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## Quality costs of machine-building enterprises in Ukraine: a control mechanism

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**Abstract.** This article deals with the mechanism of quality costs management of machine-building enterprises and the assessment of the impact of these costs on the economic performance of enterprises. The analysis of literature sources on the issue of quality costs analysis has helped to identify the need to determine the determinants of quality cost items for machine-building enterprises, especially within Ukraine. The authors select national machine-building enterprises for the research. The researchers analyze the impact of the cost of sales and other types of costs on the net income from the sale of products, which is the basis for the formation of the enterprise's profits. To identify the determining quality cost items, the researchers investigate the effect of the quality cost items on the cost of sales. The article deals with making mathematical models for the studied enterprises, as well as the algorithm for performing the analysis. The results of the study indicate the impact of the cost of sales on the net income from the sale of products of enterprises, which is the most significant factor among the studied ones. The results also indicate the significant impact of certain quality cost items on the cost of sales. The results of this study can be applied at the practical level in the analysis and management of quality costs of machine-building enterprises and other industries.

**Keywords.** Cost of sales, management, net income from the sale of products, quality costs, quality cost items.

### **1. Introduction**

Machine-building industry plays an important role in the economy of the developed and the developing countries. Due to manufacturing machines and equipment ensuring the production of good and services, machine-building industry affects various fields of the country's

economy. Production of the machine-building industry is the basis for enhancing productivity, saving energy resources, reducing the metal intensity and the effect on the society and the environment as well.

The new challenges that had emerged in front of the machine-building enterprises after Ukraine's reorientation into European markets in 2014 led to the revision of strategic plans for their development. Table 1 shows that the share of the machine-building production in the total volume of the sold industrial production in Ukraine decreases from 10.3% in 2012 to 6.9% in 2018. Hereby the volume of each group of production in the total volume of the machine-building production remains within the same range [1]. It proves the constant impact of the machine-building production on different industries of the country.

**Table 1.** The volume of the sold production of the machine-building industry of Ukraine in 2012-2018. *Source: [1]*

Group of production	2012	2013	2014	2015	2016	2017	2018
	in % to the total of industrial production						
<b>Engineering</b>	10.3	8.6	7.1	6.5	6.1	6.4	6.9
<b>Manufacture of computer, electronic and optical products</b>	0.6	0.6	0.6	0.5	0.6	0.5	0.6
<b>Manufacture of electrical equipment</b>	1.6	1.6	1.5	1.3	1.2	1.2	1.4
<b>Manufacture of machinery and equipment n.e.c.</b>	2.8	2.6	2.3	2.4	2.3	2.3	2.3
<b>Manufacture of motor vehicles, trailers and semi-trailers and other transport equipment</b>	5.3	3.8	2.7	2.3	2.0	2.4	2.6

There was a rethinking of the role of product quality in achieving competitive advantages. Some enterprises have been able to implement and certify a management system in accordance with the requirements of ISO 9001:2008, and subsequently - in accordance with the requirements of ISO 9001:2015, AS 9100:2016, ISO/TS 22163:2017, IATF 16949:2016, etc. At the same time, there came the understanding of the need for the economic evaluation of the quality management system and there was initiated the implementation of quality costs management. To compete in the market, businesses in a developing country need to use quality cost management to implement preventive measures that reduce the costs of failures, reduce appraisal costs, assessment, and continually analyze results to further focus efforts on preventing failures [2]. Quality cost management is important for improving the efficiency and effectiveness of the quality management system and for improving the economic performance of enterprises [3]. Implementing the quality cost management is important for better understanding and control of processes, achieving costs reduction goals without reducing product quality and customer satisfaction [4].

To reduce the cost of sales is one of the tasks of quality costs management. The manufacturing equipment and technology of most machine-building enterprises in Ukraine are quite outdated. Without the radical replacement of production capacities and the change of production processes to modern and productive ones, machine-building enterprises will not be able to hold the pressures of competition for a long time. Therefore, reducing the cost of sales can provide additional competitive advantages using price competition and the opportunity to earn more profit for investing in technological re-equipment of production. Technological re-equipment will help reduce non-production losses and increase productivity.

The first stage of the study is analyzing the impact of the cost of sales and different types of the costs on net income from the sale of products of machine-building enterprises. Net income from the sale of products is a component of income generation. Determining the impact of cost of sales on net income from the sale of products is a prerequisite for the second

stage of the study: identifying quality cost items that significantly affect the cost of sales of engineering enterprises.

The analysis of the quality costs, cost of sales and net income from the sale of products can be used for operational and strategic management, as well as for the realization of opportunities for optimizing the quality costs and increasing the profitability of machine-building enterprises.

## **2. Literature review**

Scientists study different ways of classifying, calculating, accounting, assessing and forecasting quality costs, analyze their impact on profitability. However, the aspect of the impact of quality cost items on some economic indicators of the enterprise, namely cost of sales, is not actually studied by the scientists, especially in Ukraine, that creates an urgent problem. For example, O. Polishchuk [5] studies the structural elements of quality costs and systemizes their classification. In his work, W. Sadkowski [6] investigates the nature of quality costs calculation and classifies quality costs calculation models. K. Antonyuk [7] analyzes the efficiency of the quality management system and approaches to the classification of costs and profit from the quality management on the machine-building enterprise. The researcher also offers a quality cost analysis technique and indicates the share of quality costs to production costs.

According to C. Raßfeld et al. [8], the German companies in the manufacturing and service industries measure the effectiveness and the efficiency of quality management systems. Their study gives an insight how quality-related costs, benefits, and profitability are assessed. According to O. Khadzhynova [9] an important component of the enterprise costs management system is the analysis and evaluation of the effectiveness of the quality system, the application of economic indicators. The author also points out that an effective quality costs system positively affects the profit of the enterprise. L. Emmanuel et al. [10] conduct the detailed analysis of the quality costs on the calculation items, identify the data to be taken into account for calculating the quality costs and explain the procedure for determining the quality cost index.

M. Sansalvador and J. Brotons [11] emphasize the importance of managing quality costs in integrated quality management and the need to use linear regression to predict quality costs. However, the study points to poor data reliability because of the invaluable hidden quality costs. In their study, A. Sailaja et al. [12] analyze all the direct elements of quality costs as well as the hidden costs of quality. It is concluded that the hidden costs of quality exceed the direct costs more than three times and significantly affect the results of the organization. P. Crosby [13] emphasizes that enterprises are able to determine only the sixth of the quality costs at the Awakening stage. Only with the development of quality management functions in the enterprise does the system of quantitative estimation of the quality costs improve and the reporting values become closer to the real ones.

The problem of identifying determinants of quality cost items at machine-building enterprises, especially in Ukraine, has not been disclosed. The impact of the quality cost items on the cost of sales at the machine-building enterprises in Ukraine has not been researched properly. Identifying such items will help to increase the efficiency of quality costs planning and management decisions. This makes the choice of this study correct and relevant within the framework of the machine-building enterprises of Ukraine.

## **3. Methodology and Research Methods**

The data for the first stage of the study are the information on the financial statements of five machine-building enterprises of Ukraine for the period from 2002 to 2018. The input for the

calculation contains annual results by the following indicators: net income from the sale of products, production costs, administrative expenses, sales expenses, other operating expenses, depreciation.

For the second stage of the study, the authors use data from 2016 to 2018 from one of the Ukrainian machine-building enterprises. The company has the system of monitoring and managing the quality costs. The output for making and estimating the regression model contains monthly costs data for each cost item and cost of sales according to the financial statements. 30 quality cost items are identified on the researched enterprise: new product development projects, re-equipment of basic production, re-equipment of ancillary production, implementation of quality management system, consulting services on the implementation of quality management system, maintenance and repair of equipment, tool maintenance and repair, remuneration of internal auditors, social payments to internal auditors, business trips on quality issues, external audit of quality management system, training on quality issues, pre-sales training, product audits, under conformity of products, labour remuneration of laboratory workers, social deductions for laboratory workers, non-capital costs for quality improvement, costs of laboratory 1, costs of laboratory 2, costs of laboratory 3, testing in third-party organizations, payroll of controllers and social payments to controllers, technology casting losses, technological losses during heat treatment, losses from internal nonconformities, losses during equipment debugging, internal costs for improving and repairing the products, warranty costs, costs of legal disputes and compensation. During the study, the authors establish the condition: all quality cost items are identified effectively and each cost item equally influences the total quality costs. Input data are obtained from the financial information of enterprises on the web-site of Stock market infrastructure development agency of Ukraine and official web-sites of enterprises, as well as specified by the managers of the enterprises [14-19].

An effective method of determining the impact of the factors on the resulting indicator is the correlation and regression analysis. Multiple regression is used to establish the relationship between many factors and the resulting indicator. The description of the regression equation is to find the approximations for the function  $F(X)$  that are based on the source statistics. The general linear regression model can be summarized as follows [20, p. 66].

$$y = a_0 + a_1 \cdot x_1 + a_2 \cdot x_2 + \dots + a_m \cdot x_m + \varepsilon, \quad (1)$$

where  $y$  is the resultant indicator (determinant, dependent variable);

$x_1, x_2, \dots, x_m$  are factors (regressors, independent variables);

$a_1, a_2, \dots, a_m$  are factor coefficients (model parameters);

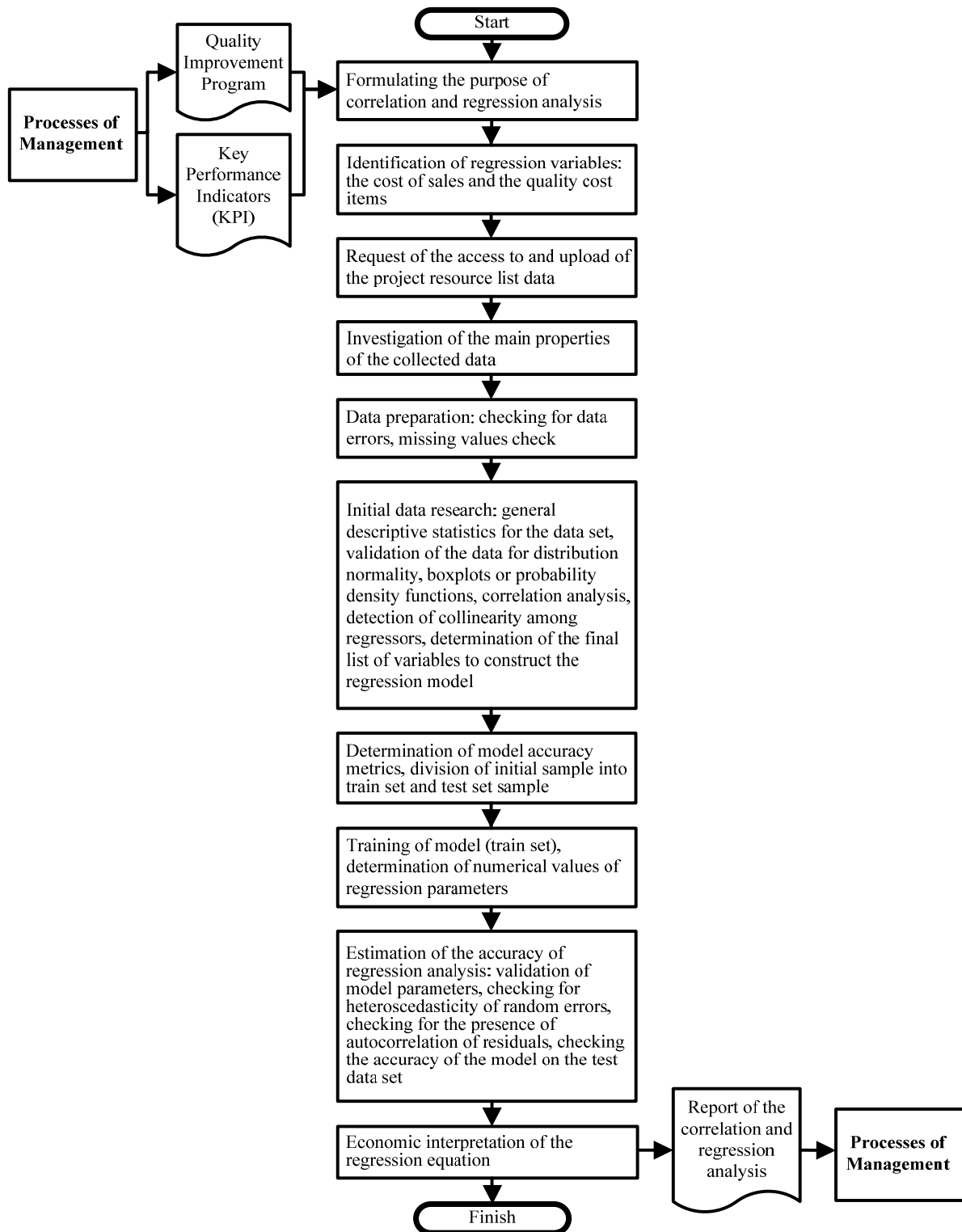
$a_0$  is a free term that determines the value of  $y$  provided that the values of the factors are zero (intersection with the  $y$ -axis);

$\varepsilon$  is the accidental error of regression dependence.

The authors use a special free open source software environment R for the calculation. Statistical processing of data and work with graphs provides greater reliability of the results of correlation and regression analysis and allows to shape the results of the study properly.

The analysis of the impact of cost quality items on the cost of sales is conducted for a single enterprise due to insufficient data on enterprises for their statistical processing. Therefore, the study provides a general algorithm for conducting a correlation and regression analysis of the cost of sales and the quality costs using the software environment R (Figure 1).

This algorithm is constructed from the point of view of the process approach and can be applied for practical purposes at machine-building enterprises.



**Figure 1.** The general algorithm of the process of correlation and regression analysis of the cost of sales and the quality costs. *Source: developed by the authors*

### 3. Results

**The first stage of the study:** The initial data set contains five economic indicators related to net income from the sale of products (Y): cost of sales (X1), administrative expenses (X2), sales expenses (X3), other operating expenses (X4), depreciation (X5). For each of the studied enterprises, the analysis results of the impact of factors on the resultant indicator are given in Tables 2-6.

**Table 2.** Results for the enterprise 1. *Source: developed by the authors*

	<b>Coefficients</b>	<b>Standard error</b>	<b>Student's t-test</b>	<b>P-value</b>
<b>Determinant</b>	-4.380e+04	3.248e+04	-1.348	0.207
<b>X1</b>	1.267e+00	5.4850e-02	21.663	9.82e-10
<b>X5</b>	2.824e+00	1.090e+00	2.590	0.027

The following model is obtained as a result of the correlation and regression analysis for the enterprise 1.

$$y = -43800 + 1.267 \cdot x_1 + 2.824 \cdot x_5 .$$

**Table 3.** Results for the enterprise 2. *Source: developed by the authors*

	<b>Coefficients</b>	<b>Standard error</b>	<b>Student's t-test</b>	<b>P-value</b>
<b>Determinant</b>	-59384.230	74452.291	-0.798	0.4406
<b>X1</b>	1.258	0.082	15.370	2.94e-09
<b>X3</b>	3.046	1.171	2.600	0.0232
<b>X4</b>	-0.080	0.044	-1.808	0.0957
<b>X5</b>	-2.858	1.441	-1.982	0.0708

The following model is obtained as a result of the correlation and regression analysis for the enterprise 2.

$$y = -59384.230 + 1.258 \cdot x_1 + 3.046 \cdot x_3 - 0.080 \cdot x_4 - 2.858 \cdot x_5 .$$

**Table 4.** Results for the enterprise 3. *Source: developed by the authors*

	<b>Coefficients</b>	<b>Standard error</b>	<b>Student's t-test</b>	<b>P-value</b>
<b>Determinant</b>	4740.348	2858.879	1.658	0.1232
<b>X1</b>	1.132	0.048	23.591	2.01e-11
<b>X3</b>	2.837	1.559	1.819	0.0939

The following model is obtained as a result of the correlation and regression analysis for the enterprise 3.

$$y = 47404.348 + 1.132 \cdot x_1 + 2.837 \cdot x_3 .$$

**Table 5.** Results for the enterprise 4. *Source: developed by the authors*

	<b>Coefficients</b>	<b>Standard error</b>	<b>Student's t-test</b>	<b>P-value</b>
<b>Determinant</b>	-90463.245	25288.275	-3.577	0.007217
<b>X1</b>	1.183	0.043	27.638	3.17e-09
<b>X3</b>	6.030	0.851	7.086	0.000103
<b>X4</b>	0.433	0.095	4.533	0.001917
<b>X5</b>	-0.997	0.209	-4.767	0.001413

The following model is obtained as a result of the correlation and regression analysis for the enterprise 4.

$$y = -90463.245 + 1.183 \cdot x_1 + 6.030 \cdot x_3 + 0.433 \cdot x_4 - 0.997 \cdot x_5 .$$

**Table 6.** Results for the enterprise 5. *Source: developed by the authors*

	<b>Coefficients</b>	<b>Standard error</b>	<b>Student's t-test</b>	<b>P-value</b>
<b>Determinant</b>	580.840	958.487	0.606	0.558
<b>X1</b>	1.10618	0.03018	36.656	5.43e-12
<b>X5</b>	-1.17032	0.9187	1.274	0.232

The following model is obtained as a result of the correlation and regression analysis for the enterprise 5.

$$y = 580.840 + 1.106 \cdot x_1 - 1.170 \cdot x_5 .$$

The results of the F-test, Breusch-Pagan test and Durbin-Watson test summarize in Table 7 that the heteroskedasticity of random errors and the autocorrelation of residuals are absent in each of the created regression models.

**Table 7.** Data from the F-test, Breusch-Pagan test and Durbin-Watson test for enterprise models 1-5. *Source: developed by the authors*

<b>Enterprise</b>	<b>1<sup>st</sup></b>	<b>2<sup>nd</sup></b>	<b>3<sup>rd</sup></b>	<b>4<sup>th</sup></b>	<b>5<sup>th</sup></b>
<b>Determination coefficient</b>	0,9836	0,9692	0.992	0.9924	0.9927
<b>F-statistics</b>	299,3	94,37	744.4	261.7	676.3
<b>P-value</b>	1.197e-09	5.829e-09	2.614e-13	1.645e-08	2.129e-11
<b>Breusch-Pagan statistics</b>	0,13448	2,1389	4.8931	0.558729	0.15108
<b>P-value</b>	0.935	0.7102	0.08659	0.9645	0.9272
<b>Durbin-Watson statistics</b>	1.4677	2,0027	1.9073	2.2628	1.647
<b>P-value</b>	0.1072	0.2997	0.3451	0.2134	0.1135

Having analyzed the regression models obtained for five enterprises, the authors can state that the cost of sales is the largest contribution to the dependent variable of the net income from the sale of products. A plus sign of the coefficient for the variable X1 in each model means that as the cost of sales increases, the net income from the sale of products of the enterprises increases.

**The second stage of the study:** The initial dataset contains information on the cost of sales (Y) and thirty indicators that characterize the quality cost items: new product development projects (X1), re-equipment of basic production (X2), re-equipment of ancillary production (X3), implementation of quality management system (X4), consulting services on the implementation of quality management system (X5), maintenance and repair of equipment (X6), tool maintenance and repair (X7), remuneration of internal auditors (X8), social payments to internal auditors (X9), business trips on quality issues (X10), external audit of quality management system (X11), training on quality issues (X12), pre-sales training (X13), product audits (X14), under conformity of products (X15), labour remuneration of laboratory workers (X16), social deductions for laboratory workers (X17), non-capital costs for quality improvement (X18), costs of laboratory 1 (X19), costs of laboratory 2 (X20), costs of laboratory 3 (X21), testing in third-party organizations (X22), payroll of controllers and social payments to controllers (X23), technology casting losses (X24), technological losses during heat treatment (X25), losses from internal nonconformities (X26), losses during equipment debugging (X27), internal costs for improving and repairing the products (X28), warranty costs (X29), costs of legal disputes and compensation (X30).

The following actions are performed in the study of initial data: review of general descriptive statistics for the dataset, validation of data for distribution normality using the

Shapiro-Wilk test [21], verification of multicollinearity among factors through the calculation of general and individual diagnostic metrics [22].

The following variables are selected to construct the regression model: tool maintenance and repair (X7), product audits (X14), payroll of controllers and social payments to controllers (X23), losses from internal nonconformities (X26).

For the studied enterprise, the analysis results of the impact of factors on the resultant indicator are given in Table 8.

**Table 8.** Results of the influence analysis of the factors on the resultant indicator for the studied enterprise. *Source: developed by the authors*

	Coefficients	Standard error	Student's t-test	P-value	Lower Confidence Interval Limit (2.5%)	Upper Confidence Interval Limit (2.5%)
<b>Determinant</b>	-56614.15	23609.83	-2.398	0.02500	-105454.80	-7773.50
<b>Tool maintenance and repair</b>	42.50	10.50	4.047	0.00050	20.78	64.23
<b>Product audits</b>	-679.03	127.07	-5.344	2e-05	-941.91	-416.16
<b>Payroll of controllers and social payments to controllers</b>	217.47	70.66	3.077	0.00532	71.29	363.65
<b>Losses from internal nonconformities</b>	31.34	12.65	2.478	0.02097	5.18	57.50

The magnitudes of the p-values in Table 8 indicate that the regressors have different levels of statistical significance: tool maintenance and repair, product audits - the lowest p-values (the lowest p-value is 0.00002), and losses from internal nonconformities are at a significance level of 0.02097.

The coefficient of determination is 0.8843. The value of F-statistics, which tests the hypothesis of the significance of regression, is generally 43.93 with a p-value of 1.895e-10, which allows considering this regression to be significant.

In determining the adequacy of the model, there is a check for the presence of heteroskedasticity using the Breusch-Pagan test [23] and the Goldfeld-Quandt test [24]. The heteroskedasticity hypothesis is tested using the p-values of these statistics: if the p-value is less than the given significance level of 0.05, then heteroscedasticity is significant.

The value of the Breusch-Pagan statistics is 4.3162, the p-value is 0.3649, so the Breusch-Pagan test does not confirm the presence of heteroscedasticity. The value of the Goldfeld-Quandt statistic is 0.88204, the p-value is 0.5726, so the Goldfeld-Quandt test does not confirm the presence of heteroscedasticity.

To test for the presence of autocorrelation of residuals [25], this study uses the well-known first-order Durbin-Watson autocorrelation criterion [26]. The calculated Durbin-Watson statistics are 1.6889, p-value = 0.1309, so we can accept the hypothesis that there is no first-order autocorrelation of residuals. Additionally, the Breusch-Godfrey test is performed to detect the second-order autocorrelation. The Breusch-Godfrey statistic is calculated to be 0.95991, p-value = 0.6188, so we can accept the hypothesis that there is no second-order autocorrelation.

The results of the study confirm the significant impact of individual quality cost items on the cost of sales.

The following model is obtained because of the correlation and regression analysis for the studied enterprise.

$$y = -56614.15 + 42.50 \cdot x_7 - 679.03 \cdot x_{14} + 217.47 \cdot x_{23} + 31.34 \cdot x_{26} .$$

This model allows to analyze the production cost on four factors:  $x_7$  – tool maintenance and repair,  $x_{14}$  – product audits,  $x_{23}$  – payroll of controllers and social payments to controllers,  $x_{26}$  – losses from internal nonconformities.

Due to the limited data set for the dissemination of results to a group of machine-building enterprises, the results of the impact of individual quality cost items on the cost of sales are obtained on the example of a single enterprise. The future research may be directed to the analysis of the impact the quality cost items on the cost of sales for a larger set of machine-building enterprises in order to identify common trends.

#### 4. Conclusions

This study is the attempt to supplement the literature on the analysis of quality costs in machine-building enterprises by examining their impact on the cost of sales and estimating the fluctuation in the cost of sales on the net income from the sale of products. The top management of machine-building enterprises of Ukraine has obviously realized the need and is taking steps to improve the quality of products by managing the quality costs. The results of the study indicate a significant impact of the cost of sales on the formation of the net income from the sale of products of machine-building enterprises. In addition, the results of the study indicate the significant impact of individual quality cost items on the cost of sales. Such judgments can be true for many machine-building enterprises. However, at this stage of the development of quality management systems, the hidden quality costs have not been recorded yet and it is necessary to make sure that the same items of quality costs have a significant impact on the cost of sales. The results show that certain items of quality costs affect the revenues of machine-building enterprises. Therefore, managers' focus on identifying and planning such quality cost items is an opportunity to reduce the cost of sales and increase the profits of machine-building enterprises. The authors hope that the results of the study will give machine-building managers a new understanding and reveal some practical aspects of quality costs analysis.

In order to improve the management of quality costs in machine-building enterprises, the researchers believe it is important:

- to ensure that quality costs data is complete for key areas of activity,
- to introduce the systematic collection of quality cost data,
- to implement the automated means of obtaining data on quality costs;
- to ensure that there are management decisions that will reduce the quality costs based on their detailed analysis.

The future research may be directed to the analysis of the impact the quality cost items on the cost of sales for a larger set of machine-building enterprises in order to identify common trends.

#### 5. Author Contributions

M.S. has contributed 80% to the development of the research – conceptualization, data collection, research methodology, analysis, concluding sections, visualization, and writing-original draft preparation. O.M., N.G., and M.M. have contributed 20% to preparing the manuscript (in equal parts) – data collection, analysis, revision, and formatting. All authors have read and approved the final manuscript.

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