Comprehensive Assessment of Quality of Technological Processes in Construction

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Abstract. A technique is proposed for determining a comprehensive indicator of the quality of technological processes in construction. The implementation of the methodology is considered on the example of the process of excavation at the site, using statistical methods of product quality control and data analysis of acceptance control of work.

1. Introduction
Official statistics of the Russian Federation indicate a large increase in the number of construction accidents. According to the analysis, about 70% of accidents in construction are associated with various kinds of defects, materials used, errors of participants in the investment construction project.

The direction of scientific and methodological research in the field of improving technology and the organization of construction work in order to increase their efficiency and quality was determined by the works of domestic scientists: Afanasyev A.A., Afanasyev V.A., Bulgakov S.N., Golovnev S.G., Gusakov A.A., and others.

Foreign researchers also made a significant contribution to the development of the theory of reliability of building structures. A review of contemporary literature and a critical analysis of publications [1-8].

In the scientific literature on the problem of the effectiveness of quality management systems in construction, the proposed methods and indicators were reduced, as a rule, to the definition of savings by reducing the overhead of eliminating waste [9-12].

Studies have shown that construction control is carried out without the use of quantitative indicators, justification of the scope of control. [13 -15] In this regard, insufficiently informative control results are not a complete basis for assessing the compliance of construction and installation works (CIW) and the construction site as a whole with the established requirements.

The problem arises of the imperfection of the methods of monitoring and assessing the quality of construction of civil buildings, taking into account the level of the system for ensuring the quality of construction, accuracy of technological processes and safety indicators.

This study was aimed at the economic feasibility and development of a method for determining a comprehensive quality indicator (CQI) of technological processes in construction, affecting the economic efficiency and competitiveness of the construction industry as a whole.
2. Materials and methods

The goal of the work is achieved by applying statistical methods for controlling the quality of construction products based on data from the analysis of acceptance control of works, legislative and regulatory acts [16,17].

The study examines the excavation work on the site during the development of excavations and the construction of natural foundations. The control method of this process is a measuring one. Deviations of indicators during the normal course of the technological process should be within the technical limits determined by the norms. The list of indicators of operational control of various construction works can be found in SNiP and GOST [18-21].

We will consider x – quantitative indicators (measured CIW) and \( T_i \) – the value of the permissible deviation of the indicator from the norm.

We take the following dependence of the production of CIW (K) on the controlled indicator (x) in the form:

\[
K = \begin{cases} 
1 - x/T_1, & \text{if } 0 \leq x \leq T_1, T_1 > 0 \\
1 - x/T_2, & \text{if } 0 \leq x \leq T_2, T_2 > 0
\end{cases}
\]

If the control volume is specified for the indicator and is equal to n, then the indicator itself takes on values \( x_1, x_2, \ldots, x_n \). Then the quality of production of CIW (K) from the controlled indicator (x) is presented in the form:

\[
K_{\text{CIW}} = \min\{K_1, K_2, K_3, \ldots, K_n\}
\]

where \( K_i \) - a value determined by the same dependence of the quality of production of CIW (K) on the controlled indicator (x). In this case, the value of K will be found by the following formula:

\[
K_{\text{CIW}} = 1 - x_{\text{max}}/T_i
\]

where \( x_{\text{max}} \) - a value as far as possible from the origin.

Thus, if one measurement is made for each particular quality indicator, then calculation (4) is used, where \( K_i \) is the value of the particular quality value. If the indicator \( x_k \) is determined at which the minimum is realized, this means that the \( K - \)th condition of SNiP is poorly fulfilled.

Using the method of analysis of hierarchies, it is possible to present a complex quality indicator with a value equal to (5):

\[
K = \alpha_1 K_1 + \alpha_2 K_2 + \ldots + \alpha_n K_n
\]

Where \( \alpha_1 + \alpha_2 + \ldots + \alpha_n \) – a priority vector of quality properties of construction products (\( \alpha_i \geq 0 \)).

The method of pair wise comparisons known in the literature is used to find it [20]. So, it is possible to assess individual quality indicators of CIW by the required number of groups of criteria. We take the number of criteria equal to 3, the lowest level of the hierarchy are the components of the priority vector \( a_{i1,2,3} \). The matrix itself will have the property of inverse symmetry, where \( a_{ij} = V_i/V_j \).

\( K_1, K_2, \ldots, K_n \) - the set of n elements (alternatives) and \( V_1, V_2, \ldots, V_n \) - their weights, respectively. Let us compare the weight in pairs, of each element with the weight, or of any other element of the set with respect to their common property or purpose (in relation to the element - the parent).

To get each matrix, the expert makes \( n-(n-1)/2 \) judgments (here \( n \) - Thus, the matrix of pair wise comparisons [K] has the form:

|       | \( K_i \) | \( K_2 \) | \( K_3 \) | \( K_n \) |
|-------|---------|---------|---------|---------|
| \( K_1 \) | \( V_1/V_1 \) | \( V_1/V_2 \) | \( V_1/V_n \) |
| \( K_2 \) | \( V_2/V_1 \) | \( V_2/V_2 \) | \( V_2/V_n \) |
| \( K_n \) | \( V_n/V_1 \) | \( V_n/V_2 \) | \( V_n/V_n \) |

Matrix filling rule:
If the element $K_1$ dominates the element $K_2$, then the cell of the matrix corresponding to row $K_1$ and column $K_2$, is filled with an integer, and the cell corresponding to row $K_2$ and column $K_1$, is filled with the inverse number to it. If the element $K_2$ dominates $K_1$, then the integer is put in the cell corresponding to row $K_2$ and column $K_1$, and the fraction is put in the cell corresponding to row $K_1$ and column $K_2$. If the elements $K_1$ and $K_2$ are equally preferable, then units are put in both positions of the matrix.

3. Results
This section presents the testing of the proposed methodology. Table 1 presents the data of indicators of acceptance control of drainage channels.

| Indicators (i = 1,2...10)                      | $x_i$       | $T_i$       |
|-----------------------------------------------|-------------|-------------|
| Channel axis                                 | +10cm       | +20cm       |
| Channel mark                                 | -6cm        | -20cm       |
| Longitudinal slope of the bottom             | +2%         | +10%        |
| Channel width along the bottom with design dimensions from 0.6 to 1 m | +5%         | +10%        |
| Channel width along the bottom with design sizes from 1 to 2 m | +5%         | +15%        |
| Turning radius                               | +1%         | +5%         |
| Slope steepness (at design values from 0.6 to 1 m) | +3%         | +15%        |
| Slope steepness (at design values from 1 to 2 m) | -4%         | -10%        |
| Slope surface flatness                       | +4.4cm      | +10cm       |

The presented quantitative indicators $x_i$ can be attributed to the CIW, property, namely, to the accuracy of the CIW.

Based on the expressions (1) and (2) we define a sequence of quality values $K_i = I - x_i/T_i$:

- $K_1 = 1 - 10/20 = 0.50$.
- $K_2 = 1 - 6/20 = 0.70$.
- $K_3 = 1 - 2/10 = 0.80$.
- $K_4 = 1 - 5/10 = 0.50$.
- $K_5 = 1 - 5/15 = 0.66$.
- $K_6 = 1 - 1/5 = 0.80$.
- $K_7 = 1 - 3/15 = 0.80$.
- $K_8 = 1 - 4/10 = 0.60$.
- $K_9 = 1 - 4,4/10 = 0.56$.

We will take at this site for the quality of CIW as the minimum value of quality:

$$K_{CIW} = \min\{K_1, K_2, K_3...K_9\}$$

Receive $K_{CIW} = 50$.

The relative importance of the elements will be established on the basis of the scale of relations presented in Table 2.
Table 2. Significance Scale.

| Significance level | Meaning |
|--------------------|---------|
| 1                  | Equal importance |
| 3                  | Some predominance of the significance of one action over another (weak significance) |
| 5                  | Significant or strong significance |
| 7                  | Obvious or very strong significance |
| 9                  | Absolute importance |
| 2, 4, 6, 8         | Intermediate values between two neighboring judgments => The situation when a compromise solution is needed |
| OB                 | If, when comparing with action \( j \) one of the nonzero numbers defined above is assigned to action \( i \) then the opposite value is assigned to action \( j \) when comparing with action \( i \) |

We assume that the assessment of individual quality CIW will be carried out according to three criteria: accuracy \( (K_1) \), reliability \( (K_2) \), environmental friendliness \( (K_3) \). The lowest level of the hierarchy is the components of the priority vector \( a_{i=1,2,3} \).

According to the calculations, the matrix of pair wise comparisons of CIW during the construction of drainage systems will take the form:

\[
K = \begin{bmatrix}
    K_1 & \frac{1}{1} & \frac{2}{1} & \frac{6}{1} \\
    \frac{1}{2} & 1 & 1 & \frac{3}{1} \\
    \frac{1}{6} & \frac{1}{3} & 1 & 1
\end{bmatrix}
\]

As a result of the calculations, the values of the components of the priority vector were obtained:

\( A_{i=1} = \alpha_1 = 0.6 \).
\( A_{i=2} = \alpha_2 = 0.3 \).
\( A_{i=3} = \alpha_3 = 0.1 \).

Thus, knowing the values of the criteria \( K_1 \), \( K_2 \) and \( K_3 \), a comprehensive indicator of the quality of excavation works \( (K_{CMP}) \) can be expressed through unit quality indicators for individual properties (6).

\( K_1 \) – an indicator of the property of manufacturing accuracy of CIW is found using quantitative indicators (Table 1).\n
\( K_1 = \min \{K_{i=1,2,3}...K_{i=9}\} = 0.50 \).

\( K_2 \) – CIW reliability property. Suppose that \( K_2 \) has two quantitative indicators: the angle of internal friction \( (x_{i=1}) \) and specific soil adhesion \( (x_{i=2}) \). According to the measurement results \( x_1 = 0.8T_1 \), \( x_2 = 0.3T_2 \). Based on formulas (1) and (2), we obtain the following quantities: \( K_1 = 0.34 \), \( K_2 = 0.90 \).

The value of a single indicator of quality \( K_3 = \min \{0.34, 0.90\} = 0.34 \).

Similarly, we obtain the value of \( K_3 \) – the property of environmental friendliness of production. We take two quantitative indicators: \( \Pi_1 \) and \( \Pi_2 \) - respectively, the maximum permissible content in the soil of harmful impurities of the 1st and 2nd substance.

According to the measurement results \( x_1 = 0.4T_1 \), \( x_2 = 0.2T_2 \). Based on the expressions (1) and (2), we obtain the following quantities: \( K_1 = 0.81 \), \( K_2 = 0.95 \).

The value of a single indicator of quality \( K_3 = \min \{0.81, 0.95\} = 0.81 \).

Thus, a comprehensive quality indicator (CQI) of CIW in this area is:

\( K_{CWI} = a_1K_1 + a_2K_2 + ... + a_nK_n = 0.6 \times 0.50 + 0.3 \times 0.34 + 0.1 \times 0.81 = 0.3 + 0.102 + 0.081 = 0.483 \).

If for some characteristic \( x \) the boundaries \( 0 \leq x \leq T_i \), are set, then a particular quality criterion can be set in the form \( K = 1 - x/T_i \). The given dependence shows that the maximum quality value will be equal to 1, which is achieved when the construction and installation work is ideally performed; the minimum quality value is 0 if the measured indicator assumes an unacceptable value. If on one building object the measured value of the quality characteristic is \( x = x_1 \), and on another building object the measured
value of this characteristic is \( x_1 < x_2 < T_1 \), then follows from the functions \( K_1 = 1 - \frac{x_1}{T_1} \) and \( K_2 = 1 - \frac{x_2}{T_2} \) and \( K_1 > K_2 \), i.e. quality indicators are ordered and this is a very important circumstance, since it is not necessary to know the exact quantitative value of the quality parameter and can be determined by pairwise comparing the quality of construction and installation works at the facilities under construction.

The obtained indicator has a value below the average, which corresponds to a rejection level of quality; measures are needed to improve the accuracy of technological processes, in order to achieve the calculated values of the indicators and guaranteed product strength.

Improving accuracy can be achieved by replacing design and survey work, changing and improving the methods of work, tooling, replacing suppliers of products, improving the skills of performers, strengthening control, etc.

4. Discussion
Building norms and rules contain their own criteria for the admissibility of certain quality attributes, which are set in the form of certain tolerance limits for the measured quality attributes. The paper proposes particular quality criteria for individual features.

The above calculations determine the function of the resulting quality, depending on all measurements made in the form of certain algorithms.

The diverse groups of properties of CIW can be described by different quantitative indicators. For example, indicators of the strength of materials, loads, and possible deviations from design schemes can be used to describe the reliability properties of CIW. This property is especially important in the process of performing CIW, as these values can vary within wide limits. There are indicators for the environmental friendliness of CIW - these may be the so-called MPC norms (maximum permissible concentrations of harmful substances in building materials).

As for the further development of the problem under study, the work done and the results obtained will allow us to determine the main directions of further research in the field under consideration, namely, further improvement of the theory and practice of multicriteria analysis of organizational and technical solutions of construction production, further development of expert assessment methods for the level of quality of construction production.

5. Conclusion
The considered example focused on the universality of the approach, the possibility of conducting a qualitative analysis of technological processes in the face of uncertainty, determining the level of quality in construction and as a consequence of its competitiveness.

The research results can be applied by industrial enterprises in solving problems in the field of improving the theory and practice of certification of products, production processes, operation, storage, transportation, sale, disposal, work, services, quality management systems and other processes of construction production.

6. References
[1] Javon Adams, Cassie Castorena, Y Richard Kim Construction quality acceptance performance-related specifications for chip seals Journal of Traffic and Transportation Engineering (English Edition)
[2] Junying Lou, Jiang Xu, Kun Wang 2017 Study on Construction Quality Control of Urban Complex Project Based on BIM In: Procedia Engineering Vol 174 pp 668-676
[3] Nokulunga Mashwama, Clinton Aigbavboa, Didi Thwala 2017 An Assessment of the Critical Success factor for The Reduction of Cost of Poor Quality in Construction Projects in Swaziland In: Procedia Engineering Vol 196 pp 447-453
[4] T Sri Kalyan, Puyan A Zadeh, Sheryl Staub-French, Thomas M Froese 2016 Construction Quality Assessment Using 3D as-built Models Generated with Project Tango In: Procedia Engineering Vol 145 pp 1416-1423
[5] Virga Salukatko, Eneli Liisma, Erki Soekov 2017 Increasing Construction Quality of External Thermal Insulation Composite System (ETICS) by Revealing on-site Degradation Factors Procedia Environmental Sciences Vol 38 pp 765-772

[6] Hany Shoukry, Hossam El-Deen H Mohhamed, Mohhamed E Abdel Razek Assessment of the expected cost of quality (COQ) in construction projects in Egypt using artificial neural network model Journal HBRC

[7] Mihai Iliescu, Remus Ciocan 2017 Modern Technologies Innovation in Use for Quality Control on Construction Site In: Procedia Engineering Vol 181 pp 999-1004

[8] Ayguns Kazaz, Serdar Ulibeyli, Bayram Er, Turgut Acikara 2016 Construction Materials-based Methodology for Time-Cost-quality Trade-off Problems In: Procedia Engineering Vol 164 pp 35-41

[9] Siti Syariazulfa Kamaruddin, Mohammed Fadhil Mohammed, Rohana Mahbub 2016 Barriers and Impact of Mechanisation and Automation in Construction to Achieve Better Quality Products Procedia - Social and Behavioral Sciences Vo 222 23 pp 111-120

[10] Romanova A I 2016 Improving the Quality of Construction Works in Terms of the Self-regulation In: Procedia Engineering Vol 150 pp 2108-2112

[11] Muge Tetik, Antti Peltokorpi, Olli Seppanen, Jan Holmstrom 2019 Direct digital construction: Technology-based operations practice for continuous improvement of construction industry performance Automation in Construction Vol 107 102910

[12] Michalis Menicou, Vassos Vassiliou, Petros Christou, Marios Charalambides 2010 A Real-Time Quality Assurance Tool for the Cyprus Construction Industry IFAC Proceedings Vol 43 Issue 17 pp 77-82

[13] Piotr Knzyak 2019 The impact of construction quality on the safety of prefabricated multi-family dwellings Engineering Failure Analysis Vol 100 pp 37-48

[14] Thomas Gittler, Eduard Relea, Donatella Corti, Giorgio Corani, Lukas Weiss, Daniele Cannizzaro, Konrad Wegener 2019 Towards predictive quality management in assembly systems with low quality low quantity data – a methodological approach Procedia CIRP Vol 79 pp 125-130

[15] Ivanov Nikolay 2016 A Study on Optimization of Nonconformities Management Cost in the Quality Management System (QMS) of Small-sized Enterprise of the Construction Industry Procedia Engineering Vol 153 pp 228-231

[16] Nikulina M E, Gorobtsov D N, Pendin V V Engineering and Geological Audit in Design and Construction of Linear Transport Facilities Procedia Engineering Vol 1892017 pp 70-74

[17] Weihui Liang, Xudong Yang, Fengna Chen, Mengqiang Lv, Shen Yang.: A Pre-assessment and Control Tool for Indoor Air Quality (PACT-IAQ) Simulation in Actual Buildings In: Procedia Engineering Vol 2052017 pp 219-225

[18] Alexander Paolini, Stefan Kollmannsberger, Ernst Rank 2019 Additive manufacturing in construction: A review on processes, applications, and digital planning methods Additive Manufacturing Vol 30 Article 100894

[19] Anna Krawczynska-Piechna Comprehensive Approach to Efficient Planning of Formwork Utilization on the Construction Site In: Procedia Engineering Vol 1822017 pp 366-372

[20] Mohamed Sayed Bassiony Ahmed Abd El-Karim, Omar Aly Mosa El Nawawy, Ahmed Mohamed Abdel-Alim 2017 Identification and assessment of risk factors affecting construction projects HBRC Journal Vol 13 Issue 2 pp 202-216

[21] Gimaltdinov I K, Levina T M, Stolpovskii M V, Solovev D B 2018 Dynamics of the Localized Pulse in Bubbly Liquid IOP Conference Series: Materials Science and Engineering 463 Paper № 022002. [Online]. Available: https://doi.org/10.1088/1757-899X/463/2/022002