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METHODOLOGY OF EVALUATING FINISHED GOODS WAREHOUSE PERFORMANCE THROUGH LEAN METHODS

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Abstract:

This paper considers the problem of evaluating the effectiveness of the finished goods warehouse of a manufacturing company, in which a modified TPM method - Total Productive Management (TPM2) - was applied to improve productivity. A multi-stage methodology was proposed, including a decision to modify the system, determination of the scope of changes, monitoring the results obtained and a multi-criteria evaluation of the changes made. The decision to make modifications to the existing system was motivated by the lower-than-expected quality of customer service (frequent delivery delays). With regard to the transport department, lean flow pillar activities were focused on analysing losses (muda) in warehouse processes (product loading and package unloading). The purpose of these activities was to minimise interruptions in warehouse processes (product loading and package unloading). "The steps for solving the problem" methodology based on Deming's PDCA cycle was used to solve the problem. The analysis covered, among other things, the information flow processes between production planning and the customer service department, the planning processes of the dispatcher, the efficiency of the loading processes, and the causes of interruptions in warehouse operations. The analyses employed the chronometry of selected works, the 5W + 1H method and the Pareto method. By using the 5S method and some characteristics of the SMED method, the organisation of loading work was decisively changed (shunting yard changes, appropriate buffers for transport equipment). The changes introduced in the system were monitored for several months. Appropriately defined OEE indicators were used to assess the behaviour of the system after the changes. The indicators consider the use of available warehouse time, the efficiency of the loading process and the quality of the tasks performed. The results that can be achieved are presented using the specific example of the finished goods warehouse of a manufacturing company in the FMCG sector.

Keywords: *effectiveness assessment, finished goods warehouse, lean indicators, OEE*

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1. Introduction

The rise of SCM (Supply Chain Management) concept has forced companies to transform from functionally-oriented to process-oriented organisations (Taylor, 2008). In a manufacturing company, the process that involves the most significant amount of capital is the manufacture of products. Manufacturing makes the mainstream of materials in the production process flowing through the individual objects of the production structure according to the adopted manufacturing methodology (Michlowicz, 2013). From a system perspective, material flows are the common element linking transport, storage and production operations. For many years, one of the most important problems within complex systems has been the occurrence of various types of waste (muda), which reduce the effectiveness of the implemented processes and, consequently, reduce the level of customer service quality. As a remedy for eliminating muda Womack and Jones (Womack & Jones, 2008) recommend a lean approach, lean thinking, by creating a value stream within the company. Lean actions can be most simply described as a process of continually eliminating waste in all ongoing processes.

The role of logistics in a company is to develop and prepare a system of activities that, using the principles and laws of logistics as well as other fields of broader science, will enable implementation of logistics activities that support achievement of outcomes defined in the company's strategy (Michlowicz, 2021).

The basic strategies include:

- high-quality customer service,
- World Class Manufacturing (WCM),
- achieving desired (specified) productivity,
- obtaining established economic and technical indicators.

In this article, the main object of research and analysis is to evaluate the performance of finished goods warehouse of a manufacturing company in which, in order to achieve World Class Manufacturing WCM, Total Productive Management (TPM2) method was implemented in all areas of the company. The complexity of assessing the performance of the system relies on the complexity of the causes of unplanned stops and interruptions (manufacturing company warehouse). Analyses of these causes were conducted during the implementation of TPM2. To evaluate the performance of the warehouse after the changes, suitably modified OEE (Overall Equipment Effectiveness) indicators were proposed.

2. Literature review

A number of concepts, or methods, can be used to address the problem of assessing effectiveness of warehouse process execution. Currently, the greatest opportunities are provided through, among others: selected methods of the lean enterprise concept, methods using artificial intelligence (AI), machine learning, concepts related to the smart enterprise, transport optimisation methods (internal as well as VRP - Vehicle Routing Problem class). The system approach to the organisation enables the interdependencies and interactions between the elements (objects) belonging to the system to be identified. Thus, when assessing the effectiveness of the organisation as a whole, such a view is necessary, not least to detect weak links. Various methods of the lean class are quite often used to achieve these objectives. In a comprehensive publication, Sangwa (Sangwa N. R., et al., 2018) describes an integrated performance measurement framework to measure the effect of implementing lean across all functions of an organisation. The paper identifies seven categories representing all organisational functions and the interrelationship of each category with lean principles. A total of 26 dimensions and 119 key performance indicators (KPIs) were identified across the seven categories. The impact of the adopted performance criteria on lean enterprise is presented in Tekez's work (Tekez E., et al., 2020). A fuzzy Analytic Network Process (ANP) approach was used to determine the lean impact value of each criterion. The issue of implementing lean concepts to improve internal transport processes is presented by Ulewicz (Ulewicz R., et al., 2015). In the case study in question, Value Stream Mapping (VSM) process mapping analysis was used to identify value stream tipping points. Complexity of using performance measures is considered in a publication by Andersson (Andersson C., et al., 2015). The authors of the paper argue that a systematically applied combined set of OEE and productivity measures can successfully lead to production improvements. A remarkably interesting approach to warehouse performance indicators is presented in the work of Rahman (Rahman N., et al., 2023). The authors analysed the most important warehouse productivity indicators for improving the effectiveness of warehouse operations.

In this paper, they described an empirical fuzzy analytic hierarchy process (FAHP) methodology. The analysis model developed by the authors is based on the adoption of three study theories: quantitative, system and productivity theories. The impact of warehouse layout and operations on performance is described by Mohamud (Mohamud I., et al., 2023). The authors conducted an extensive literature review to find the importance of these attributes (layout, operations) in determining warehouse performance (articles published in 2019-2022). An interesting study on improving warehouse performance was presented by Kim (Kim T., et al., 2018). The authors presented a methodology for planning warehouse capacity and performance based on a biased demand forecast. According to the authors, intentional forecast error can lead to smoother workflows in warehouses and thus translates into higher performance.

The strategic, holistic systems approach is proposed by Duffuaa in his comprehensive monograph (Duffuaa S.O., et al., 2015). In this work, keeping performance is considered as an integrated system including goals, strategies and processes that need to be planned, designed, constructed and controlled using statistical and optimisation-based tools. Particular importance has been attributed to the TPM (Total Productive Maintenance) method for years. A comprehensive literature review on the practice of TPM implementation by different manufacturing organisations (the review includes 148 scientific articles) is included in Jain's publication (Jain A. et al., 2014). A new concept of mobile maintenance is presented by the same authors in another publication (Jain A. et al., 2015). The impact of the simultaneous application of TPM and TQM (Total Quality Management) methods on process performance is described in a paper by Sahoo (Sahoo S. et al., 2020). In this paper, the authors presented an empirical study using survey responses from 72 manufacturing companies. The problem of improving process performance by applying the TPM method is presented in Nurprihatin's work (Nurprihatin F., et al., 2019). To achieve performance improvement, the authors proposed to apply the performance indicator OEE (Overall Equipment Effectiveness). New possibilities in overall equipment effectiveness management are included in Hung's publication (Hung Y-H., et al., 2022). A related measure of TPM is overall equipment effectiveness (OEE), which includes three components, namely availability, performance and quality, which measure different aspects of production losses. The authors propose Value-Added Overall Equipment Effectiveness (VAOEE) as a new measure to measure all identified losses in search of hidden performance. From the experience of implementing different lean methods, it is clear that far better results can be achieved by using several methods, e.g. the 5 S's, Kaizen and TPM. Such an approach is presented in Habidin's work (Habidin N., et al., 2018). The aim of the authors' research was to determine the relationship between total productive maintenance (TPM), kaizen method (KE) and innovation performance (IP). The study used the structural equation modelling (SEM) method.

Considerations related to application of machine learning technologies and ontologies in the context of predictive maintenance are described in Dalzochioa publication (Dalzochioa J., et al. 2020). An extremely important issue of smart maintenance is described in two articles by Bokrantz. In the first one (Bokrantz J. et al., 2020 a), the authors raise the issue – what is a smart maintenance and propose an inductive research approach. The authors define four basic dimensions of smart maintenance: data-driven decision-making (1), human capital resources (2), internal integration (3) and external integration (4). As a consequence of the research, the authors developed a contingency model for problematic events (Bokrantz J. et al., 2020 b). The model includes five areas: environmental contingency (1), institutional isomorphism (2), implementation issues related to change, investment and interfaces (3), the four dimensions of smart maintenance (4), and the impact on plant- and company-level performance (5).

The problem of optimising warehouse processes is covered in Tarczyński's monograph (Tarczyński G., 2019). The author presents models and methods in which he applies, among others, the concept of unsupervised artificial neural networks, the concept of dynamic programming and methods based on a simulation approach. The vast majority of authors focus primarily on picking processes, which is understandable, but the organisation of all processes is equally important, as is an appropriate strategy. The topic of strategy selection for warehouse processes is covered in a publication by Kłodawski (Kłodawski M., et al., 2017). The authors describe in detail the problems of designing and organising logistics in warehouse facilities. This paper presents an original approach to storage strategy selection. The approach uses a decision tree that shows the probabilities of selecting subsequent storage operations and the probability of unusual events. For many years, PSS (Product-Service System) class systems have been regarded as a concept that supports companies in creating competitive advantage. Issues related to the design of PSS systems are described by Salwin (Salwin M., et al., 2022). To design a selected process from the industry, mathematical modelling based on an optimisation function and computer modelling via a simulation model were used. A case study of performance improvement in a hybrid warehouse is presented in Freitas (Freitas A. et al., 2019). A hybrid warehouse, as defined, is one that combines several different processes (including warehousing, picking, shipping, line supply and production preparation tasks). Performance improvements in a bus manufacturing company were achieved by applying several lean tools simultaneously. The impact of technological and organisational innovations in the warehousing process on its productivity is described by Kudelska (Kudelska I., et al., 2020). The research was conducted using simulation models developed in FlexSlim 3D Simulation software. To improve warehouse performance, Melinda (Melinda T. et al., 2020) proposes the use of genetic algorithms. Purba (Purba H., et al., 2018) for increasing productivity in the picking process recommends one of the most important lean methods - Value Stream Mapping (VSM). A comprehensive review of research related to routing is provided by Masae (Masae M., et al., 2020). The authors analysed 735 articles in English (from the Scopus database) and proposed a conceptual framework for classifying different routing policies. Using this framework, they categorised the existing literature in terms of algorithm type (exact, heuristic and meta-heuristic) and warehouse layout (conventional, unconventional and general).

A review of practical factors in order picking planning by Vanheusden (Vanheusden S., et al., 2023) is particularly interesting. The conclusion of the authors of the publication is interesting: The results of academic research are not always applied in practice. Rather, warehouse managers apply simple policies that are easy for all warehouse staff to understand, but these policies result in solutions that are far from optimal. On the other hand, researchers often do not consider the perspective of practitioners, leaving great potential for increasing the practical usefulness of research on picking operations planning.

Detailed solutions to the various problems associated with the implementation of picking processes are addressed by a number of authors. A study of processes involving pre-picking and automated picking is described in Lee's work (Lee J., et al., 2015). Determining the shortest path to optimise forklift routes was addressed by the authors of a publication related to waste reduction and material handling (Beker I. et al., 2012). Aerts (Aerts B., et al., 2021), on the other hand, proposes that the issue of order grouping should be solved using the clustered vehicle routing problem (CluVRP) model. The problem of optimising order picking in a warehouse is the subject of an article by Buckova (Buckova M., et al., 2017). The interactive software Tecnomatix Plant Simulation 13 was used to optimise the transport distances of order picking processes in the warehouse. Application of an integrated procedure for order picking design and optimisation is proposed in Bottani's paper (Bottani E., et al., 2019). The authors proposed a structured OPS (Order Picking System) design framework organising a five-step operational programme including: layout design, picking selection, strategy and type, item allocation and route optimisation.

In many cases, the success of the solution is determined by having the right database. Decision problems related to database design are described by Jachimowski (Jachimowski R., et al., 2017). The article includes a case study for simulating warehouse processes. Application of the Analytic Hierarchical Process (AHP) to provide information for determining the optimal stock level in a warehouse is presented in an article by Alqahtani (Alqahtani A., et al., 2023). Research on the perfect order rate in logistics chains is presented in Jacyna - Gołda (Jacyna - Gołda I., et al., 2019). The Perfect Order Rate (POR) is one of the overarching measures of the quality of logistics. This article defines the concept of the perfect order rate by including new elements in the classic definition, so far rarely considered in the literature: the ability to fulfil orders according to standard procedures in organisational and safety aspects.

An extensive literature review shows that an efficiently operating warehouse contributes significantly to an important strategy of most organisations, namely high-quality customer service. To this end, new methods are being sought to improve the effectiveness of warehouse processes. At the same time as new methods of improvement, the problem of evaluating the changes made arises. Assessing effectiveness only by the performance of one process is insufficient. One possible way of multi-criteria evaluation of warehouse effectiveness is to use the indicators proposed by the lean enterprise concept.

3. Object of research

The most important difference between a product warehouse in a manufacturing company and a warehouse in a distribution centre is dependence of the production warehouse resources on performance of the manufacturing system. The diagram of the generalized production system is shown in Figure 1.

The generalized production system PS is a certain ordered set of elements E and relations R between them:

$$\mathbf{PS} = < \mathbf{E}, \mathbf{R} > = < \{\mathbf{X}, \mathbf{Y}, \mathbf{T}\}, \mathbf{R} >, \quad \mathbf{T}: \mathbf{X} \rightarrow \mathbf{Y}$$

where:

$X = \{X_1, X_2, \ldots X_i, \ldots X_M\}$; for i = 1,…M – set of external magnitudes describing input elements,

$Y = \{Y_1, Y_2, \ldots Y_j, \ldots Y_N\}$; for j = 1,…N – set of external magnitudes describing output elements,

$T = \{T_1, T_2, \ldots T_k, \ldots T_S\}$; for k = 1,…S – set of magnitudes describing the transformation of input vector into output vector,

$R = R_X \times R_Y \times R_T$ – material and information conjugations between the PS system elements and between the elements and the environment (most often close environment).

Each system and system products have a specific, finite life, the so-called lifecycle. Continuous monitoring of selected features and properties of the system (according to Fig. 1) allows you to make the right decision about system modernization.

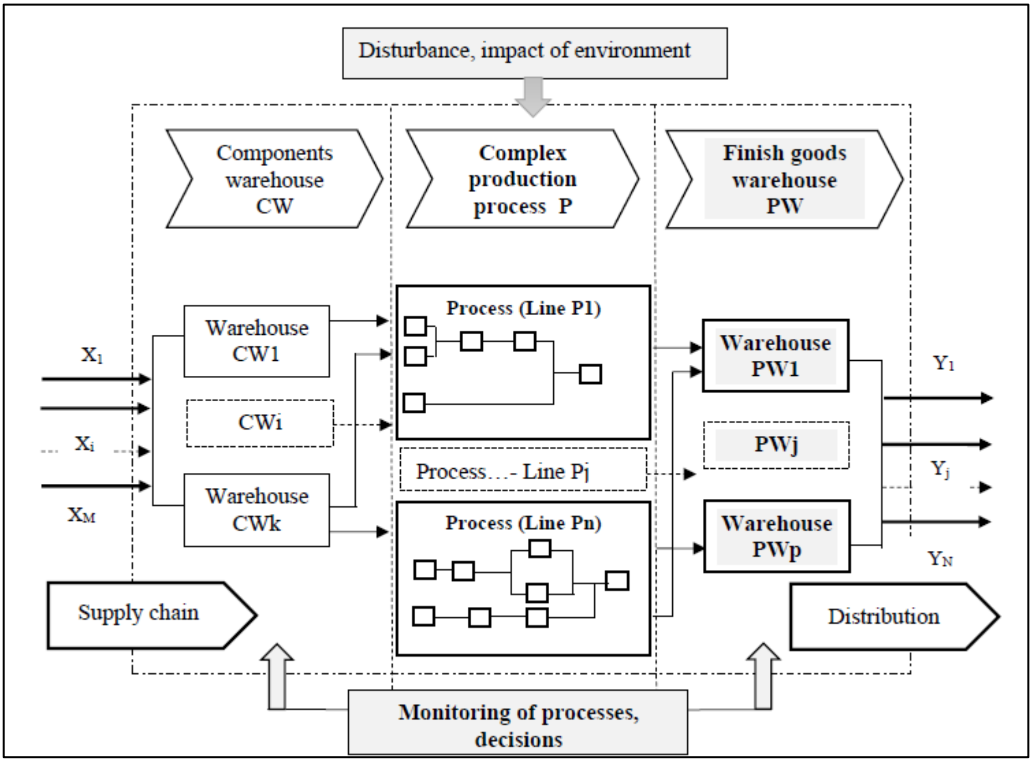

Fig. 1. Diagram of a generalized production systems PS (own study)

The reasons to make a decision to modernize the production system are usually:

- unsatisfactory economic indices,
- desire to modernize machine park,
- system adaptation to the requirements of Industry 4.0,
- approaching the fourth lifecycle phase (decline),
- limitation of availability for necessary raw materials and components,
- adaptation to changing environment requirements (e.g. EU directives).

The article analyzes the case of a system that achieves unsatisfactory economic indicators.

The factors that affect a high level of customer service are numerous. A diagram of actions enabling fulfilment of customer orders (specific batches of products) is shown in Figure 2.

For the process analysis, a company characterised by multi-assortment production of unit products was assumed. Furthermore, it was assumed that:

- customer orders are processed through the Customer Service Department (DCS),
- manufacturing of products is carried out according to the Make to Order principle,
- company employs an integrated IT system of ERP category (e.g. SAP, IFS) for most of the implemented processes,
- product storage is carried out on standard pallets in the finished goods warehouse (FPW),
- the transport department (TD) is responsible for managing the storage processes,
- product distribution processes (according to orders) are carried out through outsourcing (selected forwarding and transport company).

With such complex interdependencies, adoption of appropriate indicators for assessing customer order fulfilment appears to be a particularly important issue for the company's image on the manufacturer market.

The factors that affect a high level of customer service are numerous. An analysis of Figure 2 shows that several groups of processes and facilities can be distinguished, which have a decisive influence on effectiveness of warehousing and distribution processes.

These objects include:

1. Manufacturing system.
   Both the planning and the production schedule are generated automatically by ERP system. In every physical system, unplanned disruptions may occur due to malfunction or failure of machinery and auxiliary equipment.
   Consequently - there may be shortages of products to be shipped in the finished goods warehouse.
2. Integrated ERP information system.
   Although IT systems are characterised by high reliability, system failures may occur. Consequences of such failures can significantly affect a number of processes (production schedule, distribution schedule).
3. Dispatcher.
   The main duty of the dispatcher is to plan all warehouse processes correctly and to agree a shipment plan with internal forwarding department. Improper planning of these processes usually results in queues of cars waiting to be loaded or a shortage of cars ready to be loaded.
4. Shipping.
   Information about completion of a specific transport job must be communicated to the forwarder in advance. The consequences of the forwarder's faulty planning are most often loading stoppages due to shortage of transport means.
5. Finished goods warehouse.
   Picking and loading depend on multiple factors, including layout of storage areas as well as number of forklift operators. Any waste in the processes conducted within a warehouse results in a reduction in performance of the jobs carried out.

In each of the facilities described, there are distortions that reduce effectiveness of the final process, i.e. high-quality service provided to customers (who place orders). However, as usual, the 7 Rights of Logistics should be followed, i.e. the right customer (orderer) should receive the right product, of the right quality, in the right quantity, at the right place, at the right time, at the right cost.

Hence, there is a problem to be solved - how to evaluate such a system, what evaluation indicators can be proposed so that the fulfilment of the job of proper customer service can be monitored. It is also important that the evaluation indicators consider as many factors as possible, on which the service process depends, so that it becomes feasible to introduce changes and, consequently, to lead to an improvement in effectiveness of the entire service process.

In order to improve efficiency in various areas of implemented activities (acc. Fig. 2), a multi-stage modernization of the system was proposed.

It was decided to modernize the system in a few stages:

Stage I – decision to modernize,
Stage II – system modernization (implementation),
Stage III – evaluation of warehouse system after modernization,
Stage IV - standardization of activities and the provision of information about the change to all employees.

Stage I should include a detailed identification of reasons for modernization.

The identification result is the basis for two main tasks of the stage:

- I.1. determine the scope of modernization,
- I.2. determine the methods for modernization.

After the system modernization (Stage II), it is necessary to evaluate the system operation.

The most important tasks in Stage III include:

- III.1. choose the post-modernization system evaluation criteria,
- III.2. monitor the process and collect the data about the process (over a longer time),
- III.3. process the data statistically,
- III.4. calculate the indices chosen for evaluation,
- III.5. analyse the results and make relevant decisions on further operation of the system.

The post-modernization system evaluation algorithm is presented in Figure 3.

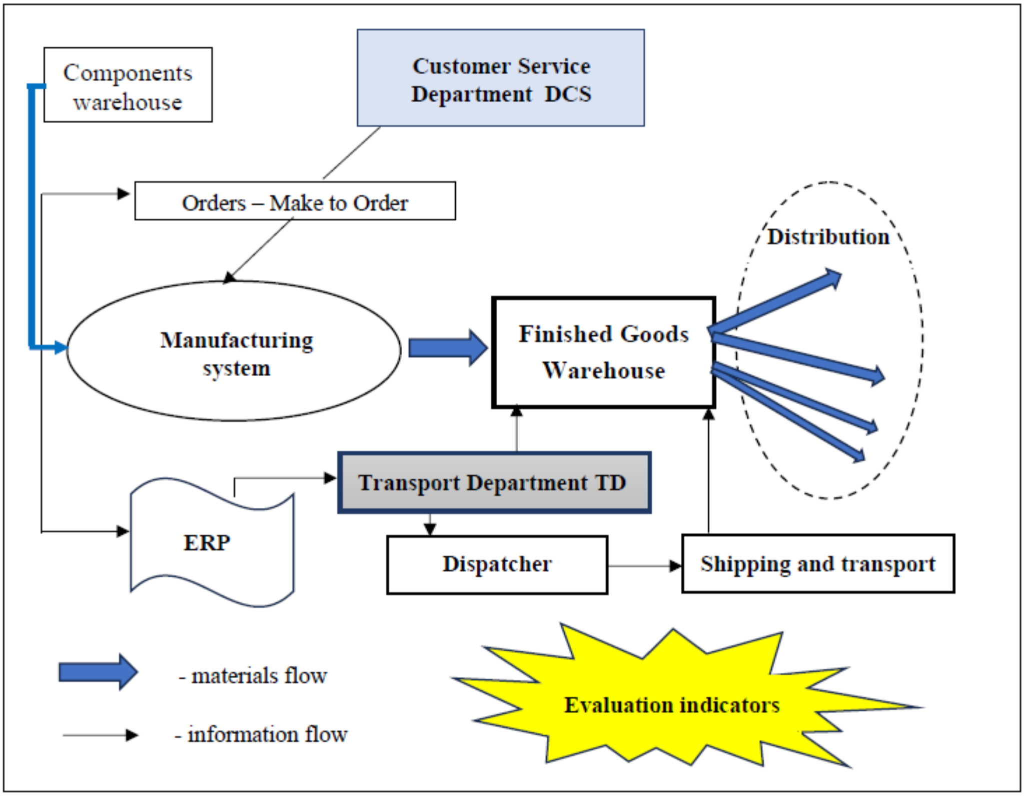

Fig. 2. Diagram of processes that affect fulfilment of customer orders (own study)

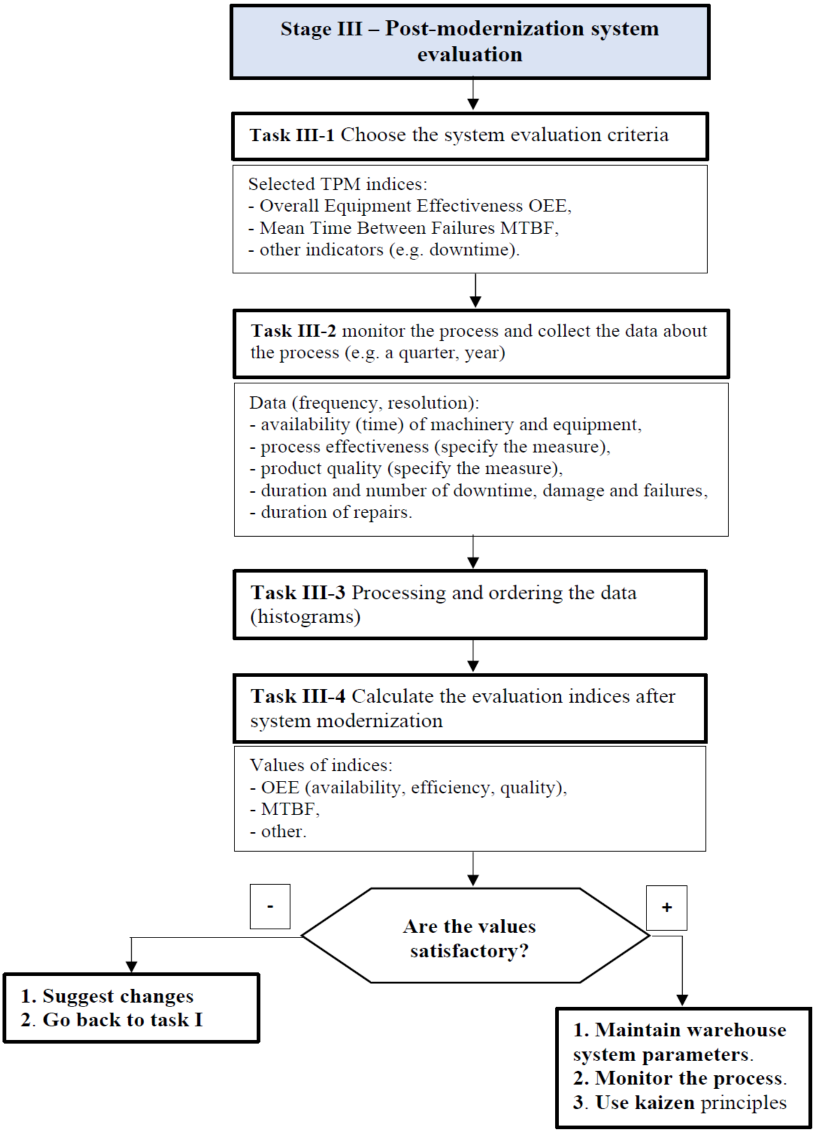

Fig. 3. Post-modernization system evaluation algorithm (own study)

4. Total Productive Management as a modernization method

The literature review shows that the issue of applying lean concepts to warehouse assessment is rarely addressed and, indeed, highly complex.

To improve the effectiveness of a manufacturing company's product warehouses, the TPM (Total Productive Maintenance) method can be successfully used in combination with others to improve warehouse processes The method is based on analysing the causes of waste and wastefulness (muda) arising in processes, and also requires systemic solutions to problems that are the cause of machine and equipment downtime and various types of disruption to the processes being carried out. The high effectiveness of the method has led to it being successfully implemented in the non-production spheres of a company, often as TPM2 or Total Productive Management. The primary objectives of implementing the TPM method are to reduce the number of equipment failures, accelerate the time to repair the equipment, eliminate micro-breaks and reduce wastefulness. The effects achieved are most often manifested in the form of increased performance and productivity, increased machine reliability and availability, reduced costs and wastefulness in the realisation processes and elimination of quality problems.

The task of introducing flow continuity improvements can be presented in several steps. In step one, a very precise identification of all processes related to manufacturing and storage is necessary. Identification and determination of current objectives for improving effectiveness of the processes should be followed by selection of methods and tools to achieve such objectives.

Thus, the initial activities include two steps:

Step I - process identification - activities: 1 – 2 – 3 – 4 ,

1. Selection of the process(es) to be analysed.
2. Drawing up an accurate diagram of the process under study.
3. Collection of data related to the process, e.g. orders, supplies, inventories, organisation, structure, etc,
4. Determination of basic parameters and quantities describing the process, making the necessary chronometry of operation times.

Step II - selection of improvement methods and tools (e.g. VSM, TPM) **– activities: 5 - 6,**

5. Description of wastefulness and waste within the process (e.g. 7 Muda, 6 Big Losses).
6. Selection of a tool (method) to improve flow continuity.

Figure 4 shows the first two steps of an algorithm to improve productivity in the studied system.

The next steps necessary to achieve a desired improvement in performance (effectiveness) and ensure continuity of material flow depend on selection of a method (tool). At this step, multitude of methods and systems currently known and proposed should be considered.

The most important factors that determine the choice are:

- type of processes carried out (manufacturing, transport, storage),
- type of company (large, SME - small and medium-sized),
- financial and personnel capabilities.

In case of choosing TPM (Total Productive Maintenance) method, the proposed algorithm is described by the following steps: from III to VI. Figure 5 shows the steps of the algorithm using TPM method.

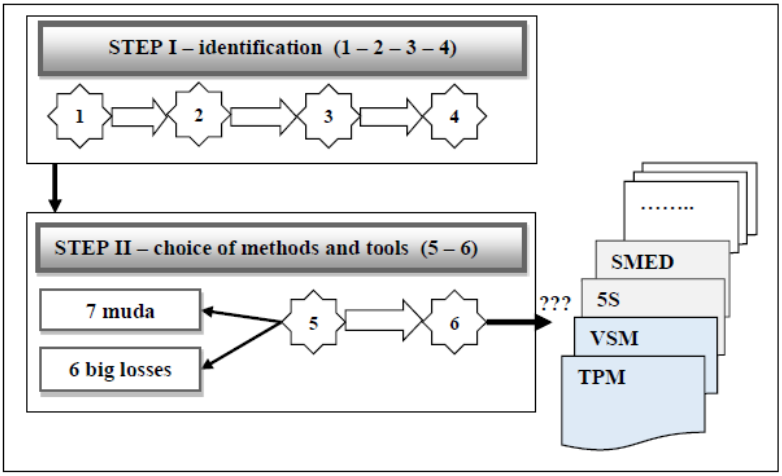

Fig. 4. Schematic of the algorithm for selecting an effectiveness improvement method

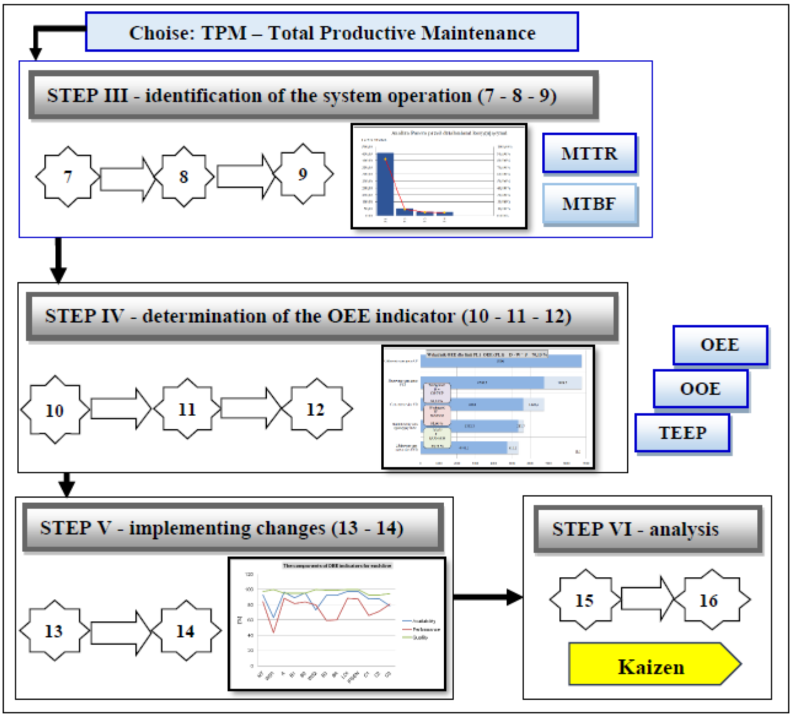

Fig. 5. Algorithm scheme - improvement using TPM method

Step III - Identification of system functioning - activities: 7 – 8 – 9,

7. Identification of process disruptions as well as equipment stoppages and failures.
8. Drawing up a Pareto diagram - causes of stoppages. Selection of causes for improvement.
9. Determination of targets - limit values of parameters to be improved (e.g. MTTR, MTBF).

Step IV - Determination of OEE indicator effectiveness - activities: 10 - 11 – 12,

10. Determination of line availability indicator (net time available, working time).
11. Determination of process performance indicator (performance achieved, nominal).
12. Determination of the quality indicator (quality achieved, quality required).

Step V - Implementation of changes - activities: **13 – 14,**

13. Development of a schedule for introducing changes into processes (picking, transport).
14. Implementation of changes to improve availability, performance and quality indicators of the processes conducted within the finished goods warehouse.

Step VI - Analysis of effects and improvement - activities: 15 – 16,

15. Analysis of effects following the implementation of changes.
16. Strict implementation of Kaizen principles!

The primary standard of the results of TPM is OEE (Overall Equipment Effectiveness) indicator. It shows what percentage of the theoretically achievable effectiveness the examined process or production line is characterised by. It is usually calculated by means of a simple formula:

$$\text{OEE} = \text{availability x performance x quality x } 100\ [\%] \tag{1}$$

$$\text{OEE} = \text{A x P x Q x } 100\ [\%] \tag{2}$$

where:
A – Availability: availability indicator; $A \in (0, 1)$,
P – Performance: performance indicator; $P \in (0, 1)$,
Q – Quality: quality indicator; $Q \in (0, 1)$.

$$A = \frac{\text{time available} - \text{stoppages}}{\text{time available}} \quad (3)$$

$$P = \frac{\text{cycle time x number of cycles}}{\text{time available}} \quad (4)$$

$$Q = \frac{\text{number of tasks completed successfully}}{\text{total number of tasks}} \quad (5)$$

Specific to the OEE indicator is that a low level of one of the indicators results in a significant reduction in the final OEE (even when the other two are extremely high). This requires seeking solutions to the most important problems in all areas related to a given implementation process.

To assess potential production possibilities, OOE or TEEP indicators can be additionally determined. In these cases, the A (availability) factor is defined differently.

For OOE - Overall Operations Effectiveness:

$$A = \frac{\text{cycle time x number of cycles}}{\text{time available (OOE)}} \quad (6)$$

$$A = \frac{\text{cycle time x number of cycles}}{\text{time available (TEEP)}} \quad (7)$$

where:

time available (TEEP) = total time available = 365 days x 24 h.

Introduction of TPM method requires (like the entire Lean Management process) the implementation of several other organisational methods:

- 5S method,

is a method of work organisation aimed at increasing quality and productivity by eliminating wastefulness resulting from disorder in the workplace. An important effect of the 5S method is the standardization of the workplace.

- SMED method,

which is a method of Single Minute Exchange Die. This method introduces what is known as external exchange, comprising activities performed outside the machine (while the machine is running), and internal exchange, comprising activities performed while the machine is stopped. This method is also used as part of internal transport processes, particularly in warehouses. SMED divides the logistical process into two parts: external and internal operations. The logistical process used under the method takes place in the following steps:

- order acceptance, selection of means of transport and route (external operation),
- preparation of shipping documents (external operation),
- preparation of palletised goods or products, e.g. Euro pallets, according to the documentation (external operation),
- loading (internal operation).

- Pareto principle,

also known as 80/20 rule, as it assumes that 80% of the results come from 20% of the causes. As a result of the observations, collection and result analysis, correlations can be obtained that are used to improve the impact of adverse causes on specific performance outcomes. With regard to transport, examples of Pareto analysis results will be presented in the applicative part of the article.

- VSM (Value Stream Mapping) method,

which consists of analysing all activities of the analysed process and its environment. By following the path of the process, following the value stream from the bottom to the top, i.e. from the consumer to the supplier, each process can be visually depicted.

Wastefulness analysis is the beginning of the entire modification process. Based on it, the problems are identified, and it is assessed how much impact each of them has on the operation of the object. Based on the wastefulness data, priorities for action are set and an action plan is established. Hence, it is particularly important to design an appropriate system for storing and collecting data. It is therefore desirable to have a transparent computer software that enables collection and storage of data and, at the same time, allows all sorts of reporting (charts, tables) as well as ongoing and periodic analysis.

The magnitudes describing the system outputs (acc. to Fig. 1) should include information needed to the evaluation of systems – about the process costs, achieved capacity, and also additional information on:

- availability of time,
- product quality,
- mean time to repair, mean downtime.

It was assumed that the output values are (Fig. 1):

$Y_1 = \overline{A}_W$ – mean time available indicator,

$A_W = \{A_1, A_2, \ldots A_i \ldots A_M\}$; $i = 1, \ldots M$ - a set of data with a fixed resolution, e.g. 1 month,

$Y_2 = \overline{P}_W$ – mean process performance indicator,

$P_W = \{P_1, P_2, \ldots P_j \ldots P_N\}$; $j = 1,\ldots N$ - a set of data with a fixed resolution, e.g. 1 month,

$Y_3 = \overline{Q}_W$ – mean process quality indicator,

$Q_W = \{Q_1, Q_2, \ldots Q_i \ldots Q_R\}$; $k = 1,\ldots R$ - a set of data with a fixed resolution, e.g. 1 month,

$Y_4 = MTBF_W$ – average system uptime (from stop to next stop).

With regard to adopted evaluation criteria (indicators), the following conditions should be fulfilled:

- Overall Equipment Effectiveness of the equipment in the warehouse under study Wi
  $OEE_{Wi} \geq OEE_{min}$ (e.g. 0.80),
- time available indicator
  $A_{Wi} \geq A_{min}$ (e.g. 0.88),
- process performance indicator
  $P_{Wi} \geq P_{min}$ (e.g. 0.90),
- process quality indicator (customer service)
  $Q_{Wi} \geq Q_{min}$ (e.g. 0.97),
- average system uptime (from stop to next stop)
  $MTBF_{Wi} \geq MTBF_{min}$ (e.g. TP hours).

An important problem with this approach to the assessment is proper and accurate adoption of limits and acceptable indicators. Their adoption can be based on experience of engineering staff, benchmarking, but also on familiarity with the specifics of the implemented processes.

5. Implementation of TPM method in the warehouse of a manufacturing company

The company is a market-recognised manufacturer of products in the FMCG sector and belongs to a global conglomerate. Steps 1 and 2 of the proposed methodology (point 3) were undertaken to improve productivity in various areas of actions performed. Activities covered several key areas, including improving quality, safety, environmental protection and lean material flow. Several lean enterprise methods - TPM, 5S, SMED and Kaizen methods - were selected for these tasks. The following mission statement was formulated for the Lean Flow pillar: *"The production environment is the logistics. Lean Flow implements activities that support the company's core objectives in the areas of production planning, customer service, forwarding, purchasing, warehouse management and internal transport."*

5.1. TPM as part of Lean Flow activities

The Lean Flow pillar was established in the company's Logistics Department for lean material flow throughout the supply chain. Planned activities included streamlining the flow and minimising the main wastefulness (7 Muda) in the flow of materials - from placing order to delivery of the finished product to the consignee. To this end, TPM teams were established across planning, procurement, warehousing and transport. Apart from TPM teams, 5S teams have been set up to improve the working conditions and environment in the assigned areas.

TD Transport Department is part of the company's logistics structure, and its role is to organise the export of products from the Finished Goods Warehouse to external consignees. Transport service is outsourced to a forwarding company. Forwarding deals with organising activities involving selection of a suitable means of transport, transport and delivery of goods in accordance with agreed documentation. The entity performing transport services in accordance with the consignment note issued by the Transport Department is the carrier. The document confirming acceptance of the goods by the carrier for transport is the consignment note, which, upon completion of the delivery process to a designated supplier, forms grounds for payment for the service.

Shipment planning for a specific assortment to be allocated begins in the Customer Service Department - DCS (Fig.6.).

All information obtained from customers (k_i) regarding demands for specific assortments is collected and analysed in DCS department. In order for DCS to schedule a shipment, a minimum of 24 pallets of goods must be ordered and a delivery time agreed with the customer. DCS manages 4 warehouses (W_j) that make up the manufacturer's group and optimises deliveries according to length of the delivery route and availability of the ordered assortments (at warehouses W_1 - W_4). Once all the data has been collected, DCS department (by 4 p.m. on the day before loading) sends an order to Transport Department to plan a requisition of vehicles for the export of goods. A schedule of deliveries to individual consignees is automatically generated in SAP® system, which includes, inter alia, place of delivery, assortment, date and time of delivery of the cargo.

Organisation of unloading and loading work is shown in Figure 7.

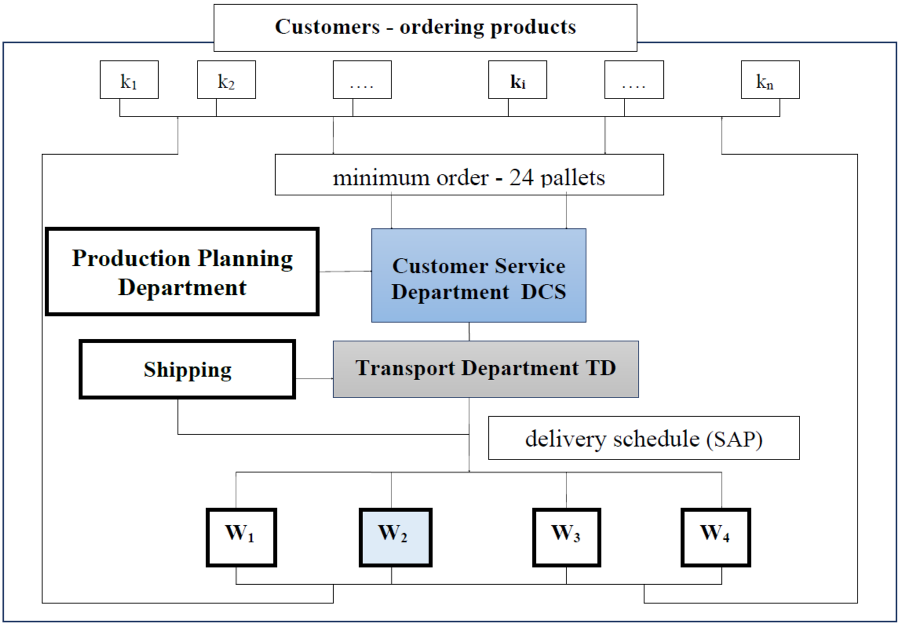

Fig. 6. Planning process for transporting products to a consignee

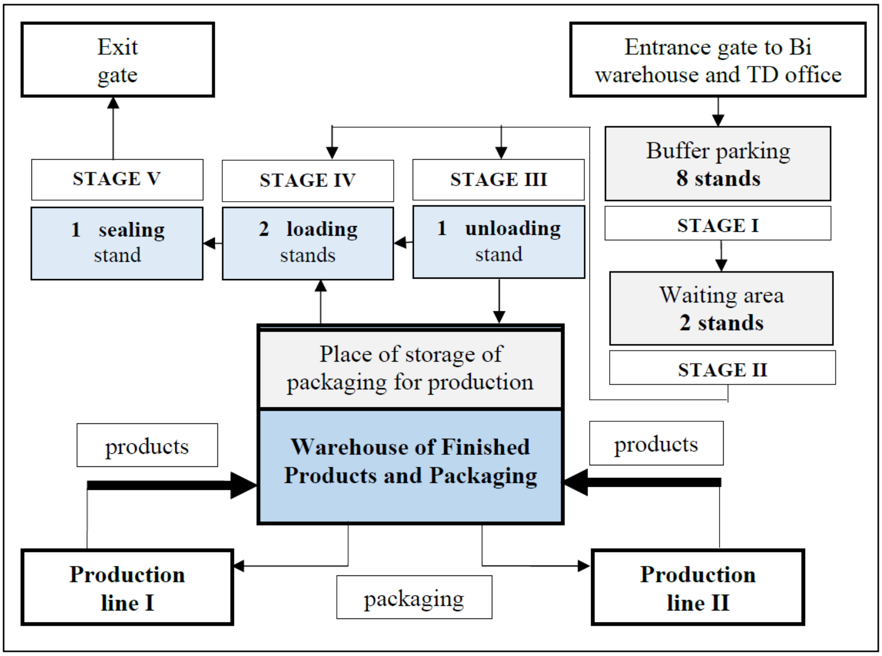

Fig. 7. Arrangement of unloading and loading in warehouse W_2

The following steps are distinguished in the unloading and loading work process:

- waiting in the buffer car park (freight carrier with advice of shipment and authorisation from the forwarding company reports to the dispatcher for the "bill of lading"),
- entry into the on-site buffer car park,
- preparation of the vehicle and waiting for loading or unloading of the packages (decided by the dispatcher based on the schedule and availability of stations),
- loading goods or unloading packages,
- sealing and departure from the site.

Basic operations carried out in the finished goods warehouse:

1. Receiving products from production lines.
2. Receiving and storing packages.
3. Transport of packages to production lines.
4. Product storage.
5. Picking.
6. Loading of palletised load units onto means of transport.

To solve the problem of excessive interruptions in warehouse operation, the "steps for problem solving" method was used, which is based on the Deming circle PDCA (Tab. 1).

The troubleshooting steps are as follows:

1. Problem definition
2. Identification of failure modes
3. Root cause analysis
4. Planning of countermeasures
5. Define actions
6. Carry out result follow up
7. Standardization

5.2. Selected results of TPM implementation

Implementation of selected lean concepts is a long-term process (usually 9 to 12 months). The first step of TPM implementation in the company under study covered a period of 6 months and included identification of processes and a description of waste (muda), as well as proposals for changes in warehouse operations. At the same time, the basic principles of 5S were implemented. This involved, among other things:

- accurate marking of individual workstations with lines,
- marking out traffic routes, routes for pedestrians to cross the manoeuvring area,
- setting up traffic organisation signs on the manoeuvring area with priority for forklift trucks.

A modified SMED (Single Minute Exchange of Die) method was used to manage the cars efficiently. According to SMED method, the logistical process was separated into two steps: external and internal operations. The logistical process applied to the service follows the following stages (Figure 5):

External operations - waiting at buffer car park (8 stands).

Freight carrier, with advice of shipment and authorisation from the forwarding company, collects the bill of lading from the dispatcher, takes a place in the car park, then undoes the tarpaulin of the semi-trailer and waits for their turn to load or unload the packages (2 waiting stands);

Internal operations - drive to the loading bays, load, drive to the sealing bay.

Based on the data analysis, it was found that the average time that cars were missing for loading for a three-month period of the year under study was 204 minutes per day for two loading shifts. During this period, 2409 cars were loaded, and the Finished Goods Warehouse recorded 557 disruptions due to various reasons. Therefore, reducing this time to 160 minutes (two shifts) was taken as the main activity objective. The second objective was to analyse the causes why cars were not put on loading.

The causes for loading disruptions were analysed using the Pareto method. Analyses were made before and after the introduction of corrective activities. Examples of the results before the introduction of the modification changes are shown in Table 2 and in the diagram of the relationship between the causes and the number of incidents (Figure 8). They show that the main cause of loading interruptions was inadequate planning of loading processes by dispatchers (more than 80% of all incidents).

The effects of the corrective activity of changing the scheduling system are shown in Table 3 and Figure 9. Faulty planning by the dispatcher decreased from 80% to less than 2%. Following modifications, the main cause of disruptions turned out to be late drivers (more than 80%).

In order to assess effectiveness of the changes implemented, indicators used at all sites of the Manufacturer Group were used (comparison available - more than 130 sites). These are: internal transport productivity index, car dwell time indicator at the site, punctuality rate of deliveries to customers.

Table 1. Troubleshooting steps using PDCA

Step	**P** - Plan	**D** - Do	**C** - Check	**A** - Action
1	Problem definition			
2	Identification of failure modes			
3	Root cause analysis			
4	Planning of countermeasures			
5		Define actions		
6			Carry out result follow up	
7				Standardization

Table 2. Disruptions in loading - by cause

No.	**Reasons for interruptions**	**Number of breaks**	**Share [%]**
1	Improper planning - by the dispatcher	458	82,23
2	Driver arriving late (to the warehouse)	51	9,15
3	System failure	25	4,49
4	No products to load	23	4,13
	Sum:	**557**	**100**

Table 3. Load disruptions after planning changes

No.	**Reasons for interruptions**	**Number of breaks**	**Share [%]**
1	Driver arriving late (to the warehouse)	42	80,77
2	No products to load	5	9,62
3	System failure	4	7,69
4	Improper planning - by the dispatcher	1	1,92
	Sum:	**52**	**100**

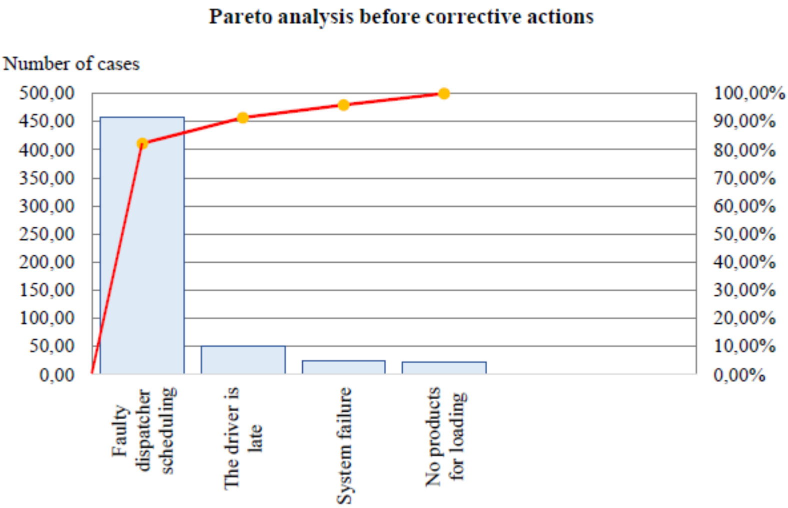

Fig. 8. Dependence of the number of loading disruptions on the main causes

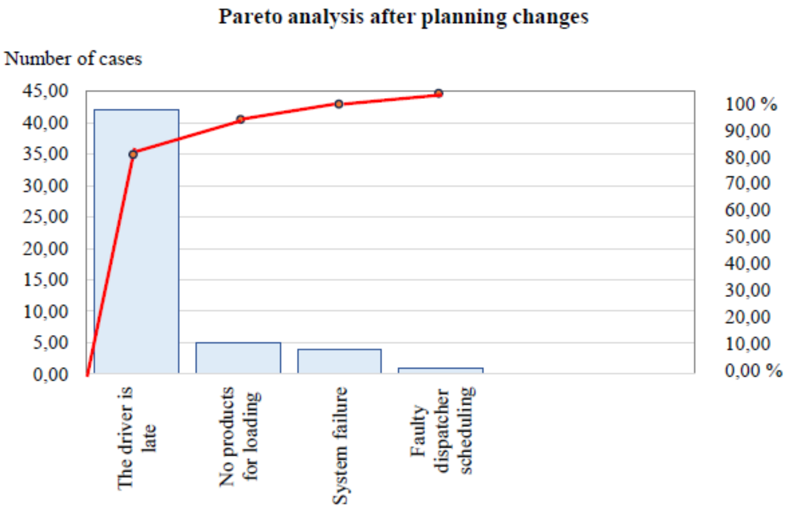

Fig. 9. Relationship between the number of loading disruptions - after planning changes

Internal transport productivity indicator P
Internal transport productivity is shown in Figure 10, comparing the plan assumptions and current implementation per month. The average loading time for a typical means of transport (24-26 pallets) was 15 minutes during the examined period. Assumed productivity rate was not achieved. The plan was to load an average of 26 pallets per hour of operator work, instead 23 pallets per hour of work were loaded.

$$P_W = \frac{P_2}{P_1} \cdot 100[\%] \quad P_W = 23/26 = 0.885 \qquad (8)$$
$$P_W = 88.5\ \%$$

Car dwell time indicator at the site
Car dwell time at the site is given in minutes (calculated as the difference between entry and exit). Dwell time is accounted for based on the document received by the driver when entering the site. Figure 11 shows the average dwell time of a car on the premises during the year. The average time during the period under study was 49 minutes, which was lower than the planned time of 50 minutes.

$$A_W = \frac{A_2}{A_1} \cdot 100[\%] \quad A_W = 49/50 = 0.98 \qquad (9)$$
$$A_W = 98\%$$

Punctuality rate of deliveries to consignee
Punctuality of delivery represents a company's credibility and demonstrates proper planning of the shipping process. Punctuality rate of deliveries to consignee is a percentage measure of on-time delivery to the customer. It is calculated from the ratio of on-time deliveries to all shipments for a period of one month. The data is taken from the bill of lading, which shows the time of delivery agreed between DCS and consignee and the time of arrival of a car entered by the customer once the goods have been delivered. Figure 12 shows that the percentage of punctuality of deliveries was higher than planned (99%) and was 99.5%.

$$Q_W = \frac{Q_2}{Q_1} \cdot 100[\%] \quad Q_W = 0.995 \qquad (10)$$
$$Q_W = 99.5\%$$

Analysis of research results and discussion
In order to determine how efficiently the transport department's resources are being used after the modifications, an OEE indicator was determined.
It should be noted that a company is considered to be in World Class Manufacturing if the OEE indicator exceeds 85%.
Thus, the Overall Equipment Effectiveness OEE in the warehouse under study is:

$$OEE = A \times P \times Q = 0.863 \times 100\% = 86.3\%. \qquad (11)$$

$$Q_W = \frac{Q_2}{Q_1}\cdot 100[\%] \quad Q_W = 0.995 \quad Q_W = 99.5\%$$

It is worth noting that the improvement in productivity:
from 23 pallets/hour to 25 pallets/hour,
will result in a change of P indicator:
from P = 0.885 to P = 25/26 = 0.962,
i.e. an improvement in the total OEE indicator as well:
from OEE = 86.3 % to OEE = 93.8 %.

The value of an OEE indicator depends on defining the individual product factors. For example, in the company under study, it was assumed that the equivalent of availability (A) is the car dwell time indicator for a car remaining on the warehouse premises. On the other hand, it is quite commonly assumed that this indicator is described by the time available to perform tasks.

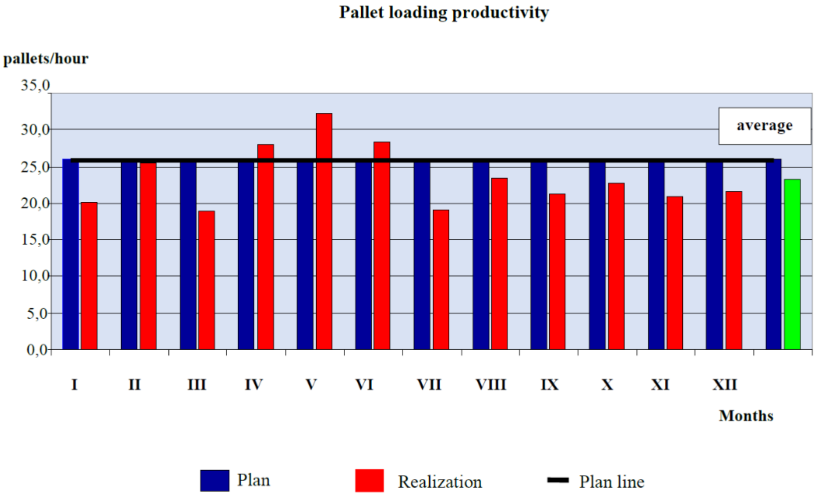

Fig. 10. Pallet loading productivity

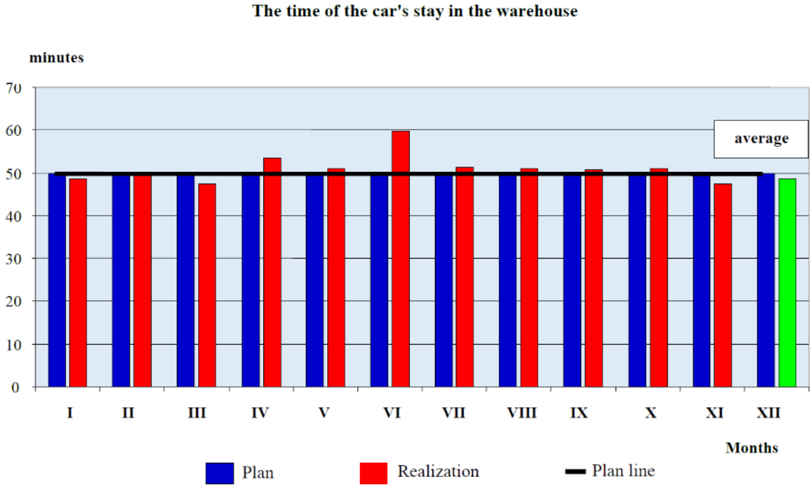

Fig. 11. Car dwell time indicator at the warehouse

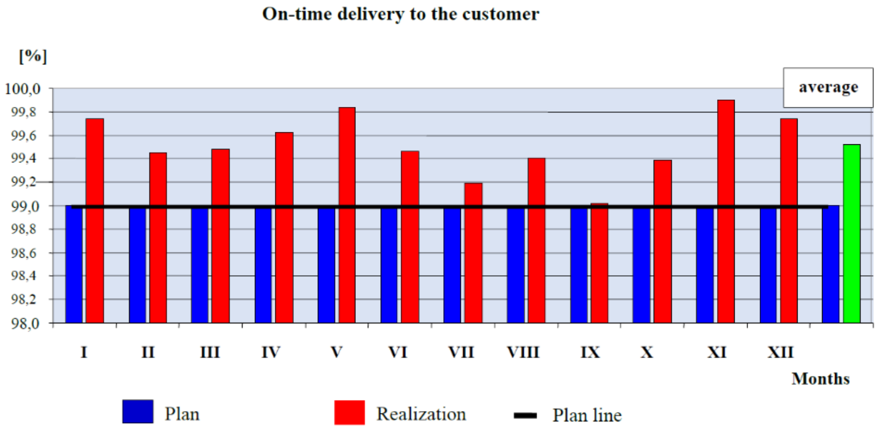

Fig. 12. Punctuality rate of deliveries to customers

In the case in question:
time available - is 2 shifts lasting 8 hours, or 960 minutes (A_1),
however, the average time for breaks of various sorts - is 204 minutes per two shifts,
therefore:
$A_1 = (960 – 204) = 756$ minutes,
then:

$$A_W = \frac{A_2}{A_1} = \frac{756}{960} = 0.787 \tag{12}$$

$A_W = 79\%$,

which implies a significant change in OEE indicator:

$$OEE = A \text{ x } P \text{ x } Q = 0.692 \text{ x } 100 = 69.2\% \tag{13}$$

However, once modifications were made to the storage process, the average disruption time was 123 minutes, which results in:
$A_1 = (960 – 123) = 837$ minutes, and hence $A_W = 87.2\%$,
which makes OEE indicator value after modifications: OEE = 76.3%,
while that value determined from the time the car was on the warehouse site was 86.3%.
This means that, in one case, a company can consider that it is achieving World Class Manufacturing (OEE = 86.3% > 85%), while in the other case it is good (OEE = 76.3%).
Similarly, it is worth to consider selection of the performance indicator. For loading, it is important that the performance is such that the loading time is within the set time. Loading time depends on the number of cycles of the transport trolley(s). Loading performance related to the hourly output of one operator is required to determine the number of operators necessary to load the truck within the imposed time window. However, if priority is given to loading time, then the performance indicator of the hourly capacity of forklift(s) is equally valuable - to load the truck within the imposed time window.
In the case study:

- specified loading time window is 15 minutes on average (23 - 26 pallets),
- hence, the hourly loading performance needed is about 100 pallets on average.

This means that 4 operators should be involved in the loading process. Note that the process of unloading packages and the process of delivering products from the production lines to the warehouse can be carried out simultaneously.
In Table 3, the energy consumption of the eight lines exceeds 600kW.h one week before the model is put into use. After the model is put into use, the energy consumption of the eight lines is reduced by 5.8%, 6.3%, 7.7%, 6.8%, 5.3%, 7.9%, 6.7% and 6.8% respectively. Before it is put into use, the one-way time of each route is more than one hour, and after it is put into use, it is basically reduced by about 10 minutes, and the minimum journey time is 47 minutes. The energy-saving model proposed in the study can effectively reduce the train energy consumption in the practical application process.

6. Conclusions

In this article, the main object of research and analysis was to assess the performance of a manufacturing company's finished goods warehouse. In order to correctly assess the effectiveness of the processes conducted in a warehouse, it is necessary to take a systemic view of the entire company's organisation. Information technologies play an important role in the efficient functioning of the warehouse. They are indispensable - from taking orders, through production planning, to organising forwarding and transporting finished goods to customers.

The use of the TPM (Total Productive Management) method significantly improved the efficiency of the analyzed finished goods warehouse. The main goal, i.e. reducing the time of interruptions in the process, was achieved (40% reduction).

This was achieved, among others, thanks to changes in planning and organization of warehouse work:

- versatility of work of unloading and loading teams depending on the situation in the buffer parking lot,
- designation of a second waiting position, parallel to the existing one, in order to improve communication between the driver and the dispatcher.
- the buffer parking lot was expanded to 8 parking spaces where cars waiting to be loaded can park (if one or two drivers are late, the dispatcher changes the schedule and a car from the queue is substituted),
- the availability of the assortment for Customer Service Department by the planner has been postponed until 12 hours from the start of production of a given assortment (probability of production line failure and lack of products to be loaded),
- disciplining drivers (analysis result of the 5W+1H method).

The basic activities related to the 5S method included:

- precise marking of individual positions with yellow lines,
- designating a path for pedestrian traffic and a passage through the maneuvering area,
- placing information boards on driver activities at individual positions,
- placing road signs about traffic organization on the maneuvering area with priority for forklifts.

All the changes and improvements described have been introduced into the scope of employee activities.

Modified OEE indicators were used to evaluate the obtained results:

- car dwell time indicator A (represents availability),
- transport productivity indicator P (represent performance - pallet loading productivity),
- punctuality rate of deliveries to customers Q (represent quality).

The results are optimistic - the OEE index calculated in this way is OEE = 86,3 %, while calculated taking into account time availability is OOE = 76,3 %. This means that, in one case, a company can consider that it is achieving World Class Manufacturing (OEE = 86.3% > 85%), while in the other case it is good (OEE = 76.3%).

It is also worth adding that it is important to comprehensively introduce different methods to improve multiple areas of the company's activities. Numerous results were obtained by introducing the 5S method, and problem solving using the 5 Why + 1 How questioning method accelerated obtaining all required answers. As in other companies, as well as in the one surveyed, changing the mentality of employees and overcoming their reluctance to introduce changes posed the greatest problems. Implementation of the TPM method within the transport department as proposed here has had the anticipated effect.

7. Conclusion

Due to the enhancement of underground rail transit, the number of rail routes has doubled, resulting in a large amount of energy waste. Aiming at this situation, this research puts forward the technology of improving train operation energy saving by using automatic train driving control strategy. On this basis, the energy saving model of underground rail transit is built by Microfield theory. To verify the practical application effect of this model, simulation and comparison tests are carried out in the study: the average impact rate and energy consumption of trains using the energy-saving model of underground rail transit proposed in the study are 0.66m/s2km-1 and 38kW.h respectively during operation. When the speed threshold is limited to 0.8 and 0.5, the train speed is closest to the target speed, which is better than the train in the comparison group. The total running time of the eight tracks using this model is 69min, 98min, 67min, 42min, 60min, 61min, 70min and 81min respectively. The total energy consumption is 298kW.h, 394kW.h, 341kW.h, 199kW.h, 280kW.h, 279kW.h, 324kW.h and 367kW.h, respectively, which are better than the comparison experimental group. To sum up, the energy-saving model proposed in this study compared with the underground rail transit has the best energy-saving effect and good stability, which can provide passengers with a more comfortable travel experience. However, this model is insufficient to study the energy consumption of train infrastructure, such as lighting and air conditioning, which will be a new direction for future research on energy conservation and emission reduction. Developing energy-saving methods for underground rail transit through research and design can help alleviate energy pressure, reduce operating costs of rail transit, and improve operational efficiency. Meanwhile, by implementing energy-saving measures, optimizing train operation speed and scheduling routes, reducing passenger travel time and improving travel efficiency. And by energy-saving train operation, the impact of rail transit on the environment can be further reduced, which is conducive to achieving green and low-carbon development of rail transit.

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