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Productivity and improvement of logistics processes in the company manufacturing vehicle semi-trailers – Case study

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Abstract
The aim of the article is to present the results of the productivity research of a manufacturing company with particular emphasis on logistics processes. The article presents another example of verification of the developed proprietary productivity method, with particular emphasis on logistic processes. An author's method is used to select indicators, measure productivity and development of processes improvement. The productivity research was carried out in a company in the automotive industry dealing in the production of semi-trailers. A productivity research procedure was developed for the company, it was measured and recommended for improvement of the selected process. The selection of the process to be improved was made on the basis of the forecasted values of the tested productivity indicators, also using econometric modelling. The results of the productivity indicators after the implementation of the improvement were also presented, which confirmed the validity of the applied method and the right choice of process improvement in the company.

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1. Introduction

Changes in the economy cause logistics and production management to be more and more important at the moment. The reasons for such changes are growing market globalization, increasing global competition, improvement of manufacturing processes and production technology, new technologies, increased emphasis on quality of processes, products, customer service, as well as increased expectations of buyers (Bendkowski and Matusek, 2013; Kovács and Kot, 2016; Wachnik, 2022). Nowadays COVID-19 also influenced manufacturing and has an influence on productivity indicators (Cai and Luo, 2020; Klimecka-Tatar and Ulewicz, 2021). The tasks of logistics include order acceptance and coordination, production planning, relationships with suppliers, purchasing, supply chain management, warehouse management, transport, etc. allowing to perceive the functioning of the enterprise as a coupled sequence of processes (Bendkowski and Matusek, 2013; Coyle et al., 2010; Grant et al., 2006; Krawczyk, 2001; Murphy and Wood, 2011).

Generally, logistics processes and productivity in a manufacturing enterprise should be analysed and improved. When examining productivity, the impact of logistical processes on the performance of the indicators should be taken into account. On the other hand, when analysing individual logistical processes in a manufacturing enterprise, it is worth focusing on their ability to impact the performance indicators of the enterprise (Rostek and Knosala, 2018).

The automotive industry has a significant share in the Polish industry, which in the year 2019 generated 8% of Polish GDP. In the same year, domestic exports in the automotive industry accounted for 21%. Therefore, the constant development of enterprises towards Industry 4.0 will allow them to maintain a high position in global supply chains (Michna and Kaźmierczak, 2020). Productivity is one of the many indicators that should be analysed in manufacturing companies. It allows you to assess how well resources are used to achieve benefits from the sale of production.

The aim of the article was to examine and analyse the company's productivity, taking into account logistics processes, and to assess the impact of improving the logistics process on the company's productivity. This is another example of the verification of the proprietary productivity research method, taking into account logistics processes.

2. Literature review

Productivity is a relationship between the goods and services produced in a certain period, and the resources consumed to produce them in that period. This relationship is expressed in equation *(1)* (A Guide to Productivity Measurement, 2011; Coelli et al., (2005); Christopher, 1985; Kosieradzka, 2012; Nagashima, 1992; Saari, 2006).

$$P = \frac{Output\ at\ based\ period}{Total\ of\ all\ inputs\ at\ base\ period} \quad (1)$$

In literature, productivity is divided due to labour and capital, as well as materials and energy. These are the most common divisions (Christopher, 1985; Kosieradzka, 2012; Rostek and Knosala, 2018). Productivity can be calculated as partial ratios. Then are different ratios for each input. It is shown in the equations *(2-5)*. In enterprises, productivity ratios can be shared according to departments, processes, positions, etc.

$$P_{Labour} = \frac{Output\ at\ base\ period}{Labour\ input\ at\ base\ period} \quad (2)$$

$$P_{Materials} = \frac{Output\ at\ base\ period}{Materials\ input\ at\ base\ period} \quad (3)$$

$$P_{Energy} = \frac{Output\ at\ base\ period}{Energy\ input\ at\ base\ period} \quad (4)$$

$$P_{Capital} = \frac{Output\ at\ base\ period}{Capital\ input\ at\ base\ period} \quad (5)$$

In a manufacturing company, taking into account the phase division of logistics, it stands out:

- supply (purchasing) - management and logistics for production materials,
- transport - this stage refers to the transportation of stored goods to the destination, it basically tracks the journey from warehouses to the client, resources to the company and also inside the manufacturing company,
- warehousing - the process of storing physical inventory for sale or distribution,
- production - this process includes managing raw materials to form a product, it mainly includes organising materials in chronological order,
- distribution – to spread the product throughout the marketplace such that a large number of people can buy it,
- reverse logistics - waste management is included in this process, the journey of a product from a company to the storage (Blanchard, 2004; Christopher, 2016; Pfohl, 1998).

Production processes can be improved through many concepts, methods, and technics for example:

- 5S (García-Alcaraz et al., 2018; Santos et al., 2014),
- Just in time (Santos et al., 2014),
- Kaizen (García-Alcaraz et al., 2018; Kosieradzka, 2012),
- Lean manufacturing/management (Pinto, 2018; Ulewicz et al., 2021; Ulewicz and Kucęba, 2016),
- Quick response (Suri and Burke, 2020),
- Theory of constrains (Borkowski and Ulewicz, 2009a, 2009b; Cox and Schleier, 2013),
- Total productive maintenance (Ben-Daya et al., 2009),
- Total quality management (Agus and Selvaraj, 2020),
- Poka-Yoke (Gamberini et al., 2009; García-Alcaraz et al., 2018).

Industry 4.0 focuses on solutions such as cyber-physical systems, the Internet of Things, cloud computing, etc. They affect the optimization of production processes (Pereira and Romero, 2017), condition the improvement of competitiveness and flexibility of enterprises and also enable better adaptation to customer needs (Herrero et al., 2020; Lu, 2017; Michna and Kaźmierczak, 2020; Kotarbiński, 2015). Consequently, the impact of implementing Industry 4.0-based solutions on the productivity indicators is not without significance.

3. Description of the method

The proposed general model for evaluating productivity (Fig. 1) was developed with a significant focus on logistic areas in an enterprise. The proprietary method is described with more detail in the article (Rostek and Knosala, 2018). In the presented model, five stages can be distinguished, which are the next stages of the entire method:

1) extracting processes, is a separation of the logistics processes in the enterprise,
2) preparing data for analysis, including a selection of indicators for evaluation, elaborating a data set, and entering data into a spreadsheet,
3) analysis and assessment of productivity, including analysis of the productivity of individual logistics processes, evaluation of logistics processes productivity and choice of processes requiring improvement,
4) developing a productivity improvement program and implementing the chosen solution,
5) control of the achieved results (Rostek and Knosala, 2018).

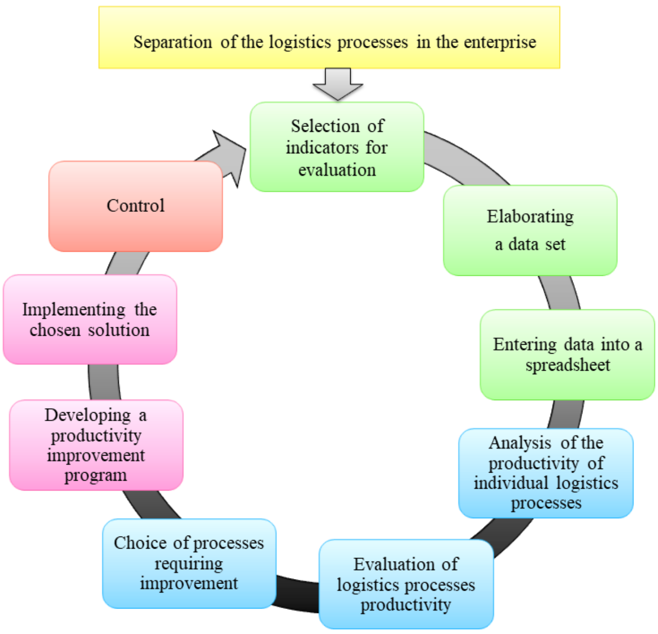

Fig. 1. A general model for assessing the productivity of manufacturing companies. Source: Rostek and Knosala, 2018

The assumptions of the method and its limitations are:

- logistics is a factor influencing the company's productivity,
- logistics processes (the logistic system of the enterprise is examined)
- size of the company (dedicated medium and big companies),
- industry (dedicated manufacturing companies),
- individual approach,
- logistics division according to flow phases,
- the application of the method is an ongoing process.

4. Case study

The verification of the presented model was carried out in a medium-sized company in the automotive industry, producing car semi-trailers. It is a highly valued provider of specialised commercial vehicle solutions for sectors such as mines, energy, military, firefighting and many more. The researched enterprise is at the 1st level of implementation of Industry 4.0 elements (Michan and Kaźmierczak, 2020).

In the examined company, a productivity research procedure was prepared, with particular emphasis on logistic processes (Appendix A). The management board, the team managing logistics processes, the team researching logistics processes and the accountant were distinguished because it is an external company (one person/outsourcing) whose task is to prepare the data necessary to perform the analysis. The accountant receives a list of data that is needed in the productivity research process and the prepared data set is passed on to the team examining logistics processes.

Management decides whether the developed productivity improvement program should be implemented or not. Less costly process corrections will be considered as management information. However, management cannot be ignored.

The team managing logistics processes are directors responsible for individual activities related to logistics and production:

- managing director,
- production manager,
- warehouse and logistics manager.

4.1. Extracting processes in the enterprise

After systematising the order of work in the enterprise, productivity research was started. The first stage, the separation of logistics processes in the enterprise, was performed by classifying the performed tasks into the appropriate logistics process. The main logistic processes are:

- supply and distribution logistics - the most time is spent on implementing supply processes; distribution is carried out to a minimum extent and falls within the framework of such processes as cooperation with contractors and partly complaints,
- production logistics, where goods transferred to production and warehouse are checked, maintenance and production organisation,
- warehousing combines production and supply as goods are kept in stock and inventory management decisions are made.

Transport is highlighted in three places because the transport processes are carried out both into and outside the enterprise, as well as inside the enterprise. Additionally, some transport is carried out and controlled by the enterprise. The waste is only stored and then transferred to an external customer.

4.2. Preparing data for analysis

The stage involving the preparation of data for analysis began with a meeting of the logistics process research team to select indicators for analysis and to verify which indicators were feasible on the basis of the archived data. A set of indicators was selected corresponding to the breakdown shown in Appendix B. On this basis, a list of input data was prepared and submitted to the accountant for data collection. Part of the data was collected by members of the team researching logistics processes. This concerned on information that they processed.

4.3. Analysis and assessment of productivity

Productivity analysis and evaluation were carried out on two levels as presented in the article (Knosala and Rostek, 2016). First, the productivity indicators were determined for the processes:

- total productivity (TP),
- supply (SP),
- production (PP),
- warehouse (WP),
- transport (TrP),
- reverse logistics (RP).

The data were collected for twelve months over the years 2018-2019. The results after data standardisation are presented in Figure 2. The analysis of the figures indicates the lack of stability of the productivity indicators in the enterprise. The main goal is to focus on the stability of the productivity indicators at this stage of the analysis. Additionally, basic data analysis was performed by determining the variability index (Table 1). The processes related to reverse logistics are characterised by the highest variability. The others processes show variability at the level of approx. 30%. It is clear that it is necessary to take action to improve logistics processes in order to stabilise productivity and strive for its improvement.

Table 1. Coefficients of variation of total and partial productivity in the examined enterprise.

Productivity	Average	Standard deviation	Coefficient of variation
TP	5.75	1.51	26.33%
PP	6.49	1.71	26.38%
WP	126.68	40.97	32.34%
TrP	133.72	37.97	28.39%
SP	253.83	61.14	24.09%
RP	8 578.95	4993.90	58.21%

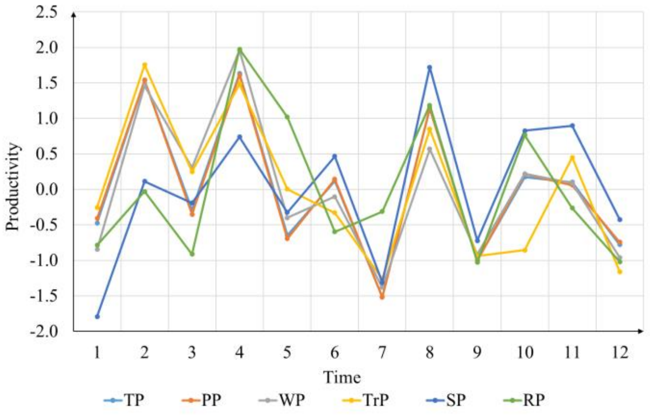

Fig. 2. Productivity indicators for the examined enterprise, taking into account a division due to logistical processes

In order to better analyse the productivity and make an appropriate decision about which process to improve, it was decided to make forecasts of individual indicators (Appendix C). In the case of this company, forecasts were built based on a linear trend model for the indicators of total productivity and the productivity of logistics processes of production, warehousing and reverse logistics. The formulas of the individual models are as follows:

- for TrP $y_t^* = -0.1189*t+6.5226$,
- for PP $y_t^* = -0.1331*t+7.3558$,
- for WP $y_t^* = -3.8623*t+151.79$,
- for RP $y_t^* = -124.76*t+9\ 389.9$,

where *t* is time.

For the other indicators, the 4-element moving average method has the smallest errors. However, for some indicators, significant forecast errors are noticeable. According to the selected forecasting models, each of the determined indicators should record an increase in value in the next month. A high value of the RMSE index indicates that the forecasts are not of the best quality. Therefore, it was decided to build an econometric model to assess which process significantly affects productivity.

The selection of variables for the model began with a preliminary analysis of the data. The coefficients of variation are at the level indicating medium variation in the data, and in the case of reverse logistics, high variation in the data. There is no quasi-constant variable, so all partial productivity indices can potentially explain the behavior of the total productivity indicator. In order to better select variables for the econometric model, the correlation between individual indicators was examined (Table 2).

Table 2. Correlation indicators (r_{ij}) for enterprise productivity indicators

	TP	PP	WP	TP	SP	PR
TP	1	0.999	0.950	0.886	0.708	0.621
PP	0.999	1	0.941	0.873	0.700	0.614
WP	0.950	0.941	1	0.895	0.662	0.639
TP	0.886	0.873	0.895	1	0.503	0.530
SP	0.708	0.700	0.662	0.503	1	0.587
RP	0.621	0.614	0.639	0.530	0.587	1

The explanatory variables should be strongly correlated with the explained variable. For this purpose, the critical value of the correlation coefficient is determined. For the analysed example, with the significance level α=0.1, this value is $r^*=0.497$. From the first column of table 2, those variables for which $r_{ij} < r^*$ should be eliminated. There are no such variables for the analysed data. Then the variable that is most correlated with the explained variable is selected - it is PP. The last step in variables selection is the elimination of variables that are strongly correlated with each other, i.e. the correlation indexes are higher than r^* - these are the variables WP, TP, SP and RP. It follows from the above that the model should take into account PP as an explanatory variable. The scatter plot of total productivity against the productivity of production logistics shows a linear relationship. Hence, the linear regression model was chosen (Fig. 3). The available tools in spreadsheets were used to determine the model formula and the coefficient of determination, which indicates to what extent the model explains the reality. The model is as follows:

$$TP = 0.0158 + 0.8835 * PP.$$

The determination index is at the level of 0.9985. So the model fits very well with the empirical data.

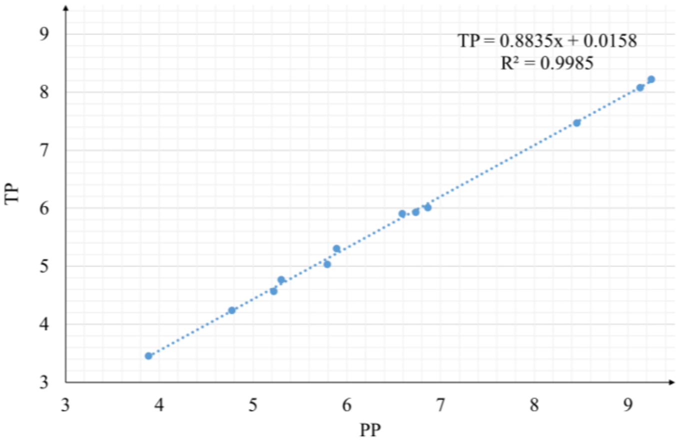

Fig. 3. Dependence of PC on PP

The analysis showed that total productivity is mainly dependent on the logistic production processes. Productivity indicators were determined for the second level of detail, i.e. the productivity of logistic production processes, taking into account the use of the following input resources:

- capital (PPC),
- labour (PPL),
- materials (PPM),
- energy (PPE).

Figure 4 shows the results for the partial productivity at the next level of detail, after data standardisation. The first two months are characterised by a very large amplitude of fluctuations. In the case of energy consumption it shows stabilisation after this period. The consumption or use of the other analysed inputs fluctuates. There is no noticeable decreasing or increasing trend and no stabilisation. At this stage of the analysis, it was found that it is worthwhile to analyse the overall activities performed as part of the implementation of logistics processes related to production.

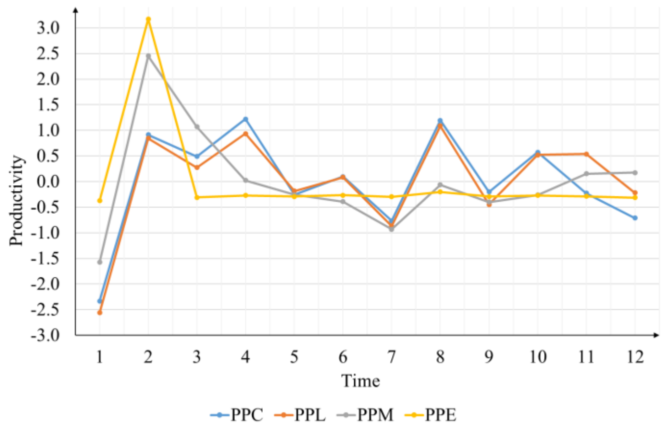

Fig. 4. Productivity indicators for the examined enterprise in the next level of detail

4.4. Developing a productivity program

Due to the development of the company, it was decided to implement the theory of constraints (TOC). Improving processes with the TOC method requires the identification of bottlenecks. It has been shown that the bottleneck in the pursuit of productivity improvement may be the production organisation. Changes in the company are introduced on a continuous basis and concern many areas. In line with the purpose of the analysis, it was proposed to reorganise the rules related to the collection of materials from the warehouse. Now, once a week, the order of the production tasks to be carried out is determined and it is decided when the appropriate materials are to be in the buffer warehouse. In addition, the buffer warehouse must be replenished before the start of the next stage of production (it used to be different before). Additionally, the company introduced the Poka-Yoke method. No robots are used in the production, therefore, to eliminate errors of welders, the structures have special holes that make it easier to put elements on and weld them in the right place.

The introduction of TOC also concerned warehouse processes. However, the reorganisation of the storage is still ongoing. Among other things, it was decided to organise the storage space and organise the materials on the shelves. Until changes, materials and raw materials have been stored according to the principle of "where there is space". Now the warehouse has been planned and equipped with appropriate storage racks. The warehouses are being prepared for the introduction of barcode-based warehouse management systems.

4.5. Control

Three months after the start of the improvements, the validity of the improvement was verified by analysing the productivity indicators. The results are shown in Figure 5, all indicators register a gradual increase in value. The most visible increase was recorded for reverse logistics processes, however it should be remembered that this is a highly variable process. This indicator is very sensitive for inputs, for example of costs related to the realisation of reverse logistic processes. The others are characterised by a similar course as total productivity. In Figure 5 total productivity (TP) is not good visible because the standardised data are almost identical to warehouse processes productivity.

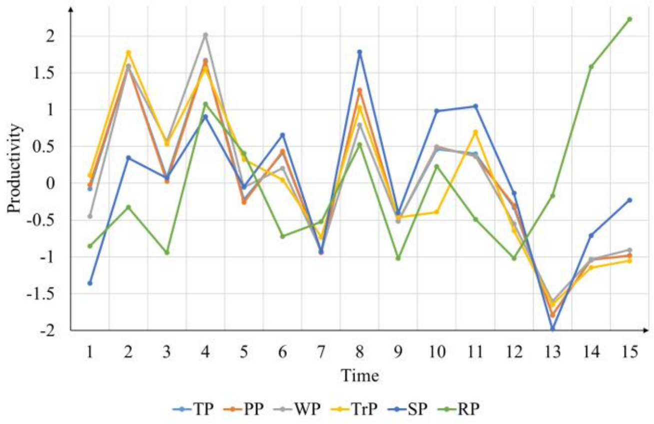

Fig. 5. Productivity indicators for 15 months, taking into account a division due to logistical processes

5. Recommendations for the enterprise

Taking into account the last chart, it is worth paying attention in the future to the convergence of the curves for total productivity and warehouse processes. This shows the relationship between these indicators. Therefore, the expected effect of the improvement in the implementation of warehouse processes is an increase in the company's productivity.

In order to further improve productivity, it is suggested to analyse reverse logistic processes also, to stabilise it in terms of even disposal of waste (Michna and Kaźmierczak, 2020). Analysing the place where the waste is generated and the possibility of its elimination will be helpful in this regard.

A very good direction for the researched company is the implementation of solutions related to Industry 4.0 and Logistics 4.0 (Efthymiou and Ponis, 2021; Frank et al., 2019; Ingaldi and Ulewicz, 2020; Reischauer, 2018; Wachnik, 2022). Especially in the field of the use of modern technologies that improve management decision-making and allow to control of processes, also remotely (Krynke, 2021). In modern management and in the context of changes caused by the COVID-19 pandemic, such a direction is very justified. An additional advantage is a fact that the company is focused on continuous development and implementation of modern solutions. Unfortunately, the related costs with it are the limiting factor.

Before implementing changes, it is worth supporting the modeling and simulation of processes (Beaverstock et al., 2017; Kaczmar, 2019). This will allow to develop of various solutions and predict their effect and verify the feasibility of implementation. Many IT tools are at the disposal of managers, for example FlexSim, Ocyave, Matlab/Simulink, Tecnomatix Plant Simulation, Arena, Enterprise Dynamics, Vensim and others (Krynke, 2021; Kaczmar, 2016). Simulations of logistic processes will allow to model a change and check its effect without interfering with the actual process. It is important that the digital model reacts quickly to changes (Kaczmar, 2019; Krenczyk et al., 2017). Thanks to this, the management board will be able to make a decision without risking financial resources.

6. Summary and conclusion

The researched company is in the process of continuous development, therefore it is interested in implementing new solutions. Focusing on productivity indicators, the first step was to systematise the logistics processes. Then, indicators for the productivity research were selected and the data was collected. It was a time-consuming process, but it was facilitated by the quite carefully conducted data archiving and a wide range of collected data. After compiling the data, the next time-consuming stage was their analysis. The examined company showed that logistic production processes have the greatest and very significant impact on the company's productivity. Solutions have been implemented to streamline the processes of planning and organising production and warehousing. The improvements implemented in the company had a positive impact not only on the production logistics but also on the warehousing processes carried out. The selection of the process to be improved was made on the basis of forecasts based on econometric modeling.

When analysing the productivity of logistics processes, keep in mind the limitations of the model:

- size of the company (dedicated medium and big companies),
- industry (dedicated manufacturing companies),
- trade-off relations,
- inconsistent, error-free employees.

In the presented case study, the change in logistics processes additionally resulted in a change in overall productivity. The productivity analysis over the entire period considered confirms this relationship. The coefficient of determination close to the value of 1 indicates a high dependence of productivity on production logistics in the examined company. Therefore, it is reasonable to say that changes in logistics processes cause changes in the company's productivity. Changes in the organisation of production logistics and warehousing resulted in positive changes in productivity. The aim of this article was achieved, productivity taking into account logistics processes was examined and the impact of improving the logistics process on the company's productivity was noticed. This is another example of the positive verification of the proprietary productivity research method, taking into account logistics processes.

Moreover, in the examined enterprise the assumption about the continuity of the productivity analysis process was also confirmed. One of the processes has been improved and it has been noticed that another area can be improved.

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Appendix A

Fig. 1. The procedure for researching the productivity, taking into account logistic processes for the examined company

Appendix B

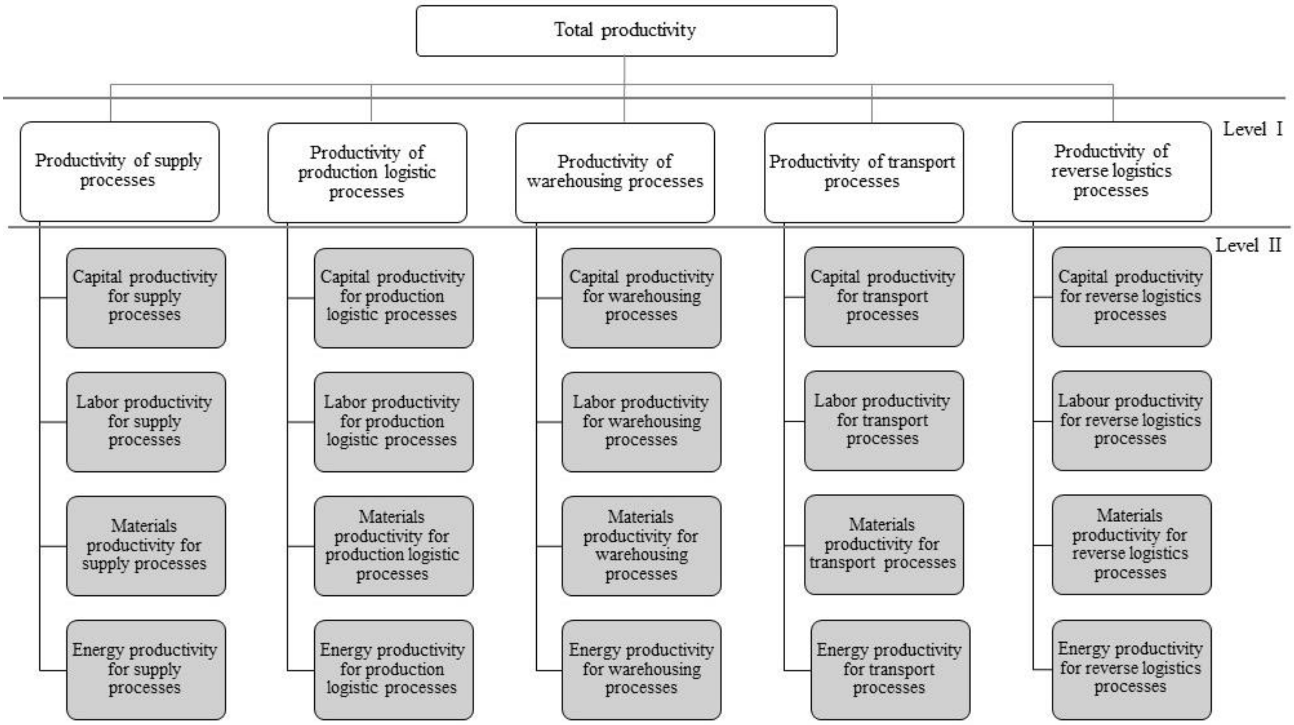

Fig. 2. Diagram of the division of productivity indicators taking into account logistics processes

Appendix C

Table 1C. Forecast of productivity indicators in the enterprise – results

	TP	PP	WP	TrP	SP	RP
ME	0.000	0.000	-0.004	-6.290	11.008	-0.007
MPE [%]	-6.100	-6.171	-0.090	-3.659	7.272	-34.902
MAPE [%]	22.600	22.784	27.134	24.554	18.422	62.250
MSE	1.932	2.476	1 361.143	896.060	2 974.380	2 267 5271.000
RMSE	1.390	1.574	36.894	29.934	54.538	4 761.856
Forecast P	4.977	5.626	101.580	109.980	262.664	7 768.020
ΔP	0.408	0.406	14.225	20.228	34.766	4 278.635
ΔP[%]	8.918	7.776	16.284	22.537	15.255	122.619

Where:
ME – Mean Error
MPE – Mean Percentage Error
MAPE – Mean Absolute Percentage Error
MSE – Mean Squared Error
RMSE – Root Mean Squared Error

制造车辆半挂车的公司的生产力和物流流程的改进 – 案例研究

關鍵詞
物流流程
流程管理
生产
生产力测量

摘要
本文的目的是介绍一家制造公司的生产力研究结果，特别强调物流流程。本文介绍了另一个验证开发的专有生产力方法的示例，特别强调了物流流程。作者的方法用于选择指标，衡量生产力和过程改进的发展。生产力研究是在一家从事半挂车生产的汽车行业公司进行的。为公司开发了生产力研究程序，对其进行了衡量并建议改进所选流程。改进过程的选择是基于测试的生产力指标的预测值，也使用计量经济学模型。还给出了改进实施后的生产率指标结果，证实了应用方法的有效性和公司对过程改进的正确选择。