\), and the dimensions are "average" \((k_s=2)\), then the generalized factor "Weight and dimensions" is one of the factors that averagely complicates the work \((k_{mas}=2)\). For the specific conditions of complexity, the set of rules can also be adjusted.

Figure 2 shows the criteria tree with convolution matrices describes 256 possible combinations of factors constraining working conditions.

**Figure 2.** An example of complex assessment of complexity factors in Microsoft Excel®

Complex assessment is carried out sequentially, folding a pair of criteria in each convolution matrix, the resulting value of the convolution matrix is used for the matrix convolution of the next level until we reach the only complex indicator interpreted as the level of construction and installation work complexity. So, in Figure 2, the elements of the matrix are highlighted in yellow, corresponding to the values of the criteria rolled up in the matrix. For example, inventory weight is high \((k_m=3)\), and the dimensions are average \((k_s=2)\), then the third row and the second column are selected in the matrix, respectively, relative to the lower right corner. In the given example, the value 2 corresponds to the matrix element in the third row and column 2, which means that row 2 will be selected on the matrix of the next level. Let the amount of inventory be "very large" \((k_q=4)\), then in the convolution matrix of weight and size with quantity, 2 rows and 4 columns are selected, which in the considered example corresponds to grade 3. Since this generalized grade is on the right according to the criteria tree, then on the top-level matrix, column 3 will be selected. In the demonstrated example (see Fig. 2), the complexity in the criterion space is 2 \((k_{li}=2)\), then the row 2 should be selected. In the final matrix, at the intersection of 2 rows and 3 columns, the matrix element has an estimate of 3 \((k=3)\). Thus, the complexity level, taking into account the considered factors in the complex, is defined as significantly complicating the work.

The works [8, 9] show the approaches to continuous and fuzzy complex assessment, using which it is possible to carry out a comprehensive assessment of any combination of factors that constrain the working conditions. Thus, the use of continuous mechanisms of complex assessment will allow taking
into account the combination of any constraining factors, which ultimately makes it possible to adequately assess the real complexity conditions.

For continuous complex estimation, it is proposed to use the additive-multiplicative approach [8, 9], which is written using the expressions (1) – (7):

\[
k^i = j^M_3 + \gamma_{k_i} \cdot \left( j^M_4 - j^M_3 \right) + \gamma_{k_r} \cdot \left( j^M_5 - j^M_3 \right) + \gamma_{k_i} \cdot \gamma_{k_r} \cdot \left( j^M_6 + j^M_3 - j^M_4 - j^M_5 \right),
\]

(1)

\[
\gamma_{k_i} = \left[ k_{M_i} \right] = \text{mod} \left( k_{M_i}, 1 \right),
\]

(2)

\[
\gamma_{k_r} = \left[ k_{M_r} \right] = \text{mod} \left( k_{M_r}, 1 \right),
\]

(3)

\[
j^M_3 = m_{rc} \in M^i \mid r = \left[ k_{M_i} \right] ; c = \left[ k_{M_r} \right],
\]

(4)

\[
j^M_4 = m_{rc} \in M^i \mid r = \min \{ k_i + 1 \}; 4 ; c = \min \{ k_{M_i} + 1 \}; 4 ,
\]

(5)

\[
j^M_5 = m_{rc} \in M^i \mid r = \left[ k_{M_i} \right] ; c = \min \{ k_{M_i} + 1 \}; 4 ,
\]

(6)

\[
j^M_6 = m_{rc} \in M^i \mid r = \min \{ k_i + 1 \}; 4 ; c = \min \{ k_{M_i} + 1 \}; 4 ,
\]

(7)

where \( M \) – is a convolution matrix \( i \)-level of the criteria tree (see Fig.1), \( k_i \) – is the left test grade, \( k_r \) – is an assessment of the right criterion.

To find the value of a comprehensive assessment of the constrained working conditions at the 1st level, the following formula should be used:

\[
k^i(k_m; k_s) = j^M_3 + \gamma(k_m) \cdot \left( j^M_4 - j^M_3 \right) + \gamma(k_s) \cdot \left( j^M_5 - j^M_4 \right) + \gamma(k_m) \cdot \gamma(k_s) \cdot \left( j^M_6 + j^M_3 - j^M_4 - j^M_5 \right).
\]

(8)

The value of the comprehensive assessment at the 2nd level will be determined by the following formula:

\[
k^i(k^i(k_m; k_s); k_q) = j^M_3 + \gamma(k^i) \cdot \left( j^M_4 - j^M_3 \right) + \gamma(k_m) \cdot \gamma(k^i) \cdot \left( j^M_5 + j^M_3 - j^M_4 - j^M_5 \right).
\]

(9)

The calculation of the final comprehensive assessment at the 3rd level of the tree is determined by the formula:

\[
k = k^i \left( j^M_3 + \gamma(k^i) \cdot \left( j^M_4 - j^M_3 \right) + \gamma(k_m) \cdot \gamma(k^i) \cdot \left( j^M_5 + j^M_3 - j^M_4 - j^M_5 \right) \right) + \gamma(k_m) \cdot \gamma(k_s) \cdot \gamma(k^i) \cdot \gamma(k_q) \cdot \left( j^M_6 + j^M_3 - j^M_4 - j^M_5 \right).
\]

(10)

Substituting the expression (8) in (9), and it, in turn, in (10), we obtain the desired equation, which determines the complexity level of construction and installation work:
\[ +\gamma(k_q) \cdot (j_5^{M''} - j_3^{M''}) + \gamma(j_5^{M''} + \gamma(k_m) \cdot (j_4^{M''} - j_3^{M''}) + \gamma(k_s) \cdot (j_5^{M''} - j_3^{M''}) + \gamma(k_m) \cdot \gamma(k_s) \cdot (j_5^{M''} + j_3^{M''} - j_4^{M''} - j_5^{M''}) \cdot \gamma(k_q) \cdot (j_6^{M''} + j_3^{M''} - j_4^{M''} - j_5^{M''}). \]

(11)

For quantitatively measurable indicators, it is necessary to determine the reduction functions, which in the simplest case are linear. Casting functions are usually divided into monotonically increasing and monotonically decreasing. In this study, all the considered criteria (see Table 1) with an increase in their values lead to an increase in the complexity of working conditions, so the reduction functions will be monotonically increasing:

\[ k_i = \frac{3(x_i - x_{\text{min}})}{x_{\text{max}} - x_{\text{min}}} + 1 \]

(12)

where \( x_i \) is the actual value of the difficulty factor in natural units, \( x_{\text{min}} \) is the value of the complexity factor, below which the conditions are considered uncomplicated, \( x_{\text{max}} \) is the maximum permissive value of the complexity factor, \( k_i \) is the reduced value of the complexity factor to a scale of 1–4 (complexity criterion).

3. Results

Let us consider an example of continuous complex assessment of the working conditions complexity, using the example of low illumination of the workplace. In the case of low light, in preparation for work, the equipment is required, shown in the table below (Table 2):

**Table 2. Criteria and their parameters for a comprehensive assessment of the complexity factor "Weak illumination of the workplace"**

| № | Criterion name                      | Incoming items | calculation formula | Total       |
|---|-------------------------------------|----------------|---------------------|-------------|
| 1 | Inventory weight                    |                |                     |             |
|   | Cable                               | 0.315 kg * 3m  | 0.945 [kg]          |             |
|   | Staples                             | 0.005 kg * 24 pc. | 0.12 [kg]       |
|   | Cord-grip lampholder                | 0.05 kg * 1 pc. | 0.05 [kg]         |
|   | Lamp                                | 0.04 kg * 1 pc. | 0.04 [kg]         |
|   | Lamp                                | 3 kg * 1 pc.    | 3 [kg]            |
|   | Total                               |                | 4.155 [kg]         |             |
|   | MIN                                 |                | 4.155 [kg]         |             |
|   | MAX                                 |                | 33.24 [kg]         |             |
| 2 | Inventory dimensions                |                |                     |             |
|   | 1 box                               | 0.42*0.33*0.2 7 | 0.038 [m³]        |
|   | Total                               |                | 0.038 [m³]         |             |
|   | MIN                                 |                | 0.038 m³          |
|   | MAX                                 |                | 0.15 m³           |
| 3 | The amount of equipment required to prepare the workplace |                |                     |             |
|   | Cable                               | 1 [set]        | 1 [set]            |             |
|   | Staples                             | 1 [set]        | 1 [set]            |             |
|   | Cord-grip lampholder                | 1 [pc.]        | 1 [pc.]            |             |
|   | Lamp                                | 1 [pc.]        | 1 [pc.]            |             |
|   | Lamp                                | 1 [pc.]        | 1 [pc.]            |             |
|   | Total                               |                | 5 [pc.]            |             |
| MIN     | from 1 to 2 sets | MAX     | over 7 sets |
|---------|-----------------|---------|-------------|
| Labor intensity of preparation of the workplace | Uniform rates and prices 23.1-3-1-02-G | 0.16 person-hour for 1 m\*5 pc. | 0.8 |
|         | Uniform rates and prices 23.1-3-2-01-B | 0.125 person-hour for 1 m\*5 pc. | 0.625 |
|         | Uniform rates and prices 23.1-17-1-01 | 0.14 person-hour for 1 pc\*5 pc. | 0.7 |
|         | Uniform rates and prices 23.1-17-2-01 | 0.03 person-hour for 1 lamp *5 pc. | 0.15 |
|         | Uniform rates and prices 23.1-17-2-03 | 0.03 person-hour for 1 lighting fixture*5 pc. | 0.15 |
| Total   |                  | 2.4 [person-hour] |             |

As it can be seen from the Table, 2, each factor is determined by the minimum and maximum permissible values in natural units. Substituting the actual values into the reduction function (12) for each criterion, respectively, we obtain the values on a single scale from 1 to 4 (in the criterion space):

1.1) Inventory weight - actual inventory weight 6.39 (used 3m cable weighing 0.945 kg, LSP 42-2x40-001 lamp weighing 5 kg, 2 36W lamps 82500 TL-D STANDARD 36W / 33-640 T8 G13 2850Lm 4000K weighing 0.152 kg each (in view of the peculiarities of the structure of the lamp, an additional cartridge is not required), staples in the amount of 28 pieces weighing 0.141 kg) with a minimum value of 4.16 kg and a maximum value of 33.24 kg will have an estimate in the criterion space 1.23:

\[ k_w = \frac{3(6.39-4.16)}{(33.34-4.16)}+1 = 1.230 \]

1.2) Inventory dimensions - the actual dimensions of the inventory 0.1365 m\(^3\) (for the previously listed type of inventory, a box of 1.3 * 0.7 * 0.15 was required) with a minimum value of 0.038 m\(^3\) and a maximum value of 0.15 m\(^3\) will be assessed in the criterion space 3.638

\[ k_d = \frac{3(0.1365-0.038)}{(0.15-0.038)}+1 = 3.638 \]

1.3) The number of required inventory for the workplace preparation – the actual number of required inventory is 2 pieces, with a minimum value - 1 piece and the maximum - 8 pieces will have an estimate in the criterion space 1.429

\[ k_q = \frac{3(2-1)}{(8-1)}+1 = 1.429 \]

1.4) Labor intensity of the workplace preparation - the actual time for laying out the equipment is 3.2 man-hours, with a minimum value of 2.4 people-hours, and a maximum value of 8 man-hours will have an estimate in the criterion space 1.429

\[ k_t = \frac{3(3.2-2.4)}{(8-2.4)}+1 = 1.429 \]
Substituting the found values into formula (11), we obtain a complex estimate describing the level of complexity \((k=1.429)\). The figure below shows the intermediate and final results of continuous complex estimation of complexity conditions:

![Complexity Estimation Diagram](image)

**Figure 3.** An example of the continuous complex assessment of complexity factors on the example of "Low illumination of the workplace" in Microsoft Excel®

*Note:* the elements corresponding to the parameters are grayed out on the convolution matrices \(j_3, j_4, j_5\) and \(j_6\)

4. **Discussion**

The methodology for assessing the construction and installation works complexity proposed in this work can be used in the management of a construction project, as well as for adjusting the cost of construction and installation works if there are such facts in the construction organization project.

The existing groups of cramped working conditions and the corresponding correction factors are shown in Table 3:

| № | Group of constrained working conditions | Range of coefficient values |
|---|----------------------------------------|-----------------------------|
| 1 | Installation work in mountainous areas | from 1.25 till 1.5           |
| 2 | Harmful working conditions (t air, MPC content in the air) | from 1.25 till 2.3           |
| 3 | Installation work in underground conditions | from 1.68 till 3.0           |
| 4 | Average working conditions | from 1.1 till 1.35           |

In this study, the average statistical working conditions, for which the range of values of the correction coefficient for cramped working conditions is 1.10–1.35 are considered. At the same time, the proposed methodology can be adapted to specific conditions, such as performing work in mountainous areas, in underground conditions and under harmful working conditions (see Table 3).
To convert the resulting value of the difficulty level from a scale of 1–4 to the range of values of the correction coefficient, the following expression [10] should be used:

\[ K_j \cdot \left( \frac{k_j - k_1}{k_2 - k_1} \right) \cdot (K_2 - K_1) + K_1 \]  

(13)

where: 
- \( K_j \) – is the required complexity factor for \( j \)-type of work;
- \( k_j \) – is the comprehensive assessment reflecting the level of complexity for \( j \)-type of work;
- \( K_1 \) and \( K_2 \) – are the minimum and maximum values of the difficulty coefficient for \( j \)-type of work, planned for use (in this study 1.10 and 1.35, respectively);
- \( k_1 \) and \( k_2 \) – are the minimum and maximum values of the complex complexity estimate for \( j \)-type of work (in this study 1 and 4, respectively);

So, for the considered example, the following coefficient is obtained:

\[ K_j = (1.35 - 1.10) \cdot (1.814 - 1) / (4 - 1) + 1.10 = 1.168 \]

Despite the fact that such calculations can be performed in already existing software products of the Decon family (Business-Decon [11], web-Business-Decon [12]), the authors have created an analogue of the software module based on Microsoft Excel® spreadsheets (Fig. 4):

**Figure 4.** Calculation of the complexity factor value, with the actual values of the integrated assessment in Microsoft Excel®

As it can be seen in Figure 4, for the given values of the criteria with an accuracy of two decimal places, the complex assessment is equal to 1.964, when transferred into the values from 1.10 to 1.35, the complexity factor coefficient is 1.18.

### 5. Summary

To test the proposed methodology, a series of computational experiments, in which the simplest constraining conditions were assessed were carried out. For these experiments the complex assessment was 1.0, and the complexity factor value was 1.1, respectively, and vice versa, a comprehensive assessment of really very difficult working conditions was carried out, according to the results of the complex assessment of which the maximum complex grade of 4.0 was obtained, and, as a consequence, the maximum value of the complexity factor was 1.35.
At the moment, using the methodology proposed by the authors, the complexity factors have been determined for such conditions as "Low illumination of an object", which is shown in this article, as well as "Dustiness, corrosion deposits, deposits of natural origin and other formations leading to preliminary cleaning of the object before performing work", "The need for a second and subsequent visits of specialists due to the impossibility of providing complete and reliable initial data to determine the work scope", "The need to collect and provide documents (technical passports) for the equipment (machines, mechanisms) used at the facility, in connection with the specifics of the object". Prior to this study, the complexity coefficients for the above-mentioned conditions have not been determined.

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