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Assessing the Impact of Making Adjustments to Design Documentation on the Production Process

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Abstract. Today's projects face rapid changes, tight deadlines, and high-quality requirements, emphasizing the importance of effective management and minimizing revisions to design documents. This article conducted a study on the impact of design documentation adjustments on the production process. It considers the main challenges arising from working with foreign design documentation and analyzes the time and resource costs associated with necessary adjustments. Based on data analysis, a mathematical model was developed that incorporates key factors such as the complexity of drawings and the experience level of employees, followed by an analysis of their influence. The results of the regression analysis can be utilized to enhance workflow and task planning within the design department. The article underscores the significance of employee experience and its effect on processing time, along with the necessity of considering task complexity levels.

Keywords: cost analysis, typical errors, adjustments to design documentation.

Introduction

In the context of globalization and intensive technological development, many enterprises engaged in repair and maintenance are faced with the need to use foreign design documentation [1, 2]. This is caused by the operation of imported equipment and machines, for which the original design documents are provided by foreign manufacturers. However, differences in standards and designations can significantly complicate the understanding and effective use of this documentation in the field [3, 4]. In order to bring these documents into compliance with the Unified system of design documentation (ESKD) requirements, significant time is required to search for information and adapt. Therefore, designers are forced to spend more time processing drawings

The aim of this study is to develop and validate a mathematical model that takes into account the degree of drawings complexity and the amount of adjustments to design documentation.

Article [3] discusses the stages of processing and factors influencing the duration of registration in accordance with the Unified system of design documentation (ESKD) requirements [4]. The work examines the main factors [5] that influence the time spent on processing design documentation, such as the drawing complexity, the number of elements, format, employee experience [6], as well as borrowings from other languages. The works [7, 8, 9] present the adaptation of design documentation to the conditions of a specific serial production of the manufacturer.

The study [10] focuses on managing changes in design documentation in engineering, procurement, and construction projects. The authors investigate the causes and consequences of such changes, including their impact on timelines, budgets, and overall work efficiency. Strategies for improvement are proposed, such as integrating project teams, involving contractors early, and enhancing collaboration.

In article [11], engineering changes are considered as a crucial part of a product's life cycle. The significant impact of these changes on productivity, cost, and quality is highlighted. The authors categorize types of changes and discuss management methods to minimize process disruptions. Design changes can trigger a chain reaction of modifications in other aspects of a product or process. The importance of analyzing the propagation of such changes and their influence on design and production is addressed in [12].

Key aspects of managing engineering changes, including their causes, impact on cost and product quality, and risk minimization methods, are described in [13].

Considering modern design approaches in the context of Industry 4.0, including digital technologies, intelligent automation, and process integration, the authors emphasize the shifts in design strategies driven by the adoption of IoT and machine learning [14]. The impact of early versus late design decisions in system development is analyzed in [15], with particular attention to how early changes can reduce costs and time expenditures in the long term.

As a rule, design documentation already takes into account the production technological capabilities of manufacturers, but the conditions of pilot and mass production have significant differences, which leads to the need for partial or even complete processing of design documentation.

1. Research methods

The literature review examined existing studies concerning the impact of various parameters on information processing within the design department. Key works on optimizing process parameters and their influence on quality and productivity were reviewed. To study the impact of different parameters, an experimental plan was developed involving four samples at two different levels of each parameter. Each experiment was repeated three times to ensure result reliability and account for potential variations. A mathematical model based on the physical principles of the processing process was constructed for numerical analysis of parameter influences. This modeling allowed prediction of parameter changes on final outcomes and process optimization. Collected data underwent statistical analysis, including variance analysis and correlation analysis. This approach assessed the statistical significance of each parameter's impact on the processing process and the reliability of the obtained results.

2. Experimental studies

To build a mathematical model from 02/01/2023 to 03/01/2023, design documentation (working drawings) received for repair by the design department of Barusan Makina LLP was selected. The conditional designations presented in the design documentation are illustrated in Figure 1.

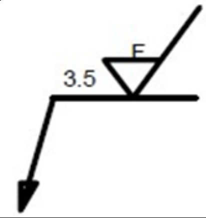
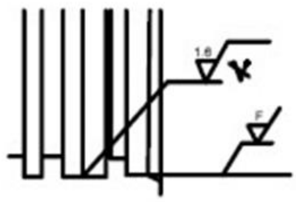
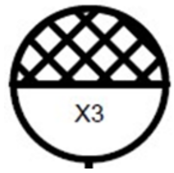
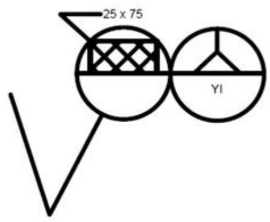
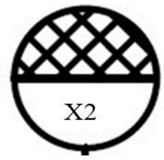
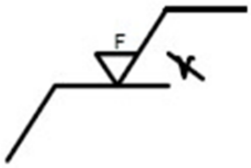
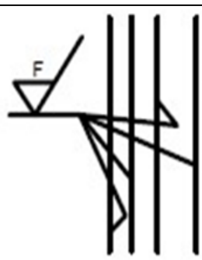
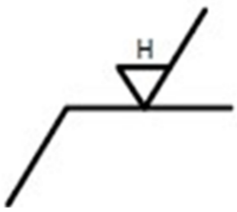
№	Sign	№	Sign
1		6	
2		7	
3		8	
4		9	
5		10	

Fig. 1. - The conditional designations in the design documentation

The independent variables influencing the amount of work performed (y) were selected:
- weighting factor z1, which takes into account the legend, dimensional lines, views and sections, etc.;
- time, taking into account the search for information, hour (Table 1).

Table 1. Initial data for experiment planning

Experiment number	Factors studied		Experimental results		
	z_1	z_2	y_1	y_2	y_3
1	0,35	0,189	2	3,2	4,5
2	0,152	0,845	1,5	2,1	3
3	0,218	0,517	1	1,4	2,3
4	0,284	1,173	0,45	1,1	1,2

z_1- weight factor: $z_1^- = 0{,}152$, $z_1^+ = 0{,}35.$
z_2- time taking into account information search, hour: $z_2^- = 0{,}189, z_2^+ = 1{,}173.$

Table 2. Initial a full factorial experiment planning matrix 2^2

Experiment number	Factors studied		Experimental results		
	Z_1	Z_2	y_1	y_2	y_3
1	+	-	2	3,2	4,5
2	-	+	1,5	2,1	3
3	-	-	1	1,4	2,3
4	+	+	0,45	1,1	1,2

For each factor, we find the center, the range of variation, and the dependence of the encoded variable xi on the natural Zi according to formulas (1). We formalize the results in the form of a table 3.

$$x_i = \frac{z_i - z_i^0}{\lambda_i} \ , \qquad (1)$$

where z_i^0 - is the center of the plan,

λ_i– the variation interval.

When encoding, all new variables will take values from –1 to +1, т.е. $x_i \in [-1; +1], i = \overline{1, k}$.

Table 3. Coding of factors

Factors	Upper level z_i^+	Lower level z_i^-	Centre z_i^0	Variation interval λ_i	Dependence of the coded variable on the natural one
Z_1	0,35	0,152	0,251	0,099	$x_1 = \frac{z_1 - 0{,}251}{0{,}099}$
Z_2	1,173	0,189	0,681	0,492	$x_2 = \frac{z_2 - 0{,}681}{0{,}492}$

Using formula (2), we calculate the average sample results for each experiment and enter the calculation results in Table 4:

$$\bar{y}_j = \frac{1}{m} \sum_{i=1}^{m} y_{ij}, \quad j = \overline{1, n}. \qquad (2)$$

Table 4. Planning matrix for processing results

Experiment number	Factors		Interactions	Experimental results			Average results value
	x_1	x_2	x_1x_2	y_1	y_2	y_3	$\bar{y}_j$
1	+	-	-	2	3,2	4,5	3,23
2	-	+	-	1,5	2,1	3	2,2
3	-	-	+	1	1,4	2,3	1,57
4	+	+	+	0,45	1,1	1,2	0,92

Calculate the coefficients of the regression equation:

$$b_0 = \frac{1}{4} \sum_{i=1}^{4} \bar{y}_j; \ b_j = \frac{1}{4} \sum_{i=1}^{4} x_j \bar{y}_j \qquad (3)$$

Table 5. Coefficients of the regression equation

b_0	b_1	b_2	$b_{1,2}$
1,98	0,1	-0,42	0,74

The reproducibility variance $S^2_{\{y\}}$ s determined by the formula (4):

$$S^2_{\{y\}} = \frac{1}{n}\sum_{j=1}^{n} S_j^2, \quad (4)$$

where S_j^2 - internal sums of sample variances of experimental results for the j-th experiment (j=1,…, n). Summing up all the elements, we get:

$$\sum_{j=1}^{4} S_j^2 = 2{,}74255$$

From here:

$$S_{coef.} = \sqrt{\frac{S^2_{\{y\}}}{n \cdot m}} \approx 0{,}24 \quad (5)$$

From the Student's distribution tables [9] for the number of degrees of freedom 8 at the significance level α = 0,05 we find $t_{cr.}$ = 2,31. Consequently, $t_{cr.} \cdot S_{coef.} = 0{,}55$. Comparing the obtained value of 0.55 with the coefficients of the regression equation, we see that all the coefficients except b_1,b_2 are greater in absolute value than 0.55, we obtain the regression equation in the encoded variables:

$$y = 1{,}98 + 0{,}74x_{1,2} \quad (6)$$

The adequacy of the model is checked using the Fisher criterion. Table value of criterion $F_{tab.}$ = 4,46. Calculated value of Fisher's criterion $F_{calc.}$ is determined by the formula (7):

$$F_{calc.} = \frac{S^2_{\text{ост.}}}{S^2_{\{y\}}} \quad (7)$$

Since $F_{calc.} = 1{,}61 < F_{tab.} = 4{,}46$, the regression equation (6) is adequate.
Let us interpret the resulting model (8):

$$y = 1{,}98 + 0{,}74x_{1,2} \quad (8)$$

Having transformed this equation, we finally obtain its form in natural variables:

$$y = 1{,}98 + 0{,}74 z_1 z_2 \quad (9)$$

3. Results and discussion

The constant (1.98) is the basic value of the weighting coefficients and can be interpreted as the minimum time for processing drawings without taking into account the complexity and experience of employees. The coefficient before z_1z_2 (-0.74**)** shows how strongly the combination of the weighting factor and processing time affects.

Conclusion

The conducted study demonstrated that adjustments to design documentation significantly impact production processes, particularly when working with foreign documentation. Based on experimental data, a mathematical model was developed that considers key factors: the complexity of drawings and the experience level of employees.

The obtained results confirm that:

- employee experience plays a crucial role in reducing the time required to process complex drawings;
- the complexity of design documentation, represented in the model by the weighting coefficient z1, directly increases the workload. However, this effect can be mitigated by improving employee qualifications;
- the combination of factors (z1 and z2) highlighted the importance of the interaction between the complexity of drawings and the time spent searching for information, allowing for more accurate predictions of time expenditures.

The practical significance of this study lies in the potential application of the developed model to optimize the processing of design documentation, including:

1) Reducing the time required for drawing modifications;

2 Improving task planning in design departments;
3) Enhancing the quality of work by accounting for the interrelation of key factors.

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