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Implementation of Lean Manufacturing Principles and Fast Structured Logic Methods in the Organizational Culture: Addressing Challenges and Maximizing Efficiency

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ABSTRACT

Currently, the concept of lean manufacturing has covered almost the entire global industry and all its sectors. This is due to the effectiveness of this concept, since with its application, along with increased productivity and quality, more products are produced with the same amount of resources and at lower costs. Today, lean manufacturing in the context of Industry 4.0 is relevant for achieving the principles of sustainable development. The purpose of the study is to analyze the features of lean manufacturing in the context of Industry 4.0 to achieve the principles of sustainable development. The paper considers the main theoretical aspects of the introduction of lean manufacturing in industrial enterprises and examines the essence and characteristics of Industry 4.0. Based on an expert survey, Industry 4.0 technologies have been identified for the implementation and support of lean manufacturing. The study concludes that the introduction of Industry 4.0 technologies, such as enterprise resource planning systems, industrial Internet of Things, automation and robotics, augmented and virtual reality, and radio frequency identification in industrial enterprises, into lean manufacturing not only lead to a reduction in losses but also serves as the best way to eliminate them. Flexible forecasting of changes in the supply and demand of a product helps to plan production volumes more accurately, which allows manufacturers to avoid further surpluses and losses.

1. INTRODUCTION

The industry of Russia, Kazakhstan, Belarus, and Azerbaijan currently has a significant number of issues, where the main problem is the low level of profitability of business entities [1]. The low level of financial and technical support of enterprises often combined with an inefficient personnel management system, slow down the process of updating and reproducing competitive production. As world experience shows, enterprises need to reach a new level of management and production process, introducing the latest management approaches that fully meet modern requirements [2]. Lean manufacturing (LM), a management concept aimed at eliminating all types of losses and achieving maximum efficiency in the use of material, labor, and other resources in production can become such a management technology. Numerous manufacturing companies are interested in reducing losses, increasing productivity, and improving product quality indicators [3].

New opportunities for the development of the LM management concept have emerged in connection with the spread of digital technologies and the beginning of the fourth industrial revolution, called Industry 4.0. If we summarize the research findings, many manufacturing companies are focused on finding newer and innovative technological solutions. Some of the ongoing social, cultural, and economic changes have proved to be so breakthrough that they have contributed to the initiation of revolutionary changes in various industries [4-7].

Thus, the relevance of the paper and the formulation of the problem lie in the possibility of achieving the principles of sustainable development based on the implementation of the concept of LM in the context of Industry 4.0.

The novelty of our work is in the description of the possibility of using modern Industry 4.0 technologies to support LM. As the practice of production management based on the principles of sustainable development shows, it is difficult for business entities to make informed decisions on LM implementation at Russian enterprises in the absence of appropriate methodological tools.

The purpose of the paper is to analyze the possibilities of Industry 4.0 technologies for the introduction and support of LM.

In this paper, we tried to answer the following research question: What are the main technologies of Industry 4.0 that can be used to implement and support LM?

The paper is organized as follows. The next section provides a review of the literature on the LM concept in industrial enterprises at present, as well as the essence and characteristics of Industry 4.0. Further, the research method and the results of the study are presented and discussed. The conclusions show the potential of using Industry 4.0 technologies to support LM. These data complement existing research on this issue. At the end of the paper, the limitations of the study are defined.

2. THEORETICAL BASIS

2.1 Theoretical aspects of the implementation of LM in industrial enterprises

LM refers to a management concept that focuses primarily on optimizing business processes [8]. The goal of LM is to minimize costs and maintain high quality at a minimum cost.

It is believed that the LM core is a process of eliminating losses that do not carry value for the buyer but consume resources. According to LM theory, the activities of any enterprise can be divided into two groups: operations and processes that add value to the consumer and operations and processes that do not add any value to the consumer [9].

Initially, LM technologies were used in industries producing discrete product categories characterized by discontinuity of the production process over its entire length. However, later this concept was adapted to continuous production and found its application in trade [10], services [11], healthcare [12], and the public sector [13, 14].

The introduction and development of LM technologies in production provide some advantages, which include reducing production losses; reducing the cost of production; increasing productivity while reducing labor costs; improving product quality; and increasing profitability [15].

To implement the LM concept, the following tools are used: 1) delivery exactly on time (the Just in Time system) [16]; 2) extraction system and custom work (the Kanban system) [17]; 3) rapid equipment changeover (Single-Minute Exchange or Die, SMED) [18]; 4) total productive maintenance system (the TPM system) [10]; 5) workplace streamlining (the 5S method) [19]; 6) error protection (Poka-Yoke) [20]; 7) standard operating procedures (SOP); 8) quality improvement (the Kaizen system) [21], and others.

The implementation of LM is a long process that brings changes not only to a company's production concept but also to the mentality of employees. It is accompanied by employee training, the formation of an initiative group for implementation, holding meetings to find possible solutions, and support for consultants in difficult transformation situations. To accelerate the implementation process and obtain the desired results, some researchers recommend applying the basics of constraint management theory, i.e., starting the implementation process not along the entire production chain but in the bottlenecks of the production system [22].

The application of LM basics can give significant results. The advantage of LM is that the concept consists of 80% organizational features and only 20% technological features [23].

While in the late 1980s, LM was used mainly to reduce costs, today we are talking about a green approach to achieving the principles of sustainable development by an enterprise based on the use of technological achievements of Industry 4.0 [24]. Therefore, one of the main tasks of LM at present is the integration of individual business operations into a single, fully optimized system where all components are effective, including production, marketing, distribution, and transportation [25-27].

2.2 The essence and characteristics of Industry 4.0

Currently, the fourth industrial revolution is taking place, called Industry 4.0, which is focused on system integration and networking using digital technologies [28]. Thus, the automatic exchange of information in the production process between people, machines, and information technology (IT) systems within an industrial enterprise or between various IT departments operating in the enterprise is ensured [29, 30].

Due to Industry 4.0, business owners have better control over the production process and access to all aspects of their activities, which allows them to increase efficiency and optimize processes [31]. Another great advantage is the increased flexibility of production, which is made possible by minimizing the time required to adapt machines to new requirements. Production tools record all cases of reduced efficiency and waste, which allows manufacturers to increase production efficiency and gain a decisive competitive advantage [32].

With the beginning of the fourth industrial revolution, new technologies and concepts appeared, without which Industry 4.0 could not function. The first of these concepts is the Internet of Things (IoT) [33] This idea is a combination of various objects, ranging from not only the ones directly connected to the Internet, such as computers, smartphones, or tablets, but also household appliances and electronics, to large production lines, machine tools, and robots that are used in various industries [34] The advantages of such solutions include saving time, reducing costs, and speeding up the flow of information and increasing the efficiency of employee use, which leads to increased production efficiency [35, 36].

Industry 4.0, combining the fields of technological innovation and the concepts of value chain organization, is revolutionizing almost all sectors of the manufacturing industry. The use of automation and robotics tools makes it possible to develop and improve modern production lines [37]. The driving force of change also includes the employees of companies with interdisciplinary technical knowledge and communication skills and the ability to work in a team, which allows them to use and implement new solutions to create more flexible production lines. Due to these changes, companies have the opportunity to achieve better results, increase competitiveness, and acquire new customers.

3. METHODS

3.1 Research approach

Following the described approaches to the features of LM in the context of Industry 4.0, to achieve the principles of sustainable development, a qualitative and quantitative approach to research was chosen as the most appropriate method for the study of complex phenomena in the context of heterogeneity and uncertainty of initial information.

To identify Industry 4.0 technologies that can be used to implement and support LM, a qualitative case study was considered the most appropriate research strategy. The resulting data are more informative and voluminous compared to a simple quantitative study since they provide a higher level of detail, which facilitate the collection of information and feedback from the expert pool.

3.2 Empirical context

Following the purpose of the study, we conducted a selection of scientific sources, which was carried out using the Russian Scientific Citation Index (RSCI) and the international Web of Science and Scopus databases, using the keywords "digital technologies", "lean manufacturing", and "Industry 4.0".

We also studied the experience of companies in Kazakhstan, Azerbaijan, and Belarus to analyze and compare the organizational culture of modern enterprises.

3.3 Data collection

The data was collected between April 10 and July 10, 2023, by analyzing the scientific literature on the research problem, selecting an expert pool, following an expert survey by e-mail, and processing and analyzing the survey results.

Emails offering to participate in the survey were sent to 52 experts from Kazakhstan, Russia, Belarus, and Azerbaijan. The criterion for selecting the expert pool was the availability of publications on the research problem in peer-reviewed publications of at least three papers. The experts were contacted via email and given 10 calendar days to complete the survey. 47 people agreed to take part in the survey, after which they received emails with a question that we were interested in after completing the analysis of the research literature. In the emails, the experts were asked to justify the answers in any format.

In order to ensure a higher response rate and mitigate potential non-response bias, we implemented a systematic reminder and follow-up process. Initially, a reminder was sent to all experts who had not yet responded two days after the initial deadline for the survey. Subsequently, two follow-up emails were sent, each spaced two days apart, to those who still had not responded. This approach was designed to encourage maximum participation while respecting the time and availability of the experts.

All survey participants had been warned about the purpose of the survey and knew that the organizers of the study were planning to publish its results in a generalized form.

After receiving expert responses, we sent a second email to the experts, where we asked them to arrange different Industry 4.0 technologies used to implement and support LM in a particular order, assigning points, depending on the level of their importance. After that, the rank of each of the parameters was determined, according to the scores given by the experts.

3.4 Data analysis

For a more objective analysis of the data obtained during the expert survey, the degree of consistency of expert opinions with mathematical processing of the results was measured using the Kendall concordance coefficient (W): W=12S/n2(m3-m), where S is the sum of the squares of deviations of all estimates of the ranks of each of the technologies of Industry 4.0 from average value; n is the number of experts; and m is the number of technologies being evaluated.

Further, the information obtained during the expert survey was processed to determine the weights with the construction of a rank transformation matrix and subsequent calculation of the arithmetic mean of the individual weights for each of the technologies. The final weight values determine the importance of a particular Industry 4.0 technology from the experts' point of view.

In data analysis, the triangulation method was used for the validity and reliability of the results of the empirical study. The triangulation was performed through the triangulation of researchers, when several researchers participated in the project and each of them took part in the processing of information. After that, a discussion was held on each topic, and information agreed upon by all participants of the study was entered into the report. The triangulation process made it possible to increase the reliability of the expert survey data and improve the quality of the information received. All the results obtained from the study were recorded in the research report.

4. RESULTS

Based on the results of the field study (expert survey), Industry 4.0 technologies were identified that could be used to implement and support LM (Table 1).

Table 1. Key Industry 4.0 technologies for implementing and supporting LM

No.	Industry 4.0 Technologies	Rank	Weight
1	Enterprise resource planning (ERP) systems	1	0.34
2	Industrial IoT (IIoT)	2	0.22
3	Automation and robotization of industry	3	0.17
4	Augmented reality (AR)	4	0.11
5	Virtual reality (VR)	5	0.08
6	Digital twins	6	0.05
7	Radio Frequency Identification (RFID) technology	7	0.03

Notes: 1. Compiled based on the expert survey; the value of the concordance coefficient W=0.74 ($p<0.01$), which indicates a strong consistency of expert opinions.

5. DISCUSSION

In the context of Industry 4.0, most enterprises use a wide range of IT systems and software offered by the market. The implementation and use of integrated IT systems in various types of enterprises has gradually become a standard, without which it is difficult to imagine the functioning of a company.

Based on the study of companies' experience, it was determined that several Kazakh enterprises began to integrate digital technologies into their production processes. For example, the Aktogay branch of the AK Altynalmas JSC, a producer of gold bars, uses artificial intelligence to remotely control the grinding process, as does GL (Azerbaijan), which uses AI to analyze seismic data at deposits. Engineers from MapData, the Minsk research and development (R&D) office of MapBox, also achieved serious success: they use computer vision in tasks of recognizing the traffic situation on a video stream. The Maker LLP in the machine-building industry achieved complete automation from design to production. The Prommashkomplekt LLP implemented a high-tech automated complex to produce railway wheels.

An integrated IT system in a broad sense can be defined as an IT system designed and organized according to a modular principle. It covers the entire enterprise, and therefore all areas of its activity. This makes integrated IT systems universal systems, i.e., with functions corresponding to most enterprises.

The group of integrated IT systems that support enterprise management also includes ERP class systems that allow one to comprehensively manage an organization by integrating all levels of company management. These systems are extremely useful in planning and interpreting all the processes taking place in the company.

The main tasks of an ERP system are to operate in the following areas [35]: planning, for example, forecasting demand for a given product; procurement and storage, i.e., supply chain management in general; control, i.e., comparing expected effects and results with those achieved by the company; integration of the company's system with supplier systems or clients; reporting and documentation; finance; and human resource management.

The progressive development of communications technologies means that integrated IT systems are also developing and opening new communication opportunities. Thus, ERP systems have expanded their capabilities and ERP II class systems have been created, which, in addition to all the capabilities of ERP systems, have an additional Internet communication capability.

The architecture of the ERP II system, which includes modules of the traditional ERP system, has been expanded with an additional set of features. The central element of the ERP II architecture is the ERP system, which is based on a set of additional systems. The customer relationship management (CRM) system has expanded the functions of the sales and distribution module. The supply chain management (SCM) system supports the production and supply logistics module. This has expanded the support of processes within the company with information from business partners, which makes it possible to manage the resources not only of one company but also of all cooperating partners in the supply chain. PLM (product life management) is an extension designed to manage the product lifecycle. The system includes product design and production, quality management, and product market assessment. The subsystem, whose task is to support strategic enterprise management, is called SEM (strategic enterprise management). Its tasks include strategic planning, capital investments, and financial consolidation. It is mainly based on the data warehouse and the information contained therein [36].

Support for LM when using an ERP II class system in the company includes reducing operating costs by simplifying business processes, as well as reducing management and operating costs. In industrial enterprises:

• there is a significant increase in productivity due to efficient and effective planning,

• more efficient planning is provided, which, for example, allows for better organization of material flow management and reduction of excess stocks,

• it becomes possible to react quickly in case of a shortage of materials or raw materials (due to constant monitoring), which means that they improve the order fulfillment process and increase timeliness,

• effective human resource management is ensured, information about employees is safe, and all actions related to human resources, payroll, or working hours are performed efficiently.

ERP II class systems are focused on external integration and business partners. The main purpose of using the system is to maximize profits and maintain a stable and competitive position in the market. Simply put, the ERP II system is an integrated management system that combines CRM and ERP systems, additionally using Internet communication [36].

The next Industry 4.0 technology that has an impact on LM is the IIoT. Its main element is the creation of systems of combined sensors and actuators operating in a common network. To be able to fully satisfy customers, many automation companies offer solutions specifically prepared for IIoT applications in the industry. Due to the IIoT, access to huge amounts of data can be carried out much faster and more efficiently than ever before. Many innovative companies have started to implement the IIoT using smart connected devices in their factories. The IIoT creates a connection between devices and the enterprise. It uses sensors, advanced analytics, and intelligent decision-making. Oil and gas companies were the first to develop an infrastructure in which sensors, advanced analytics, data processing, and automation were used to support LM [33].

The most important IIoT capabilities affecting LM include:

• the growing intelligence of sensors that detect and analyze data (and then send it further through various types of communication gateways),

• distributed processing system, installation of PLCs (programmable logic controllers) closer to machines that control and reduce overload and increase flexibility and production efficiency,

• the ability to select the optimal parameters of the production process due to sensor data,

• integration of the iIoT infrastructure with new technologies, for example, robotics, VR, software, AI, drones, etc. within the framework of Industry 4.0 assumptions.

Researchers believe that future maintenance solutions will be able to predict equipment failures, which will reduce production downtime by up to 70%. They also estimate that companies implementing the IIoT will increase their efficiency by up to 30%, reducing maintenance costs by 30% [33].

Another Industry 4.0 technology that has an impact on LM is the robotization of industry. Researchers note that LM and robotization support each other and make it possible to obtain a stable, optimal production process. This is achieved by eliminating unnecessary steps and stabilizing the cycle time [37].

The introduction of robotics into a manufacturing company allows [37] for increasing efficiency and quality, improving production scale, and continuous improvement of production processes. An industrial robot, when properly implemented, makes it possible to implement LM. The most important aspect is the implementation method, which considers accessibility, flexibility, and reliability when using robots on workstations or production lines.

The use of industrial robots at production stations and lines very often makes it possible to offer various concepts of solutions even at the design stage. Industrial robots are indispensable in areas where the implementation of the principles of the LM concept is most justified, i.e., in the so-called bottlenecks of production, where reliability and highly developed preventive diagnostics are of the greatest importance. Robotization of production processes is equivalent to LM adoption, since it allows for reducing production time and reproducibility of quality, increasing work efficiency, and improving communication and information flow [32]. This is possible provided that the robotic cell is integrated into a holistic and harmoniously interacting system where the robot itself is an executive element [28].

When implementing LMin an industrial enterprise, the main possibility of AR is to reduce downtime caused by breakdowns or other problems during production. Using AR systems, an employee, after superimposing a virtual image on a real one, can immediately notice the defect and, due to the instructions, carry out immediate repairs. In the absence of a repair or maintenance manual, the employee can contact a specialist who instructs them on an ongoing basis to solve the problem. Such assistance may take place even when the employee and the specialist are in different countries. Using AR opens up a new way of servicing machines. This is done to minimize the risk of making any mistake. Service technicians can scan the code on the replacement part very quickly to obtain further instructions leading to proper installation. Due to this technology, maintenance specialists do not need special training for machine maintenance and repair [34].

AR allows one to create virtual products before they are manufactured. This provides great convenience because it is possible to assess whether the product is correct and meets all previously expected specifications as early as the production planning stage, which saves a lot of time. In another situation, after detecting defects, one should make corrections and create another prototype. In the automotive industry, huge amounts of money are invested in design systems using AR and VR. They allow one to obtain various data, from visual and acoustic simulations and tactile sensations to testing prototypes exclusively with AR and VR systems. This gives great opportunities and allows companies to create projects even for several years ahead [29].

AR is also used in the company's internal logistics. Using barcodes, it is very easy to trace, record, and document the path of each semi-finished product in the production shop, from the very beginning to the placement of the finished product in the warehouse. Due to the use of barcodes, the employee will quickly find the location of the products in the warehouse. The goal is to replace widely used scanners. This speeds up the operation of the company inside the warehouse and provides information to office employees without the need for their verification.

However, despite the growing popularity and number of implemented AR systems for industrial enterprises, these are only innovative solutions. The daily use of AR is still a long way off.

VR, when implementing LMin an industrial enterprise, can be used to monitor production lines and the enterprise. Special systems, the so-called digital twins, are used to monitor data in real time and optimize production processes based on this data. Currently, it is one of the standard technologies used by large manufacturing companies, as well as companies in the automotive and aerospace industries. An example is Ford's European subsidiary, which has implemented virtual manufacturing technologies to create a safe and efficient work environment. VR was used in combination with motion capture and 3D printing. This made it possible to optimize the workplace and reduce the number of injury-related accidents by 70%. Ergonomic problems of employees also decreased by 90% [38].

However, currently, only large companies use virtual technologies and take advantage of their competitive advantages. The widespread use and acceptance of VR require better devices and software at a lower price [39].

Experts called the so-called digital twins, or virtual copies of systems, processes, or physical objects, another means of supporting LMin an industrial enterprise. All changes occurring in a real object are recorded by sensors and reflected in its digital copy. This allows one to understand the processes during the actual use of the facility, effectively carry out remote control, predict events, detect failures at an early stage, and control component wear [31]. Digital twin technologies are used by enterprises to test new products before they are put into mass production and use, which facilitates development and improvement. Digital twins are created due to the development of the IoT and sensors. The transmitted data creates real-time feedback between physical objects and their digital twins. Machine learning and AI are increasingly being used in this field [31, 40].

The expert called RFID the latest technology in Industry 4.0, aimed at supporting LMin an industrial enterprise. This is a method that allows wireless identification of objects using radio waves.

Currently, RFID is used in industrial processes, logistics, production management, and everyday life. The main task of RFID is the identification and categorization of a particular object in such areas of industrial production as process automation and the identification of products, tools, machines, and materials. This ensures efficient flow, facilitates management processes, and increases the efficiency of operations. This method supports management at various stages of the product development process.

6. CONCLUSIONS

In this paper, answers were given to the following research questions: whether it is possible to consolidate the interests of the main stakeholders and what are the main modern technologies of Industry 4.0 that can be used to implement and support LM.

As our results showed, the implementation of the LM concept helps not only to reduce losses but also to find the best way to eliminate them and to search for such options that will allow working with nothing to reduce. Flexible forecasting of changes in the supply and demand of a particular product helps to plan production volumes more accurately, which avoids further surpluses and losses. Another way to build LM can be the adaptation of technological advances in Industry 4.0, such as ERP systems, IIoT, automation, robotics, AR, VR, and RFID.

Despite the theoretical and practical contributions, this study is partially limited by the size of the expert sample and therefore does not allow generalizations. We are aware of the need to conduct parallel research on this issue. The overall results of several studies, including experts, will allow us to create a more generalized picture of LM in the context of Industry 4.0 as a factor in achieving the principles of sustainable development.

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