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IMPLEMENTATION OF INDUSTRY 4.0 ELEMENTS AND THEIR IMPACT ON THE ENTERPRISE PRODUCTIVITY

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Purpose: The main incentive for choosing the topic of the study is related to the need to look for solutions to fundamental problems related to the activities of manufacturing enterprises that must meet the requirements of market competition by achieving competitive advantages and increasing productivity. The subject of the study are advanced manufacturing technologies, characterized by a high level of innovation and automation, and their impact on the productivity of a manufacturing company. The aim of the study is to assess the impact advanced manufacturing technologies on the productivity and production quality on the example of a company producing parts and components for rail vehicles.
Design/methodology/approach: the study analyzed the literature on productivity and calculated productivity indicators based on the company's financial data. Moreover, the participant observation method was used to assess the reorganization of the production process, and a survey was conducted for company employees to determine the validity of the implemented technological investments. The case study concerns a company producing parts and components for rail vehicles.
Findings: The level of approval of investments in advanced manufacturing technologies and their impact on the quality and efficiency of the manufacturing process of was determined. The implementation of advanced manufacturing technologies allowed the company to: shortened the manufacturing process by approximately 40%, the number of procedures was reduced from nine to five, and the number of employees participating in it was reduced from ten to five.
Originality/value: assessment of the effects of the use of advanced technologies, the study is addressed to the management of manufacturing enterprises.
Keywords: productivity, manufacturing technologies, production, improvement.
Category of the paper: Research paper.

1. Introduction

Increasing the standard of living of society and economic growth are the main effects of improvement productivity, which affects the availability and quality of services and products offered. Productivity goes hand in hand with competitiveness, contributing to income growth and reducing inflation. Too slow a rate of productivity growth may lead to economic stagnation, and a long-term lack of growth may lead to recession (Marciniak, 2013). The concept of productivity is sometimes perceived in as an indicator of economic phenomena, or in a broader sense, as an activity aimed at the development of innovation, improvement, increase in efficiency, and progress. Focusing on progress is extremely important, but it involves undertaking and implementing difficult tasks that require a lot of commitment. In development-oriented countries, improving productivity is supported by government agencies and organizations (Lis, 1999; Fried, Lovell, Schmidt, 2008).

Productivity is the ratio of the amount of output produced and sold in a given period to the amount of input resources used or consumed. This means that productivity can be interpreted as the efficiency of using the system's input resources - energy, materials, human labor, information capital, time - in the production of goods and services constituting its output. Productivity growth requires classifying the factors affecting it and indicate those that have priority importance for a given organization (Bai et al., 1997; Kosieradzka, Lis, 2000; Fried, Lovell, Schmidt, 2008; Battisti et al., 2018; Xiao et al., 2022).

To cope with this, entrepreneurs should systematically and properly manage productivity. This requires monitoring productivity using objective indicators and taking various actions, including pro-development and investment ones, in order to increase the level of productivity and, as a result, improve long-term competitiveness (Muthiah, Huang, 2006; Kosieradzka, 2012; Gajdzik, 2014; Trojanowska et al., 2018).

The recently noticeable dynamic development of technology, including the expansion of automation and the use of robots in production and the expected development of the use of IoT and AI technologies in production processes, being the basis of the Industry 4.0, is significantly changing the role played by employees in production systems. There is less employee involvement in direct operation of machines and manual control of their work. Human work is now largely limited to supervising and controlling processes. Efficient use of resources and energy is crucial in the search for a better productivity result (Davies, 2015; Tortorella et al., 2021).

Industry 4.0 is a complex process of technological, process and organizational transformation of enterprises, related to changing their business model and integrating the value chain in the overall product life cycle. The condition for this transformation is the advanced use of digital solutions and data resources, and its goal is mass personalization of the production of goods and services in response to individual customer needs (Śledziewska, Włoch, 2020).

The main incentive for choosing the topic of the study is related to the need to look for solutions to fundamental problems related to the activities of manufacturing enterprises that must meet the requirements of market competition by achieving competitive advantages and increasing productivity. The subject of the study are advanced manufacturing technologies, characterized by a high level of innovation and automation, and their impact on the productivity of a manufacturing company. The aim of the study is to assess the impact advanced manufacturing technologies on the productivity and production quality on the example of a company producing parts and components for rail vehicles.

2. Material and methods

The scope of the empirical study has a three points related to the topic of productivity growth through the use of advanced manufacturing technologies that are an element of Industry 4.0.

The first perspective includes an assessment of the impact of the implementation of selected production techniques on the productivity indicators of enterprise X. For this purpose, on the basis of data coming from the company's financial reports and balance sheets from the next four years:

- production volume expressed in net sales revenues,
- employment level in number of people,
- total assets value,
- operating costs,

the following company productivity indicators were calculated:

- asset productivity $P_a = P / T$, where P_a – asset productivity, P – net sales revenues, T – total asset value,
- employment productivity $P_R = P / R$, where P_R – employment productivity, P – net sales revenues, R – employment,
- material and energy productivity $P_S = P / S$, where P_S – productivity of materials and energy, P – net sales revenues, S – consumption of materials and energy,
- total productivity $P_C = P / K * 100\%$, where P_C – total productivity, P – net sales revenues, K – total costs.

The second research problem concerns the analysis of the way the production process was reorganized in the company. This was possible due to the capabilities of the implemented technologies, which allow for improved material flow, improved quality of manufactured products and increased flexibility of the production system. For this purpose, a map of the technological process was presented. It includes the original state and the current state achieved thanks to the new production potential.

The third point contains the results of the survey. It regards the advisability of investing in advanced manufacturing technologies, which was addressed to three groups of company employees. The first group consisted of plant quality control employees, the second group included employees responsible for production management, and the third group included employees directly related to production. The questions concerned the assessment of the appropriateness of investments in advanced manufacturing technologies. 10 people completed the survey questionnaire. The survey was conducted directly, the respondents assessed the theses on a scale of 1÷10, where 1 meant disagreement with the statement and 10 indicated full support.

3. Enterprise productivity results

This part of the study presents the values of selected enterprise productivity indicators over a period of 4 years, in the context of which investments in advanced manufacturing technologies were implemented. There is a systematic increase in asset productivity in the analyzed period (tab. 1). Significant company's investments in advanced manufacturing technologies took place in the first and it was the purchase of a peripheral welding machine and a CNC machine tool. The biggest investment was carried out in the third year, with the purchase of a laser cutting machine and a press edge. Despite high-budget investments, it is growing asset productivity.

The employment productivity index indicates the value of total revenues per employee. The decline in employment productivity in third year was the result increasing employment related to staffing of newly purchased devices. Improvement employment productivity can be observed in last year, where despite a similar employment, the result achieved is much better.

The value of total productivity remained at a similar level in the analyzed period. To sum up, the values of productivity indicators do not clearly confirm the impact of technological investments on the increase of productivity in enterprise X.

Table 1.
Value of selected productivity indicators in enterprise x

Year / Productivity indicators	1	2	3	4
Asset productivity [PLN]	2,13	2,44	2,52	2,83
Work productivity [PLN]	2,33	2,61	2,63	2,88
Productivity of materials and energy [PLN]	3,57	3,20	2,87	2,80
Total productivity [%]	103,51	103,50	103,30	103,71

Source: own elaboration.

4. Improving the production process - results of the use of advanced manufacturing technologies

The case study concerns a company producing parts and components for rail vehicles. The modernization of production techniques in the analyzed case allowed for significant reorganization of the production process. The results of the comparison of the production process before and after the implementation of advanced manufacturing techniques (automatic welding machine, automatic machining center) are presented in this part of the study. By analyzing the production process of the first part of the pressure vessel, i.e. the operation of preparing the shell, a comparison was made of the current process with the process after the applied modifications. The course of individual processes is presented in the framework diagrams presented in Fig. 1 and 2. The process diagram (Fig. 1) contains 9 technological and logistic operations. Comparison of the diagram from the state before the changes with the diagram of the production process after the changes were applied (Fig. 2) indicates that the introduced process modification reduced the production process by four operations. This translates into a shorter duration of the tank shell production process and a smaller number of employees involved in it.

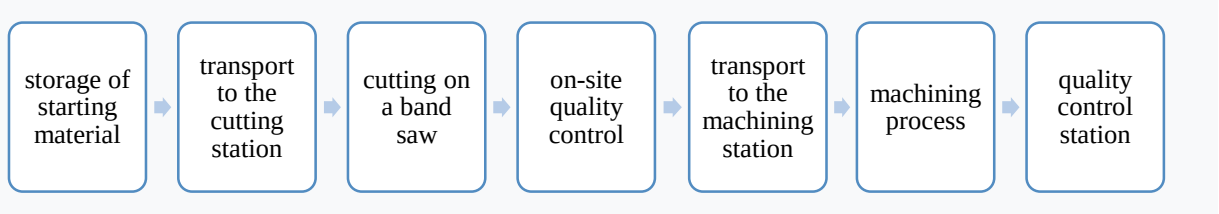

Figure 1. Diagram of the pressure vessel production process before changes.

Source: own elaboration.

Figure 2. Diagram of the pressure vessel production process after changes.

Source: own elaboration.

A comparison of the processes discussed, i.e. the time needed for their implementation and the number of employees participating, is presented in table 2.

Table 2.
Production process before and after modification (comparison for 10 pieces)

Process flow before changes				Process flow after changes		
Operation number		**Number of employees**	**Operation duration**	**Operation number**	**Number of employees**	**Operation duration**
1		1	10	1	1	10
2		2	45	2	1	250
3		1	200	3	1	20
4		1	20	4	1	30
5		1	30	5	1	60
6		1	180	-	-	-
7		1	20	-	-	-
8		1	30	-	-	-
9		1	60	-	-	-
sum	9	10	595	5	5	370

Source: own elaboration.

In the process comparison, consideration was given to; the number of process operations, the number of employees involved in performing a given procedure and the time needed to perform each of them. The production process after the modernization of production techniques includes 5 operations, whereas before it consisted of 9 operations. It is similar when we compare the number of employees involved in each process - here we managed to reduce the number by half, to five. This is of great importance in the labor market, which is currently an employee's market, due to the large supply of jobs. The changes introduced in the process for individual operations allowed to shorten the entire process time by approximately 40%. This is a very good result, which will significantly reduce the costs of this process and, as a result, will contribute to greater profitability of the production of the compressed air tank. The second operation in improving the compressed air production process is the welding of the bottom-stub assembly.

Table 3.
Production process before and after modification (comparison for 10 units)

Comparative feature	**Manual welding**	**Automatic welding**
number of employees	1	1
staff with high welding qualifications	Yes	no
Possibility of substitutability employee after a short time on-the-job training	No	yes
Consistency of welding parameters through the entire work shift	No	yes
Process efficiency	50 units/8h	200 units/8h
Reproducible high quality welded joints	no	Yes
Adapting to the difficult working environment	No	yes

Source: own elaboration.

A comparison of both welding methods was possible using the comparative analysis tab. 3. This analysis includes 7 comparative features. The first feature is the number of employees needed to carry out the process, and the second feature is information about their welding qualifications. The next differentiators allowed us to determine the quality of welded joints and the stability of the processes. The comparative analysis allowed for a comparison of both welding methods. The knowledge obtained in this way allowed us to determine the suitability of modernizing this operation in the compressed air tank production process. In the welding methods studied, the number of workers performing this task is the same. However, the robotic welding process does not require such high welding qualifications from the operator as in the TIG method. This is particularly important because the demand on the labor market for such employees is high, which is associated with their high financial remuneration. The possibility of replacing an employee in robotic welding is much easier. On-the-job training will allow you to continue working with this device. This is possible because the programmed parameters and attached additional equipment do not require too much operator involvement. The sudden need to replace an employee with extensive manual welding skills is not easy to implement due to the high complexity of this method, which requires extensive practice. Continuity of the process, maintaining high welding parameters and quality throughout the entire work shift is very difficult to achieve during manual welding. The monotony of this activity and the forced body position cause fatigue to increase over time. These ailments do not occur when welding with a welding robot arm. This machine is dedicated to work in a difficult work environment. The levels of production efficiency achieved by both methods clearly support the use of the robotic method. The result achieved is four times higher than manual welding. This makes it possible to use this method to weld other details from the company's product range, and to engage a highly qualified employee with manual welding skills to work on other products.

5. Results of the survey assessing the validity of investment in advanced manufacturing technologies

Employees from three groups of the company's organizational structure participated in the survey. These were: quality control employees (3 people), production managers (3) and production workers (4). The survey was conducted face-to-face. The survey question is as follows: "Investment in advanced manufacturing technologies caused X? The respondents assessed the accuracy of the answers to the adopted thesis on a scale of 1-10.

Table 4.
Assessing the validity of investment in advanced manufacturing technologies survey results

X - Answer	Control quality			Production manager			Production workers				Mean
	1	2	3	1	2	3	1	2	3	4	
Increased production efficiency	10	8	6	9	10	9	7	7	8	7	8,1
Improving the quality of manufactured products	10	7	7	8	10	9	8	7	8	5	7,9
Reducing the number of defects and non-conformities during production	8	8	9	8	9	7	9	5	5	5	7,3
Improving work safety	5	6	5	9	9	5	7	5	5	5	6,1
Increased competitiveness	10	6	5	8	10	8	6	4	8	5	7
Possibility of establishing cooperation with foreign contractors	5	5	5	8	7	8	9	5	9	5	6,6
Reducing production costs	8	7	4	9	8	4	7	4	6	7	6,4
Increase in prestige enterprises	5	6	3	10	10	5	9	6	10	5	6,9

Source: own elaboration.

The obtained survey results (tab. 4) confirm the thesis about the advisability of modernizing the machinery. The introduction of advanced manufacturing technologies has a beneficial effect on improving productivity and production quality. The highest ratings were given to statements directly related to the term productivity, such as: increase in production efficiency, improvement in product quality, reduction in the number of deficiencies and non-conformities during production. The assessments given by the surveyed employees have a large degree of discrepancy between individual answers.

6. Summary

The process of examining productivity in an enterprise is a very complex process. This is not only due to the various specifics, but also to the complexity of the issues related to productivity.

Analysis of financial data, comparison of production techniques, and a survey conducted among employees are research methods that are a criterion for assessing productivity in the company, which allowed for a substantive assessment of the company's production processes. The adopted hypothesis of the work was to demonstrate the positive impact of investments in advanced manufacturing technologies on the company's productivity. The support for the statement about the beneficial impact of modernizing the machinery on productivity was not clearly confirmed in the analysis of productivity indicators in the examined period of the plant's operation. However, the survey results and comparisons of conventional and advanced manufacturing techniques on the example of a selected product clearly demonstrated the advisability of the plant's technological development.

The prepared summary highlighted differences in time, quality and cost of producing this product. Due to the changes made in the first selected operation, the duration of the procedure was shortened by approximately 40%, the number of procedures was reduced from nine to five, and the number of employees participating in it was reduced from ten to five. The results in the second modified operation allowed for an increase in production efficiency while improving the quality of welded joints. The effect of the proposed changes in the identified problem areas is an increase in efficiency and obtaining higher quality products, which allows for gaining a competitive advantage. Determining and defining weak stages of the process allows you to look for the causes of this condition. Identification of process imperfections becomes a determinant for developing modification and improvement plans.

The conclusions from the research and the assessments obtained from the survey constitute a recommendation for the company's activities in improving production technologies, which may translate into an increase in productivity. As shown in this work, following innovative manufacturing technologies has its justification, and expenditure on the development of advanced manufacturing technologies should be continuous.

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