Ensuring sustainable development of enterprises based on lean production methodologies and six sigma

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Abstract. In the article, the main goals, principles, and methods of Lean Manufacturing are thoroughly examined, taking into account the experience of its implementation in various enterprises and organizations. This analysis is based on scientific publications regarding the implementation of Lean Manufacturing tools and technologies in recent years. The article also analyzes the sustainable development of the main approaches to the combined use of Lean Production technologies and the Six Sigma concept, considering the current economic situation. An example of a successful integration of Lean Manufacturing approaches and the Six Sigma concept is provided.

1 Introduction

Lean production (Lean manufacturing, Lean production) is a production philosophy that has been formed based on Japanese management concepts, answering the question of how to do more and better while spending less. In the mid-20th century, lean production emerged as a methodology for managing production and businesses, primarily in the automotive industry [1] (Krafcik, 1988). Many well-known manufacturing companies have successfully used lean technologies for several decades, proving their effectiveness: Boeing, Porsche, John Deere, Ford, GAZ Group, Rosatom, and others. Lean production tools are used not only in industry. There are examples of their successful application in areas such as banking, logistics, healthcare, construction, trade, administrative management, and education systems [2].

The main goal of Lean is to create product value, and frugality and savings of material and time resources are just consequences that create competitive advantages. Taiichi Ohno, a top manager at Toyota and one of the main ideologists of Lean, said: "To follow Lean means to give the customer what he wants, how much he wants, and when he wants it." Therefore, lean technologies are primarily about customer orientation, and only then about careful use of resources. This approach has proven to be quite effective. The consumer receives the product they need of high quality at the right time, and the producer saves resources significantly and does not lose profit.

Many studies and publications are devoted to the effectiveness of lean manufacturing
technologies [3]. The application of Lean is considered as a concept that allows minimizing
time, labor, and material losses at all stages of creating a product or service that represents
value for consumers. Let's list the main factors that affect resource losses:

1. Overproduction: This is the main factor of resource loss. It requires costs related to
production, transportation, and storage of unsold products. It does not guarantee profit
if the produced product is not in demand.

2. Excess inventory: This acts as a factor of financial costs. The need for proper storage
and accounting of produced or purchased materials is also an additional factor.

3. Unfinished production and waiting: This acts as a factor of financial costs. It requires
additional expenses, similar to excess inventory.

4. Incorrect logistics: This acts as a factor that determines transportation costs. It consumes
company resources that are accounted for in the cost of the finished product but do not
add value to the product for the consumer.

5. Defective products: This acts as a factor requiring resources for reissuing and disposing
of defective products.

6. Unnecessary stages of production processes: These act as factors of time costs. They
require changes in the technological chain and actions of personnel by eliminating
unnecessary stages without harming the final product.

7. Imperfect technology: This acts as a factor of insufficient production capacity and lack
of technological capabilities, preventing meeting all consumer demands for the product
(both quantitative and qualitative).

8. Incorrect personnel management: This acts as a factor of non-rational use of time costs
and unrealized potential of personnel.

In this regard, the elimination or minimization of the above-mentioned losses serves as
the basis for the concept of lean production. To achieve these goals, careful planning and
phased implementation of several processes are necessary.

Herman Khatkov (Editor at Skillbox Media) suggests an original approach to defining the
goals of lean production in his publication "Telling about Lean Production - a system that
helped transform Japan" [4]. According to the author, the main goal of implementing lean
production is to find so-called "bottlenecks", which are technological operations or stages of
production that slow down or stop the production process. To expand these "bottlenecks,"
the following measures are proposed:

- Conducting analysis and identifying the strengths and weaknesses of the business.
- Formulating a list of goals and results that require achievement through lean production
methods.
- Selecting lean production tools necessary to achieve the set goals and results.

Essentially, the author uses a hybrid approach to implementing lean production
principles, suggesting adapting lean production technology to the company's business
processes: "When implementing lean production, it is important to integrate new
technologies into the system without breaking it - after all, the business is already making
money from this system. A flexible approach will help strengthen the company's strengths
and mitigate its weaknesses. This will lead to rapid and multiple growth in economic
results..." [4]. To achieve goals and implement lean production technologies, it is impossible
without using appropriate rules, methods, and tools. The most comprehensive modern set of
tools used in lean production implementation and issues of evaluating its effectiveness are
presented in O.V. Vershinin's publication "How Lean Production Helps and Which
Businesses It Is Suitable For" [5], which examines the most common tools used by various
enterprises around the world in lean production for many years.
2 Materials and methods

Another important aspect of implementing lean production is evaluating its effectiveness. Vershinin O.V. suggests evaluating the effectiveness of implementing lean production and its impact on business processes using traditional methods, including the use of Little's Law [6]. According to the developers of the lean production system, its implementation can have a significant impact, leading to the following expectations after implementing lean production, taking into account its influence on the company's main business processes [5]:

- The possibility of reducing the manufacturing cycle time by 10-100 times.
- The possibility of reducing defects by 5-50 times.
- The possibility of reducing downtime by 5-20 times.
- The possibility of increasing labor productivity by 3-10 times.
- The possibility of reducing inventory by 2-5 times.
- The possibility of accelerating the introduction of new products to the market by 2-5 times.

Despite the optimistic assurances of developers and managers involved in the implementation of lean production technologies in industrial and commercial enterprises of the Russian business community, it seems reasonable to conduct an expert assessment of the effectiveness of lean production in three classic directions.

1. Management Reporting. Alignment of lean production philosophy with the company's development strategy, KPIs, management and employee engagement ratios, customer satisfaction index, etc.

2. HR Reporting. Implementation of professional training programs.

3. Production Reporting. Achievement of goals related to reducing losses, improving product quality, implementing production programs, optimizing supplier and dealer relationships, and enhancing customer service quality.

The use of lean production tools allows for an increase in the speed of production processes (a factor reducing the execution time of operations) and the efficiency of processes (reducing financial investments, lowering costs, and increasing the efficiency of investments). «Every service or product has certain things that it must do in order to perform acceptably from a customer’s viewpoint. Functional analysis breaks the service down into its key tasks. This will help generate multiple solution ideas for each function, usually displayed in a tree diagram» [6]. O.V. Vershinin suggests describing this relationship using Little's Law. In general, the law "...defines the lead time for a job or order as the ratio of the number of orders in the system to their execution rate...":

\[ T = \frac{W}{S} \]

where

- \( T \) — Average time spent to complete a process within the system.
- \( W \) — Average number of cycles (orders) in the system.
- \( S \) — Average process execution speed or system throughput.

Interesting results from a study of the relationship between the four types of Lean Six Sigma organizational culture [7]. The concepts of lean production, which are based on reducing the technological cycle time, are detailed in the article by Nikeshin P.O. titled "The Role of Lean Production in the Modern World" [8]. The notion of aligning the production process based on the discreteness of all actions performed by workers and their synchronicity is introduced. According to the proposed model, all participants in the production process should perform their actions in harmony, which, in turn, offers the following advantages: batch volumes are reduced, corresponding control is strengthened at production stages, and high product quality is ensured. Consequently, each participant is fully engaged, and there is an awareness of their personal contribution to achieving the company's maximum profit as a
goal. In fact, "the result emerges as that of a cohesive team, workplace conflicts diminish, employee motivation arises, and labor productivity increases.

3 Results

Furthermore, systematically implementing lean production technologies and tools links the investment component (investment input) with the resulting effect (in terms of increased process execution speed within the production cycle). There are three components of investments when implementing lean production tools:

1. Production investment component (modernization and purchase of new equipment).
2. Personnel investment component (employee training programs, engaging consulting with necessary competencies, recruitment policies for attracting new staff).
3. Optimization investment component (cost reduction program, optimization of production processes and technological cycles).

To maintain objectivity in the conducted research, it is necessary to acknowledge that the implementation of lean production, in addition to the obvious benefits associated with increased efficiency and returns on investment, also comes with several drawbacks. The primary ones are reflected in Table 1 presented below [8].

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Minimization of losses.</td>
<td>1. Supply Disruption Risks. The primary factor is associated with minimizing warehouse space.</td>
</tr>
<tr>
<td>1. Environmental component. Reduction in waste and emissions.</td>
<td>2. High levels of required investments related to the implementation of new technologies and modern equipment.</td>
</tr>
<tr>
<td>2. Optimization of working time costs.</td>
<td>3. Production Conflict Risks in case employees do not accept the concepts and tools of lean production.</td>
</tr>
<tr>
<td>3. Minimization of warehouse space.</td>
<td>4. Risks of reducing customer satisfaction levels in cases of supply failures and logistical disruptions.</td>
</tr>
<tr>
<td>4. Minimization of defects and defect detection at every production stage.</td>
<td>5. Challenges related to the formalization and standardization of production processes.</td>
</tr>
<tr>
<td>5. Enhancement of consumer properties of the final product.</td>
<td>6. Management risks associated with the complexity of implementing lean production tools.</td>
</tr>
<tr>
<td>6. Minimization of financial costs for organizing the production process.</td>
<td></td>
</tr>
<tr>
<td>7. Opportunity to implement a development strategy based on modern production organization approaches and the utilization of the latest advancements in modern technologies.</td>
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<tr>
<td>8. Pursuit of improvement. All employees continuously seek ways to enhance their own achievements and outperform competitors.</td>
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<tr>
<td>9. Implementation of a market penetration strategy based on product quality improvement (achieving the necessary level of customer satisfaction).</td>
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Nikeshin P.O. notes that the identified shortcomings of the lean production concept are mainly associated with inefficient organization of work, primarily at the initial stage of implementation. The issues of effectively implementing the lean production concept require
the search for ways to algorithmize actions for the implementation of lean production technologies. These issues are addressed in the work of Ganebnaya E.V. and Fokin O.V. "Agile Project Management in Lean Production" [9]. The article analyzes the possibility of integrating traditionally opposed Agile and Kanban approaches in the management of large-scale manufacturing enterprises and proposes an algorithm for implementing the lean production concept through the formation of small working groups functioning based on the Scrum methodology.

Currently, the spheres of application of lean production cover a wide range of manufacturing, financial, entrepreneurial, and governmental companies. As correctly noted by O.V. Vershinin in his article [5], the implementation of lean production usually begins (is realized) in enterprises that have encountered serious problems. Such problems may include: sharp decline in profitability, increase in the percentage of defective products, insufficient range of product assortment, presence of complaints and claims from customers.

In 2017, a series of state standards for lean production were developed in Russia [10]. "The standard is based on accumulated experience in improving the efficiency of activities and aims to increase customer satisfaction through effective application of the lean production management system. GOST R 56404 establishes general and universal requirements for the lean production management system, which can be applied to organizations of any business direction. Organizations that strive for recognition of their lean production management system can use this standard for certification and fulfillment of contractual obligations..." [10]. Another original approach to improving the efficiency of production business processes has been the "six sigma" methodology.

The contemporary concept of "six sigma" encompasses three methodological directions. The first one focuses on the philosophical aspect of "six sigma" as a movement. The other two directions represent the methodology for managing business processes and optimizing production processes. In the current economic reality, "six sigma" has emerged as one of the most sought-after methodologies for process management in both production and investment activities. 255 of the world's largest companies from the Fortune 500 list use "six sigma," including Amazon, Boeing, Ford, GlaxoSmithKline, and Samsung. It is one of the most widely implemented management concepts in the world.

The application of the "six sigma" methodology allows for the optimization of technological and production cycles of core business processes, achieving maximum return on investment by ensuring high-quality products while minimizing defects and waste. These goals are achieved through the application of tools based on specially developed management principles, as well as mathematical and statistical analysis and modeling methods.

The concept of "six sigma" as a methodology for implementing management processes was proposed in the 1980s by Bill Smith, a manager at Motorola. After the implementation of the management principles proposed by the "six sigma" concept in General Electric, the methodology gained wide recognition and popularity. Initially, the methodology was based on mathematical statistical methods adapted to production management by Japanese quality specialist Genichi Taguchi. The results of the analysis and conclusions of the "six sigma" methodology are based on the use of parametric and non-parametric statistical methods, which are used to test hypotheses about the degree of influence of various factors on achieving optimal parameters of business processes [11].

Thus, the "six sigma" methodology allows for reducing the standard deviation of a random variable from its mean value within a given tolerance range, using various methods and tools for managing business processes, primarily in the industrial sector.

In his article "Analysis of the Process Methodology of 'Six Sigma'" [12], Karamyshev A.N. notes that the application of the "six sigma" methodology aims to improve the quality of the produced product by optimizing and stabilizing the technological process and other business processes of the company.
The proposed classification allows for revealing six main principles for building the concept of "six sigma" [12].

1. Customer orientation (forming a genuine interest in satisfying customer needs).
2. Building decision-making algorithms based on statistical analysis methods.
3. Building corporate culture.
4. Application of process-oriented management methods (management focused on processes and their optimization. Process analysis is carried out within the framework of created working groups).
5. Adjustment of management processes considering changes in the external environment (emergence of new product requirements, creation of new consumer properties).

The "six sigma" concept serves as a process-oriented management that allows for optimizing production processes and ensuring a reduction in defects in finished products while continuously improving company performance. Based on the set tasks, the implementation of the "six sigma" concept can be presented in the form of three interconnected elements:

- Optimization of existing processes.
- Development and implementation of new processes.
- Control over current (operational) processes.

Let's formulate the main elements used as a methodology when implementing the "six sigma" concept:

- Formation of a set of criteria, characteristics, and parameters of production and business processes based on the principle of customer orientation and the company's development strategy, taking into account the provision of the necessary product quality.
- Application of algorithms that allow for reliably recording characteristics and parameters of production and business processes that reflect selected key indicators.
- Application of algorithms for analyzing obtained parameters and characteristics of managing production and business processes.
- Organization of a system for monitoring production and business processes. Monitoring key parameters. Prompt implementation of management decisions to eliminate problems or deviations of production and business processes from optimal settings.

At the current stage of development and implementation of digital technologies, the methodology using the "six sigma" concept has become widely used in various fields of economic activity. In this regard, it seems expedient to analyze the existing advantages and disadvantages of the "six sigma" concept, taking into account the experience of implementation (Table 2) [14].

**Table 2. Key Advantages and Disadvantages of the "Six Sigma" Concept**

<table>
<thead>
<tr>
<th>Advantages of the &quot;Six Sigma&quot; Concept</th>
<th>Disadvantages of the &quot;Six Sigma&quot; Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Potential for improving the quality of manufactured products and standardizing technological operations in production processes.</td>
<td>1. Requirements for staff training, the need for developing additional competencies.</td>
</tr>
<tr>
<td>2. Low level of investment required for implementing the methodology.</td>
<td>2. Lack of a developed concept for all business processes, not just production and technological processes.</td>
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Based on the conducted research and analysis of the implementation experience of the "six sigma" concept, the following conclusions can be drawn:

1. The customer orientation of the "six sigma" methodology.
2. It ensures an increase in the quality of produced products.
3. It ensures the stabilization of technological operations in major production and business processes.
4. It provides the ability to proactively identify weak points in the organization of production and business processes and apply process management decisions to them.
5. It implements a methodology that allows for a reduction in defects and an improvement in the quality of production and business processes of the company.
6. The possibility of creating a combined system of process management for production and business processes based on the integration of the "six sigma" concept with the lean production methodology.

It is evident that the implementation of lean production concepts requires the search for ways to algorithmize and optimize actions for implementing lean production. Ganebnikh E.V. and Fokina O.V., analyzing the possibility of integrating traditionally opposed Agile and Kanban approaches in managing large-scale production enterprises, propose an algorithm for implementing lean production technologies through the formation of small working groups operating based on the Scrum methodology [9]. Based on the conducted research and considering the obtained results, it seems reasonable to consider the possibilities provided by the optimal combination of the "six sigma" concept and the process management methodology of lean production.

The lean production methodology analyzes the value creation flow for consumers within production processes and minimizes all types of waste, while "six sigma" focuses on stable achievement of necessary results in technological operations and minimizing production defects. The implementation of lean production concepts typically starts from the "Improvement" stage, bypassing the "Define" and "Measure" stages inherent in the "six sigma" concept.

In practice, during the "Improvement" stage, data on the implementation of production and business processes are collected. The team within the working group analyzes the collected data and formulates preliminary hypotheses about the causes of deviations in the improved processes. Additionally, during the "Define" stage, the scale of identified problems is assessed. In the next "Measure" stage, quantitative values of parameters and characteristics are obtained and analyzed in relation to existing resources [15].

In the "six sigma" concept, there are also certain drawbacks, as mentioned above. Let's conduct a comparative analysis of the capabilities of the researched concepts in order to determine which shortcomings of the "six sigma" methodology can be compensated for by applying lean production tools.

We can identify five directions that ensure the achievement of a synergistic effect from the application of the "six sigma" concept with elements of lean production tools. The methodology of applying "six sigma" rarely analyzes production and business processes from the perspective of assessing the effect of added value. Therefore, the task of eliminating non-value-added operations falls out of the optimization process. Lean production methodology requires restructuring of the business process or operation (to eliminate non-value-added operations) in all analyzed cases.

The application of "six sigma" methodology dictates the need for optimizing the
production cycle time and accelerating decision-making. In pursuit of results related to optimizing time factors, experts in the field of "six sigma" methodology overlook the fact that speed characteristics of the optimized process are directly correlated with quality criteria. In the optimized model, there is no limit to the amount of work in progress, which, according to Little's Law, directly affects cycle time. Without a limit on work in progress, "...reducing cycle time will remain a dream..."

One of the most significant risks for a company is customer loss. The specific nature of applying lean production is that all losses, which are explicitly identified using lean production tools for production and business processes, are considered "internal" losses. However, based on the analysis of practical use of lean production concepts, it can be proven that the probability of customer loss is largely correlated with minimizing internal losses. Implementing lean production involves delivering products quickly, without additional losses and with minimal costs. It should be acknowledged that a company may produce an unwanted product that will be difficult to sell.

The "six sigma" concept proposes a more constructive approach, incorporating mechanisms that allow for the consideration of the "voice of the customer" and describing customer loss as a defect. The tools used in the "six sigma" concept include approaches similar to those used in lean production, such as total productive maintenance, value stream mapping, 5S, etc. The listed lean production tools serve as effective methods for improving the speed of production and business processes. Implementing the "six sigma" methodology with adapted lean production tools will enable a company to achieve maximum productivity while optimizing production and business processes. For example, using the kaizen method allows for the implementation of short-term projects by utilizing a specialized group of experts. The application of this method enables the rapid achievement of the desired result in a short period of time.

Research shows that the quality of implementing the "six sigma" concept sharply increases when using lean production tools to eliminate stages of production and business processes that do not add value. Figure 1 presents data demonstrating the effect of cumulative defects on the actual throughput capacity of industrial and business processes (service delivery process map).

The presented example clearly demonstrates that by combining Lean Manufacturing methods and implementing the "Six Sigma" concept, a company is not only able to optimize the number of operations but also achieve the required level of quality in the remaining operations up to 5 σ. In fact, the company ensures a real throughput of up to \((0.9976) \times 100 = 99.8\%\). The analysis of the implementation of the "Six Sigma" methodology and Lean Manufacturing concept has shown that there is currently no theoretical resolution regarding the priority and sequence of applying Lean Manufacturing and "Six Sigma" tools in the optimization of business processes within the company.

![Fig. 1. Actual throughput capacity (Source: Six Sigma Research Institute)](image-url)
When optimizing business processes using lean manufacturing methods and the "Six Sigma" concept, there is some correlation in the implementation of management decisions and possible intersections. However, the synergy of using lean manufacturing tools and the "Six Sigma" methodology has the most favorable impact on the company's management culture and the adoption of effective management decisions. It is proposed to form an optimal set of tools for both lean manufacturing and "Six Sigma," taking into account the selected criteria for evaluating management decisions. For example, it is preferable to use ROIC (Return on Invested Capital) and NPV (Net Present Value) as criteria.

The integration of the capabilities provided by lean manufacturing and the "Six Sigma" concept allows the formulation of five laws to optimize decision-making in managing business processes within a company:

1. The Law of the Market: Issues related to the company's customer orientation, serving as the primary strategic goal. Priority is given to criteria such as ROIC and NPV.
2. The Law of Flexibility: Establishes a direct relationship between the speed of any production or business process and its potential flexibility.
3. The Law of Focus: States that 20% of core operations (technological stages) account for 80% of delays in any production cycle.
4. The Law of Speed: The speed of any production cycle is inversely proportional to the volume of work in progress (Little's Law).
5. The Law of Complexity and Costs: Increasing the complexity of the offered service or product leads to increased non-value-added work and an increase in work in progress.

An example of the combined use of lean manufacturing and the "Six Sigma" concept is the AIS "Dispatcher" [16], developed by the "Digit" Group. The system allows connection to any industrial equipment in the enterprise and monitors the progress of production processes. The system is built using a set of core lean manufacturing tools and implements an algorithm for collecting and analyzing equipment and personnel performance statistics, while the digital algorithms of the "Six Sigma" methodology synergize with the lean manufacturing toolkit, optimizing production and technological cycles to ensure maximum return on investment while maintaining the highest quality of the output through the standardization of production process results and technological operations.

As a Lean Manufacturing methodology, the "Dispatcher" AIS (Automated Information System) implements production plan smoothing algorithms. It ensures the cyclical nature of the production process, creates excess production capacity by utilizing factors such as the release of time resources and reducing equipment setup time. It generates a virtual map of the production process, from raw material supply to product delivery. The system incorporates algorithms for reducing inventory levels and optimizing the distribution and scheduling of equipment workloads. The algorithms of the "Six Sigma" concept implemented in the "Dispatcher" AIS utilize information structuring, data collection methods, information and business process analysis methods, and methods for implementing process management decisions. A significant portion of the applied methods is based on mathematical and statistical tools, as well as the modern achievements of management science.

The advantages of the "Dispatcher" AIS (Automated Information System) include low implementation costs and improved overall production system reliability. The algorithms described above are implemented by the system developers in the form of the following modules:

1. Production Monitoring Module:
   a. Control of equipment usage and load.
   b. Assessment of production losses, including downtime.
   c. Automation of continuous production monitoring.
2. Production Optimization Module:
   a. Identification of bottlenecks in the production chain.
c. Reduction of defective product output.
d. Optimization of work schedules.

3. Downtime Management Module:
   a. Reduction of unplanned downtime duration.
   b. Optimal planning and execution of equipment maintenance work.
   c. Implementation of algorithms for accounting and efficient use of typical repair cases.
   d. Long-term forecast for the use of spare parts and consumables.

4. Production Digitization Module:
   a. Connecting all workstations to a local network.
   b. Transition from paper-based document management.
   c. Integration of production systems into a unified information space.
   d. Control of the entire product life cycle.

The optimal combination of the "Six Sigma" concept with the Lean Manufacturing methodology in the management of production business processes allows enterprises using the "Dispatcher" AIS to analyze production and technological processes in real-time based on loss minimization algorithms. The algorithms of the "Six Sigma" concept focus on achieving consistent results in production processes and technological operations, minimizing the percentage of defects [16].

4 Conclusion

Currently, the assessment of the innovative potential of industrial enterprises in various sectors of the Russian business community is on the agenda, as well as determining the relationship between the effectiveness of assessing innovative potential and the overall performance of the enterprise. Issues related to the functioning of industrial enterprises implementing innovations in the context of global and national macroeconomic instability require further consideration. Proven and reliable technologies are needed to improve the efficiency of all business processes of industrial enterprises. "To fully harness the advantages of the Lean approach, in addition to the flow method, it is necessary to consider the use of additional Lean manufacturing techniques that complement it well" [17]. In this regard, the joint use of Lean manufacturing methodologies and the "Six Sigma" concept produces the best results. Further research and the development of a theoretical solution regarding the priority and sequence of applying Lean manufacturing and the "Six Sigma" concept within the optimization of business processes in a company are required.

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