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**SYMBIOSIS BETWEEN THE LEAN MANUFACTURING
CONCEPT AND PROGRESSIVE INFORMATIZATION***

**SYMBIOZA KONCEPCJI *LEAN MANUFACTURING*
Z POSTĘPUJĄCĄ INFORMATYZACJĄ**

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Summary: The purpose of this article is to present a number of IT systems and technologies that support the solutions of the Lean Manufacturing (LM) concept. The enterprises' pursuit to improve the efficiency of their business activities caused a revolution in the use of information systems. Contemporary organizations wanting to occupy leading positions on the market cannot do it without appropriate IT solutions that will facilitate the analysis of business processes and making the right economic decisions. Nevertheless, each company is a separate "living organism" that should be treated individually, and the information technology used should become a way to solve specific problems and support the implementation of certain improvements. This article presents a number of IT solutions that are or may become in the near future support for Lean initiatives.

Keywords: Lean Manufacturing, informatization, IT systems and technologies.

Streszczenie: Celem niniejszego artykułu jest przedstawienie szeregu systemów i technologii informatycznych pełniących funkcję wsparcia dla rozwiązań koncepcji *Lean Manufacturing* (LM). Dążenie przedsiębiorstw do poprawy efektywności swojej działalności gospodarczej spowodowało rewolucję w zakresie stosowania systemów informatycznych. Współczesne organizacje, chcąc zająć czołowe pozycje na rynku, nie mogą obejść się bez odpowiednich rozwiązań informatycznych, które ułatwią analizę procesów biznesowych oraz podjęcie właściwych decyzji gospodarczych. Niemniej jednak każda firma jest odrębnym „żywym organizmem”, który powinien być potraktowany w sposób indywidualny, a zastosowana technologia informatyczna powinna stać się sposobem na rozwiązanie konkretnych problemów i wsparciem we wdrożeniu określonych usprawnień. W niniejszym artykule przedstawiono rozwiązania informatyczne, które są lub też mogą stać się w najbliższym czasie wsparciem dla inicjatyw *Lean*.

Słowa kluczowe: *Lean Manufacturing*, informatyzacja, systemy i technologie informatyczne.

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1. Introduction

Widespread informatization¹, as a result of the development of ICT tools and technologies, places high demands on enterprises operating on the market, thus shortening the distance between them and their clients. In these conditions there is a need for a flexible response to the needs of recipients by implementing new IT solutions. Global trends indicate the necessity of introducing changes and adjusting the organizational model of activities to changing economic conditions under the constant pressure of time and there is no indication that this will change.

Significant changes affect all areas of enterprise operation. The production area is no exception and signals a clear problem that requires systematic research. Currently, enterprises face many complex challenges, related, among others, to the need for quick action and decision-making, high efficiency and flexibility to enable adaptation to the client's needs. The implementation and realization of these goals depends on the management of modern technologies, in most cases based on complex and extensive data sources, which are both the result and cause of the development of modern trends [Magruk 2016, p. 16]. A number of tools and methods that have recently been used, today are inefficient and ineffective. In turn, modern methods or concepts of enterprise management, such as Lean Manufacturing, require IT support to achieve the best results assumed in them. In order to maintain a strong competitive position, organizations are increasingly reaching for such IT systems which are designed to automate specific processes, thereby reducing their workload and, consequently, the costs of the enterprise. Due to the need to process an ever-increasing amount of data, modern companies see informatization as an effective tool to achieve their goals.

2. Lean Manufacturing towards Industry 4.0

The elimination of waste applies to all activities carried out inside and outside the production hall. These activities are focused on creating added value, which aims to improve competitiveness through an efficient production process and effective use of resources [Nasution et al. 2018, p. 1]. Lean Manufacturing is a concept of business management that helps to improve production processes and increase employee satisfaction with their work [Singh et al. 2010, pp. 157-168]. Comprehensively speaking, LM postulates systematic identification and elimination of waste in accordance with the creation of continuous flow, taking into account the principle of pulling, as well as the continuous improvement of company processes, involving each employee in these processes and using the minimum of needed resources to

¹ *Informatization* – the process of transforming the economy and society into an information society based on information. Informatization assumes increasing the number of IT systems and financial resources allocated to projects related to IT technologies [Brzozowska et al. 2016, p. 57].

reduce the company's costs, increase its flexibility, and also obtaining maximum customer satisfaction by creating value for him/her. To achieve this, Lean uses a number of tools, including Visual Management, teamwork, Jidoka, 5S, JiT, standardization, Poka-Yoke, VSM, TPM, SMED etc. [Pawłyszyn 2017, p. 44]. Production according to the LM concept (Figure 1) sets itself, among others, the following tasks:

- minimize labour costs and production lead time for new products;
- guarantee timely delivery of products to the customer;
- improve the quality of goods while reducing production costs.

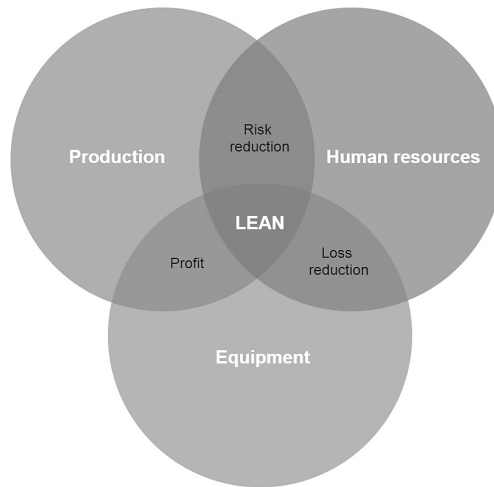


Fig. 1. The triad of Lean Manufacturing concept links

Source: own elaboration.

A number of successful applications of a given concept in companies [Piasecka-Głuszak 2013, pp. 99-111; Indykina 2015, pp. 337-341; Alves et al. 2011], as well as numerous publications on the concept of Lean testify to its practical and application character and are an important topic of interest for organizational units. The Lean Manufacturing concept, properly promoted and developed, significantly contributes to achieving a strong market position: faster, more flexible, more reliable delivery of goods and services generates revenue growth due to increased sales to existing customers, as well as an increase in market share by maintaining existing customers and generating new ones [Schonberger 2019, pp. 359-371].

The popularity of Lean Manufacturing results from several reasons. First, the objective development of quality management tends to develop the most effective business management methodologies, among which Lean Manufacturing is considered to be the most modern. Secondly, LM is based on principles that are particularly important in conditions of an ever-changing market economy and is aimed at the comprehensive reduction of losses and does not require significant

investment to fully satisfy customer requirements not only in terms of the quality of delivered products, but also their completeness, topicality, timeliness, etc. Thirdly, the history of Lean Manufacturing development is a collection of success stories of the most famous companies in various branches of the world economy: from the automotive (heavy) industry to commercial (consulting) services. Fourthly, LM is the most successful symbiosis of market management principles (produce only what is needed) and administrative-decision-making (strategic planning and management by objectives) [Vasil'yev et al. 2015, p. 3]. Fifthly, Lean Manufacturing is a highly up-to-date concept that fits the current reality and tends towards future economic trends. It solves a number of problems, and at the same time maximizes the use of company resources, organizes and increases responsibility in the workplace by e.g. delegating tasks and prerogatives, creates a clear and understandable value stream, allows the company to respond quickly to a changing environment.

The fourth industrial revolution – Industry 4.0² – which is entering into the life of organizational units, forces them to adapt to current trends. The implementation of the Lean Manufacturing concept in an enterprise facilitates and accelerates the implementation of the solutions proposed in Industry 4.0. A global study carried out by The Boston Consulting Group has shown that leading industrial companies recognize the importance of both Lean Manufacturing and digitization in their long-term planning. In a survey of more than 750 production managers, 97% of respondents from the automotive industry said that Lean Manufacturing would be important in 2030, compared with 70% who indicated that this is important today [Küpper et al. 2017, p. 4]. Moreover, the authors of the conducted research point out that new digital technologies are necessary to achieve a higher level of impact of Lean solutions. Therefore, Industry 4.0 can be understood as a higher level of Lean Manufacturing concept. From the considered perspective, the implementation of even basic Lean tools is appropriate and even desirable.

3. The role of informatization in business management

The Informatization of production processes nowadays is becoming a necessity. Today enterprises have to deal with large data sets, operate with current and relevant data, and process them skilfully. In addition, the time aspect coupled with the possibility of obtaining information, which will become the basis for making specific decisions, becomes important. In view of the above, the conclusion is that the management concepts themselves and the tools or methods they offer will not guarantee success without appropriate IT support. The effectiveness of enterprise

² The term *Industry 4.0* refers to numerous physical and digital technologies that combine through analytics, artificial intelligence, cognitive technologies and the Internet of Things to create digital enterprises that are connected to each other and capable of making more informed decisions. Digital enterprises can communicate, analyse and use data to drive intelligent activities in the physical world [Renjen 2018, p. 9].

management is primarily determined by the capabilities of the IT system in the field of obtaining, processing and transferring information. Role models and models of development of Management Information Systems (MIS) appearing in the literature indicate a close relationship (linkage) between the area of management and the area of information technologies in the organization (Figure 2). Changes in management processes related to organizational development shape information needs that affect the development of management IT systems [Luściński 2011, pp. 47-48].

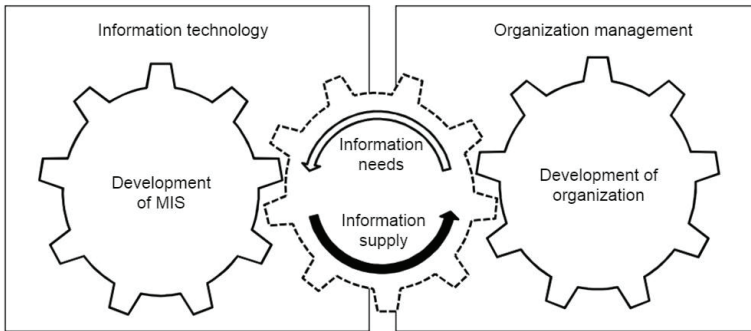


Fig. 2. Interdependence of the organization's development and its MIS

Source: [Luściński 2011, p. 47].

IT systems are usually understood as a complex of software and hardware tools as well as methods of production, transmission, processing and use of information in systems ensuring the flow of goods. The dominant direction of IT systems development in relation to production processes is the integration of information flows based on modern methods of data processing and transmission.

The development of informatization in enterprises is connected with the growing role of information in economic processes, as well as the development of communication and computer technology. The importance of information in the modern world is determined by the following factors: large share of information in the total cost of goods and services; large share of information resources in total employment (qualified human resources); the integrating function of information in the economic organism of society, which decisively ensures the efficient functioning of the economy; an innovative function, manifested in generating scientific and technological progress.

The choice of appropriate IT systems and technologies for a particular enterprise should depend on its business profile as well as its size. At this time, when large enterprises can use complex integrated IT systems dedicated to the processing of a significant amount of data, small enterprises can be focused on standard or simplified system solutions. A properly selected IT system will enable the quick and precise making of the right decisions.

The expected improvements achieved thanks to IT systems can be grouped into specific categories [Gradusova et al. 2014, p. 19]:

- shortening the duration of the production cycle (reduction of investment in company assets, reduction of material transport costs, shortening of production lead times, reduction of inventory in progress);
- reduction of material inventory (reduction of investments in enterprise assets, reduction of material transport costs, increase in the quality of provided services);
- better use of production resources (reduction of working time losses, reduction of machine changeover times, increase of equipment availability);
- reduction of material costs (increasing delivery timeliness, the ability to order small batches, reducing the number of defective materials);
- improvement of product quality (reducing the number of production shortages, limiting disruptions in production schedules, reducing the number of machine changeovers, preventing a decrease in sales);
- improving the quality of customer service (shortening delivery time, ensuring consistency between finished products inventory and customer demand, timely delivery, intensified communication with customers);
- effective cost management (efficiency and accuracy of cost calculation, ability to quickly analyse costs, ability to analyse the causes of deviations from the plan, ability to identify the most profitable types of products);
- improving the organisation of storage and handling of materials (increasing efficiency while reducing labour intensity, improving service quality, more accurate and efficient control processes);
- simplified accounting and financial management (availability of accurate and up-to-date financial information, optimization of financial relations with suppliers and consumers).

It should be noted that the implementation of selected IT solutions is not an easy undertaking, and in some cases it is also long-term and expensive. Therefore, it is important to have the right approach to choosing the optimal solution. Nevertheless, thanks to the use of IT systems in the organization, it is possible to organize its internal processes, collect, register, process, and select data as well as integrate with key business partners and clients of the company.

4. IT systems supporting the Lean Manufacturing concept

Nowadays the implementation of production according to the principles of the Lean Manufacturing concept requires more and more informatization of the process in order to provide full information about the inventory, semi-finished products and work in progress. The basis of LM is having knowledge about what production can be 'lean down'. The source of this knowledge is information collected, processed, selected and made visible by various types of IT systems. Selected IT tools supporting the implementation and monitoring of Lean initiatives will be presented below.

ERP systems

Enterprise Resource Planning (ERP) integrates all information of the enterprise, groups it and then processes it to streamline the company's work as much as possible. Used most often in manufacturing enterprises, it allows responding quickly to fluctuations in demand [Szatkowski 2014, p. 396]. Lean Manufacturing as a business practice does not depend directly on the implementation of the ERP system, but the latest generation of these systems offers significant support for Lean initiatives. The ERP system can assist in searching for waste sources, as well as identifying the reasons for their occurrence. This is made possible by collecting and archiving a whole range of information on processes carried out in the enterprise. Thanks to coherent and up-to-date information on specific resources, as well as specific activities, the management can analyse and make appropriate decisions to improve ongoing activities.

At first it may seem that Lean and ERP are two opposites. ERP uses anticipated demand, while Lean uses real demand. ERP is based on recorded data. The main goal of Lean Manufacturing is to eliminate waste during production (including unnecessary data registration). Another difference is that ERP is top-down, while Lean is bottom-up. These differences indicate the need to compromise between Lean and ERP, which is not always an easy task. However, a properly implemented ERP system focused on supporting lean activities in a company should result in improved outcomes. It should also be noted that manufacturers who decide to use Lean methods and eliminate waste can now freely configure the ERP system and adjust the way they use it.

MES systems

One of the key features of using Lean Manufacturing methods is the ability to change processes through their optimization. However, this does not happen quickly. Manufacturing Execution System (MES) controls the proper execution of processes, tracks deviations and responds quickly to them, i.e. performs process monitoring. In other words, it is a system supporting production operations. The use of MES is more effective if the initial process is built using Lean Manufacturing methods and many losses have already been eliminated. In addition, the MES operative reacts to different deviations, such as machine failures, change of workpiece parameters, the appearance of orders with a higher priority, etc.

With the help of Lean methods, the type and amount of information can be optimized, and the MES system can transfer this information between workstations (and also between the company, suppliers and customers). Moreover, in this case not all information can be displayed, but only those that are currently needed at the workplace. Because MES is usually integrated with other enterprise systems, information on various process aspects can come from other systems or also be transferred to them. It can be said that Lean Manufacturing optimizes processes

methodologically while MES ensures that this methodology is followed [Vedmid' 2017, pp. 7-8].

Quality management is an important area in the Lean Manufacturing concept, where the emphasis is shifted from quality control methods to defect prevention methods. Statistical quality control methods implemented as part of MES systems allow for identifying dangerous process deviations in advance and taking appropriate action even before the defect occurs. Methods for analysing the causes of defects allow to identify more precisely the place of production where a change is required and implement specific Lean solutions. The use of MES systems in quality control processes minimizes time losses related with a given process, and also eliminates the possibility of errors.

APS systems

Production planning is a very difficult challenge, depending on the industry in which the company operates, taking into account the minimization of the inventory, maintaining an optimal level of production costs, managing the machines' work schedule, the level of complexity of manufactured products or unplanned downtime. Advanced Planning and Scheduling (APS) – is a system that allows to accurately determine, among others, possible delivery times, optimal sequence of orders and operations, as well as optimize material management and inventory volume in real time. Data for quick SMED changeover and TPM machines operation obtained by Lean Manufacturing methods are included in APS during production planning. In addition, they can be included in various ways depending on the planning criteria. Current changes in the production process (e.g. machine failure, delays in the delivery of materials) are immediately taken into account through replanning of production orders.

Lean Manufacturing concept methods such as Just in Time (JIT), Continuous Flow and Heijunka are usually built into APS systems by programmers as a set of tools. However, due to the real complexity of production, different approaches and toolkits are used depending on the specific case. Nevertheless, APS systems allow achieving a balance between storage costs, production costs and customer service costs [Żabińska 2015, p. 249]. It is also possible to create in the APS system so-called “*test plans*”, compare them and transform one of them into a real plan. APS can also serve as an analytical tool with “*what if*” and “*why delay*” functions, creating the possibility to virtually verify the consequences of a planned process change.

Many APS systems are independent programs that require integration with the ERP system at the implementation stage. Thanks to the APS functionality, the company gains a fully flexible and global production plan which reflects the actual state of resources and contributes to the removal of bottlenecks. An alternative to the purchase of an independent APS system and the implementation of an integration project with applications used in the enterprise are ERP systems with a built-in APS

module. The architecture of such a solution eliminates, among others, the costs of APS and ERP integration, costs of maintenance of multiple interfaces and databases, costs of errors resulting from the data flow between applications and ultimately costs of cooperation with many IT solution providers [Szafranski 2018, p. 51].

Electronic Kanban

Kanban – in the traditional Lean Manufacturing approach, these are cards that signal the quantitative demand for specific materials/products, as well as containing instructions about their destination in the context of analysis of a specific process. Kanban is a key element of the “pull” system, which allows for significantly reducing stocks in progress. Kanban ideology indicates that one should not do anything more than is needed, do nothing in advance and report the emerging need only when it is really necessary [Vedmid’ 2017, p. 8].

Due to technical development, traditional Kanban is gradually being replaced by the implementation of the electronic Kanban system (E-Kanban). According to Gilpatrick and Furlong, *“the ideal Kanban system is the E-Kanban system”* [Gilpatrick, Furlong 2004, p. 69]. E-Kanban belongs to the area of enterprise IT systems and presents a signalling system that uses a combination of various technologies to trigger the flow of materials in the enterprise. Electronic Kanban differs from the traditional one in that it uses technologies that replace traditional elements, i.e. Kanban cards, barcodes and electronic messages. E-Kanban systems can be integrated into enterprise resource planning (ERP) systems. Integrating E-Kanban systems into ERP systems allows for real-time demand signalling across the supply chain and improved visibility. Data pulled from E-Kanban systems can be used to optimize inventory levels by better tracking supplier lead and replenishment times, and eliminates lost cards [Mayilsamy, Pawan Kumar 2014, p. 2].

Automation of data collection – Smart Dust

Collecting data to analyse Lean initiatives can be very time-consuming. Modern devices often allow automatic collection of measurement data or data on the condition of equipment and automatic transmission to IT systems. Smart Dust can become one of such modern devices. Smart Dust – is a network of small computers (MEMS) equipped with a processor, limited memory, wireless communication interface, autonomous power supply and a set of sensors suitable for a given task [Aruväli et al. 2010, p. 573].

The use of intelligent dust will ensure ongoing visibility of components in production, allowing real-time monitoring and tracking. Not only that, Smart Dust can contribute to the better management of production and logistics processes. Microelectromechanical systems (MEMS), often called motes, can communicate with each other, activate each other when necessary (e.g. at the control stage) and have communication mechanisms to transfer the collected data back to the main system for processing. Thanks to the motes, it is possible to monitor the machinery

in order to facilitate timely maintenance or check the conditions (temperature, humidity, vibrations, etc.) in which production will be carried out. Smart Dust can also perform the function of inventory control and track products from the moment they are created in production plants, through shipping, until the customer receives the product [Marr 2018]. In addition, for security purposes motes can wirelessly monitor people's work and production progress, which is one of the main assumptions of the Lean Manufacturing concept.

Smart Dust is a solution that will help to detect changes in the production hall and predict possible problems. In turn this will allow avoiding unplanned interruptions in production. Motes are able to measure virtually everything in almost any conditions. The data collected by the motes is wirelessly transferred to the cloud, the main data system or other motes. The downside of this solution is the high cost of implementation (satellites and other elements needed for full implementation).

Thanks to MEMS it will be possible to collect data for the analysis of Key Performance Indicators (KPI) used in Lean Manufacturing, such as Overall Equipment Effectiveness (OEE), Inventory Turnover or the number of deficiencies and repairs.

Visualization of the production process

One of the most important elements of the Lean Manufacturing concept is Visual Management, which is a set of tools facilitating production management, increasing its transparency, preventing errors and enabling analysis. There is a need for the constant monitoring of production in the production plant. Real-time visualization of production process parameters for its participants thanks to modern technologies enables a better understanding of the various stages of the process, and also facilitates carrying out control activities. Competitiveness on the market is developing at a very fast pace, so optimization of production in order to meet deadlines without losing quality becomes an unavoidable aspect in company management.

The digitization of production allows for detailed monitoring in real time. Digital technologies allow to collect and reconcile often heterogeneous and distributed data, automate their update and transmit dynamically on the most appropriate media (e.g. wall boards) in a way that is understandable for all employees. Information screens or monitors can provide insight into current production progress, indicate the level of achievement of the assumed goal or existing delays, display Andon alerts³, etc. All types of messages can be immediately detected and taken into account in the production process thanks to the dynamic display of data in real time. Electronic work instructions can also be used at work stations, which gives, among others, the possibility of having current instructions at any time and eliminating losses associated with the movement of employees to search for paper instructions. Such instructions are usually created using Computer Aided Design (CAD) systems and then used in production.

³ *Andon* is a visual way of communication using light signals, which gives the opportunity to stop the production process when a defect occurs [Antczak, Puchała 2014, pp. 48-49].

Digital boards can also be used to issue shift tasks and report on their completion. The required work instructions are then linked to the production task and, if necessary, an additional check of its preparation can be carried out before starting work at a specific workstation. In turn, digital sequencing tables provide customer-oriented teams, operators and managers with a view of the current state of the production hall, including information flow, availability of materials, readiness and irregularities. They support employees in carrying out production in sequential order according to customer demand.

Virtual and augmented reality in production

In order to use Lean Manufacturing methods more efficiently, it is necessary to implement a Product Lifecycle Management (PLM) system in an enterprise, which automates the stages of design and technological preparation of production. PLM combines all data, processes and business aspects related to a given product throughout its entire life cycle – from design to disposal. They are a natural and necessary complement to CAD systems, as well as a necessary complement to ERP and MES systems. The development of the digital modelling function in PLM systems has led to the appearance of such terminology as virtual production, digital production, etc.

Virtual Reality (VR) allows simulating production processes to reuse existing knowledge and optimize technology before launching a new product on the market. In addition, VR provides feedback from actual technological operations and integrate them with the product design process, so that enterprises can solve production and technological problems at the product design stage. Such an approach is part of the Lean Manufacturing concept [Vedmid' 2017, p. 10].

Augmented Reality (AR) is still a relatively new technology that is constantly evolving and has more and more applications in various sectors, including manufacturing. AR is a system that combines the real world with elements of the virtual world, ensuring interactivity in real time and enabling users to have freedom of movement [Rusek, Pniewski 2017, p. 12]. This is possible thanks to the combination of vision systems, image processing, data exchange with IT systems and displaying complex information. In the context of Lean Manufacturing, AR can bring benefits such as [Piątek 2017]: simplified information exchange (thanks to AR, production department employees can directly report problems to engineers and maintenance teams, display KPIs in real time, and analyse information – all without disrupting production); reduction of downtime (implementation of augmented reality systems allows faster response to problems with machines and technological installations); displaying current data (operators can display information about the machine or process; in addition – e.g. by scanning QR codes – workers can have access to video materials, graphics, etc. in real time to operate or repair the device. For example, virtual objects can be shown as attached to the real ones, showing how a part needs to be assembled or disassembled. In the same way, video clips can show a procedure that is difficult to describe in text form), etc.

Thanks to the use of augmented reality, the probability of making a mistake is reduced, the time of performing individual activities is shortened, it can be possible to solve difficult problems by people who are not experts in a given field, and thus waste can be eliminated and production costs minimized.

5. Conclusion

Nowadays, when companies are struggling with the ever-increasing amount of data and the increasingly complex processes of analysing and processing, no modern concepts of enterprise management (including the concept of Lean Manufacturing) will be able to bring maximum benefits without the use of various types of standardized or dedicated IT systems and technologies. Nevertheless, one should always be aware that technologies and IT systems are primarily a tool supporting management processes, used to coordinate and control the progress of these processes aimed at achieving the goals set before them. Just having an IT tool does not guarantee success, but its lack – especially in a large enterprise – can lead to negative consequences. The main aspect taken into account when purchasing an IT system should be not the amount of money spent on it, but the added value that the company can obtain by implementing the solution in its environment. In order for investments in IT solutions to be profitable, it is necessary to use them competently, not only to possess them. The availability of IT tools is a necessary condition, but not sufficient to achieve success in business.

Knowledge is the real key with regard to informatization. Users of IT solutions should know for what purpose and how to use them, when should they use them, what are the expected results from their use, etc. In relation to Lean Manufacturing, IT systems and technologies should ensure that the company obtains the best results from observing the assumptions and principles of a given concept. It should be remembered that the main premise for capital growth is knowledge, not money.

To sum up, it should be emphasized that progressive informatization has become an integral part of modern organizations. Along with the continuous development of IT, business is also developing. Information technologies and business management exist in symbiosis, which ensures that they have high chances of coexistence and creating synergistic effects for organizational units.

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