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Assessing the impact of integrating lean manufacturing methods into the quality management system on the efficiency of a mechanical engineering enterprise

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Abstract:

This article presents the results of improving the quality management system in mechanical engineering enterprises based on the principles of lean manufacturing and evaluates the effectiveness of the proposed integrated management model. The study harmonized the requirements of ISO 9001 and IATF 16949 standards, the process approach, and lean manufacturing tools such as value stream mapping, 5S, Muda-Mura-Muri, 5Why, 4M, Kanban, just-in-time delivery, quick changeover, total productive maintenance, statistical process control, and failure mode and effects analysis. The effectiveness of the improvements was determined based on expert evaluation criteria covering the subsystems of strategic management, personnel activities, and production processes.

Keywords:

quality management system, lean manufacturing, mechanical engineering, ISO 9001, IATF 16949, value stream mapping, 5S, process efficiency, expert assessment, Pearson correlation, Student's t-test, continuous improvement

1. Introduction

In the mechanical engineering industry, simultaneously ensuring product quality and production efficiency is a key factor that determines the competitiveness of enterprises. The growing complexity of modern engineering products, stricter requirements for technological precision, shorter delivery times, and rising consumer demands are limiting the ability to manage production processes solely through final product inspection. Such conditions require building quality directly into the production process, identifying potential defects before they occur, using resources rationally, and reducing non-value-adding activities.

The ISO 9001 standard stipulates that quality management should be organized based on a process approach, risk-based thinking, leadership accountability, and continuous improvement [1]. In automotive manufacturing and its component-producing enterprises, these requirements are further elaborated by the IATF 16949 standard [2]. However, the certification of a management system does not always automatically guarantee a reduction in production losses, shorter cycle times, or increased resource utilization efficiency.

The theoretical and practical foundations of the lean manufacturing concept are centered on eliminating activities from production processes that do not create value for the consumer. The Toyota Production System, formulated by T. Ohno, established the identification and reduction of waste as a crucial condition for increasing production efficiency [3]. J. Womack and D. Jones systemized the principles of value, value stream, continuous flow, pull production, and continuous improvement as the core components of lean manufacturing [4]. J. Liker, in turn, emphasizes that the effectiveness of this approach depends not only on

individual technical tools but also on management culture, employee involvement, and continuous improvement [5].

Value stream mapping enables the systematic analysis of processes and the identification of non-value-adding operations [6]. Research by Shah and Ward has also shown that implementing lean manufacturing practices as a set of interconnected tools, rather than as separate methods, has a stronger impact on enterprise performance [7]. Holweg analyzed the evolution of lean manufacturing and substantiated its transformation from a simple set of production tools into a comprehensive management concept [8].

Recent research has focused on the issues of integrating quality management and lean manufacturing. Bacoup et al. demonstrated the need to harmonize loss reduction principles with standardized management mechanisms when transitioning from a quality management system to a lean quality management system [9]. Yadav and Desai substantiated the need for a systemic mechanism that combines organizational, technological, and human factors for the effective implementation of lean manufacturing [10]. It has also been noted that integrating ISO standards with lean management principles serves not only to ensure compliance with standard requirements but also to increase operational efficiency within an enterprise [11, 12].

Nevertheless, the issue of harmonizing the quality management system and lean manufacturing in machine-building enterprises, implementing them based on a unified management model, and comprehensively evaluating the results based on quality, process, and economic indicators has not been sufficiently systematized.

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2. Research methodology

The study encompassed the production activities of machine-building enterprises, their quality management processes, and the mechanisms for applying lean manufacturing tools. The practical research was conducted on the cases of “Andijan Freight Car Building and Repair Plant” JSC, “Asaka Davr Butlovchi” LLC, and “Nawas” LLC. The impact of the proposed improvement model on production processes was analyzed in greater detail using the example of “Asaka Davr Butlovchi” LLC.

The research methodology was based on the requirements of the ISO 9001 and IATF 16949 standards. During the study, methods of analysis and synthesis, comparison, systematic and process-based approaches,

expert assessment, observation, grouping, and mathematical statistics were utilized.

3. Results and Discussion

The initial expert assessment revealed that while elements of quality management were present in the machine-building enterprises, the principles of lean manufacturing had not been formed into a unified system across all management levels. Notably, the processes subsystem recorded the lowest result with 4.6 points. Strategic management was rated at 5.2 points, and employee performance at 5.5 points.

After the implementation of the improvement model, positive changes were observed across all subsystems.

Table 1

Results of the expert assessment before and after improvement

Subsystem	Previous state, score	Subsequent state, score	Absolute change	Post/Pre Index, %
Strategic management	5.19	7.03	+1.84	135.45
Employee performance	5.54	7.34	+1.80	132.49
Production Processes	4.60	6.76	+2.16	146.96

An increase in the strategic management assessment score from 5.19 to 7.03 points represents a relative improvement of 35.45%. Positive changes were noted in the areas of clarity of strategic direction, personal involvement of leadership, formation of key performance indicators, and systematic monitoring of consumer demand.

The average score for employee activities increased from 5.54 to 7.34 points. The involvement of employees in lean manufacturing, along with improvements to the motivation system, mechanisms for encouraging

rationalization proposals, and the development of internal leaders, influenced this result.

The largest absolute change was observed in the production processes subsystem, where the average score increased from 4.60 to 6.76 points. This result demonstrates the effectiveness of practical measures aimed at 5S, visual management, waste identification, production flow coordination, and in-process quality control.

After the improvements, not only did the average values increase, but the dispersion of the assessment results also decreased significantly.

Table 2

Descriptive statistics of the expert assessment results

Subsystem	State	Mean	Variance	Standard deviation	Coefficient of variation, %
Strategic management	Before	5.19	1.88	1.37	26.33
Strategic management	After	7.03	0.62	0.79	11.25
Personnel	Before	5.54	1.77	1.33	24.04
Personnel	After	7.34	0.39	0.63	8.65
Processes	Before	4.60	0.92	0.96	20.77
Processes	After	6.76	0.64	0.80	11.89

In the strategic management subsystem, the dispersion decreased from 1.88 to 0.62, in the personnel subsystem from 1.77 to 0.39, and in the production processes subsystem from 0.92 to 0.64. The decrease in the coefficient of variation across all subsystems indicates that the evaluation results

have stabilized. In particular, the reduction of the coefficient variation from 24.04% to 8.65% in the personnel subsystem signifies that the disparity in the development of system elements has substantially narrowed.

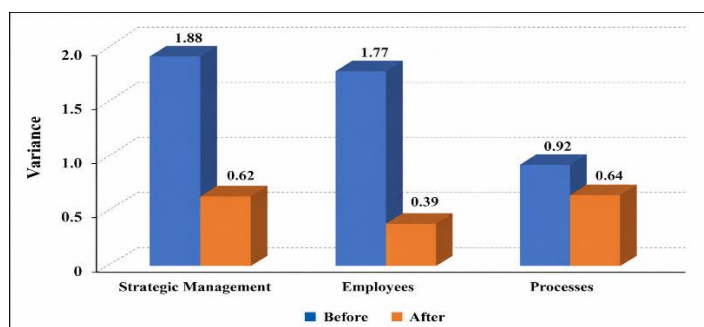


Fig. 1. Comparison of dispersion based on evaluation results

The Pearson correlation coefficient was calculated to determine the relationship between the previous and subsequent evaluations.

Table 3

Correlation between previous and subsequent expert evaluations

Subsystem	n	Pearson coefficient, r	Student's T-test, t	Result
Strategic management	7	0.9926	18.22	statistically significant
Personnel	5	0.9884	11.28	statistically significant
Processes	9	0.9334	6.88	statistically significant

For all subsystems ($r > 0.9$), a very strong positive correlation was found between the previous and subsequent indicators. This indicates that the growth after the improvements was not due to random changes in individual indicators but rather occurred consistently across all evaluation items.

The calculated values from the student's t-test were higher than the critical values at the corresponding degrees of freedom, which confirmed the statistical significance of the identified correlations at the $\alpha = 0.05$ level.

The improvement model also had a positive effect on the direct technological indicators of production.

Table 4

Key Production Indicators After Model Implementation

Indicator	Before	After	Change
Operation time per part	9.5 minutes	8.7 minutes	-0.8 minutes
Share of defective products	1.8%	1.2%	-0.6 percentage points
Effectiveness of management decision-making	80%	90%	+10 percentage points

The reduction in operation time from 9.5 minutes to 8.7 minutes shows a time saving of approximately 8.4% per operation. The decrease in the share of defective products from 1.8% to 1.2% signifies a reduction of about 33.3% from the initial level. The effectiveness of management decision-making increased from 80% to 90%.

The economic efficiency of the model was achieved by shortening the production cycle time, reducing labor intensity, optimizing the volume of work-in-progress, and using material resources more efficiently.

Table 5

Economic Results of Implementing the Improvement Model

Enterprise	Economic benefit achieved	Payback period
"Nawas" LLC	130 million UZS	1.2 years
"Asaka Davr Butlovchi" LLC	138.4 million UZS	2.2 year's
"Andijan Freight Car Building and Repair Plant" JSC	146 million UZS	2.05 years

These results confirm that the proposed model is not limited to improving quality indicators but also has a positive effect on the economic efficiency of production processes.

DISCUSSION

The results obtained indicate that a quality management system and lean manufacturing should not be viewed as independent management approaches, but rather as interconnected elements of a single system. While a quality management system creates the institutional framework for regulating processes, defining responsibilities, monitoring results, and managing non-conformities, lean manufacturing complements this system by providing tools to identify waste, accelerate flows, and increase resource utilization efficiency.

This conclusion is consistent with the approach proposed by Shah and Ward, which advocates for applying lean manufacturing tools as a set of interconnected practices [7]. The study's finds that the process subsystem improved from 4.60 to 6.76 points-a higher rate of improvement compared to other subsystems-also demonstrates the direct impact of practical lean tools within the production environment.

However, the results also showed that the effectiveness of lean manufacturing is not determined solely by individual tools such as 5S, Kanban, or value stream mapping.

Employee motivation, senior management involvement, the availability of key performance indicators, and a system for regular monitoring of results are crucial factors for the sustainable operation of the system. This aspect aligns with the concept, put forward by J. Liker, of viewing lean manufacturing in conjunction with management philosophy and corporate culture [5].

Another important feature of the proposed model is that it treats quality and efficiency not as separate outcomes but as mutually formative indicators. For example, 5S and standardization not only improve workplace organization but also reduce unnecessary movements, shorten operation times, and decrease the likelihood of errors. Value stream mapping, in addition to identifying waiting, excess inventory, and repetitive operations, also indicates at which points process control needs to be strengthened. While FMEA and statistical process control serve to enhance quality stability, Kanban and demand-driven management optimize the flow of materials.

The lean quality management approach proposed by Bacoup et al. also presents the integration of standardized management system mechanisms with lean manufacturing principles as a factor that enhances efficiency [9]. The concurrent improvement of research results at the strategic



management, personnel, and process levels suggests that this approach is also applicable to machine-building enterprises.

A key finding of the descriptive statistical analysis is that the improvements resulted not only in an increase in average scores but also in a decrease in the variance and coefficients of variation. This indicates that the gap between the strong and weak elements within the system has narrowed. For instance, the decrease in the coefficient of variation in the personnel activities subsystem from 24.04% to 8.65% signifies that activities, which were previously individual initiatives, have evolved into a more systematic management practice.

The Pearson correlation results further support this conclusion. The strong positive correlations in strategic management ($r=0.9926$), the personnel subsystem ($r=0.9884$), and processes ($r=0.9334$) indicate that their overall level has increased while preserving the relative structure of the pre-improvement evaluation items. Therefore, the model served not to artificially inflate specific indicators but to systematically elevate the existing management system to a higher level of development.

Changes in production indicators also confirm the consistency of expert evaluations with practical results. The reduction in operation time, decrease in the share of defective products, and increase in the effectiveness of management decisions show that the positive shifts in expert evaluation results are also reflected in real technological processes.

Thus, integrating the standardized requirements of a quality management system with the loss-reduction tools of lean manufacturing allows machine-building enterprises to enhance quality, efficiency, and economic outcomes within a single management framework.

4. Conclusion

The research, conducted based on the integration of the quality management system and lean manufacturing methods in machine-building enterprises, yielded the following scientific and practical results.

First, an improvement model was developed that harmonizes the requirements of ISO 9001 and IATF 16949 with the principles of lean manufacturing. This model encompasses process analysis, loss identification, determination of priority improvement areas, selection of appropriate tools, implementation, and monitoring of results.

Secondly, because of implementing the model, the average score for the strategic management subsystem improved from 5.2 to 7.0 points, employee performance from 5.5 to 7.3 points, and production processes from 4.6 to 6.7 points. The most significant change was observed in the production processes subsystem.

Thirdly, the decrease in variance, standard deviation, and coefficients of variation across all subsystems after the improvements indicates that the management system has stabilized and the development gap between its individual elements has narrowed.

Fourthly, a very strong positive correlation was identified between the initial and subsequent expert assessments. The following values were obtained: for strategic management ($r=0.9926$), for personnel ($r=0.9884$), and for processes ($r=0.9334$). Using the Student's T-test, it

was confirmed that the correlations are statistically significant at a 95% confidence level.

Fifthly, because of the model's practical implementation, the operation time per part decreased from 9.5 to 8.7 minutes, the proportion of defective products fell from 1.8% to 1.2%, and the effectiveness of management decision-making increased from 80% to 90%.

Sixth, as a result of reducing production cycle time, labor intensity, and work-in-progress volume, as well as optimizing the use of material resources, an economic effect of 130 million sums was achieved at "Nawas" JV LLC, 138.4 million sums at "Asaka Davr Butlovchi" LLC, and 146 million sums at "Andijan Freight Car Construction and Repair Plant" JSC.

The research results showed that the complex integration of the quality management system and lean manufacturing tools is an effective mechanism for stabilizing quality, reducing waste, improving production processes, and increasing economic efficiency in machine-building enterprises.

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