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Optimizing Warehouse Machine Maintenance for Efficient Automated Packaging

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Abstract:

Purpose: *This article aims to determine the potential for warehouse maintenance using overall equipment effectiveness (OEE) and related metrics.*
Design/Methodology/Approach: *Used observation and internal data to identify warehouse maintenance functioning and calculate OEE and related metrics for two key machines for the automated packaging process.*
Findings: *For both machines analysed, low utilisation can be indicated. It is supported by the results of one of the components of the OEE indicator. The machine underutilisation during the period under review was influenced by the pandemic and the specific nature of the goods that the machines could not handle. The other two components of the OEE indicator, i.e. quality and performance, were satisfactory.*
Practical Implications: *The study showed that the OEE measure can be a key tool for measuring and controlling the efficiency of machines and maintenance in the logistics industry.*
Originality value: *Application of OEE in the context of the maintenance issue in a warehousing environment.*

Keywords: *Overall equipment effectiveness, maintenance, total productive maintenance, warehousing, packing.*

JEL Classification: *M20, L25.*

Paper type: *Case study.*

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1. Introduction

Effective warehousing is related to the operation of the warehouse, more specifically, its location, its equipment with various types of resources, and the skills and competencies of its employees. The indicated elements translate into the correctness of warehouse operations and effective management, resulting in cost savings and high customer service (Gunasekaran *et al.*, 1999).

Without properly organized warehousing, ensuring effective distribution in supply chains is impossible. Rouwenhorst *et al.* (2000, p. 515) emphasised that "the efficiency and effectiveness in any distribution network (…) is largely determined by the operation of the nodes in such a network, i.e. the warehouses." The previous characterisation of warehouses as a "necessary evil" has shifted toward viewing them as a key resource or function that affects logistics, and service costs and enables efficient fulfilment of customer orders (Faber *et al.*, 2017).

Warehouses provide a seamless flow of goods and materials from supplier to customer (Stragas and Zeimpekis, 2011). How warehousing will ultimately be carried out and how measurements of achievement will be shaped depends on the utilization of resources, including their technological sophistication and integration (device-to-device, device-to-human). In an ideal storage process, equipment and devices should operate 100% efficiency 100% of the time (Mahroof, 2019; Winkelhaus and Grosse, 2020).

However, the conditions in which warehouses operate vary, so the priority should be to detect and eliminate losses, a key approach of the Total Productive Maintenance (TPM) philosophy known and practised mainly in manufacturing environments (McKone *et al.*, 1999). According to TPM, inefficiencies arise on the equipment side, but also on the side of the people who operate them. They result in lower volume and quality of products and services, higher costs of maintenance, and therefore, maintenance activities (Alsyouf, 2007).

Thus, efficient warehousing is dependent on the activities of maintenance departments. They have the technical knowledge, and their actions significantly impact the operating time and efficiency of equipment (Ylipää *et al.*, 2017). It is worth noting that maintenance in most companies is seen as a cost center (Alsyouf, 2004). Mobley (2002) pointed out that 15-60% of maintenance costs are attributed to maintenance activities, which significantly impacts the profitability of the entire organization.

Due to globalization and remaining competitive, companies increasingly take different measures in their maintenance and storage or production systems. They do this by implementing new technologies, automation and robotization, and the principles of lean, JiT, TQM, TPM concepts. This is changing the nature of maintenance from a cost to a profit center, where added value is created for the business and customers. Verifying the efficiency of storage and its resources requires the use of appropriate methods of measurement and metrics. There are many indicators for measuring the effectiveness of warehousing and its areas and maintenance, but they are often different measures that cannot be integrated (Jonsson and Lesshammar, 1999; Ghalayini and Noble, 1996).

Schmenner and Vollman (1994) pointed out that most companies used the wrong measures and did not use the right ones in the right way. Although many years have passed since the study's results were published, the theses are still valid. This implies the need to identify critical dimensions in the performance measurement system (what to measure) and optimal measure characteristics (how to measure) (Schmenner and Vollman, 1994).

One measure that verifies efficiency holistically is overall equipment effectiveness (OEE), which is part of TPM. OEE is used to measure equipment productivity. OEE also improves productivity and optimizes equipment by identifying unnecessary losses and reducing and eliminating them (Kumar *et al.,* 2014). This, in turn, is a source of service delivery cost reduction in the context of warehousing, maintaining competitiveness and satisfying customer demand (Huang *et al.*, 2011).

This article aims to determine the potential for warehouse maintenance using OEE and related matrices with a focus on the automated packaging process. In the empirical study, we attempt to answer the following research question:

Whether can the use of OEE and related indicators be effective in the warehousing area?

The article contributes in a variety of ways. Firstly, the article refers to studies about efficiency and effectiveness using OEE (Alnounou *at al.,* 2022; Sari and Darestani, 2019; Ylipää *et al.,* 2017). There is a lot of research on measuring effectiveness and efficiency, mainly in production (Førsund, 2017) and less on warehousing using measures or approaches other than OEE (Gunasekaran *et al.,* 1999).

Second, the study shows the application of the OEE measure for a service area, i.e., the automated packaging in the warehouse. Previous publications in this area focus on presenting the application of OEE only for manufacturing companies, including production machinery. Some publications are purely conceptual in nature (Muhiri and Pintelon, 2006), and others additionally show the practical side of using OEE (Alnounou *et al.,* 2022; Raju *et al.,* 2022; Dal *et al.,* 2000; Ylipää *et al.,* 2017; Tobe *et al.,* 2017).

Third, the authors link the TPM issue to OEE in the article. The publications broadly refer only to the calculation of OEE or present its modification (Garza-Reyes, 2015; Eswaramurthi and Mohanram, 2013; Jonsson and Lesshammar, 1999). They do not consider the TPM concept more broadly, particularly in a warehouse environment.

Otherwise, the articles describe the maintenance issue without referencing OEE (Ge *et al.*, 2022).

2. TPM and Related Metrics, and OEE

Ylipää *et al.* (2017) indicate that OEE results in the industry are not as satisfactory as other researchers portray (Tobe *et al.*, 2017). The main reason relates to equipment failures in the rework process, which affects downtime, which translates into losses, low achievement measures, and high operating costs. Equipment availability and reliability have become critical in capital-intensive operations (Raju *et al.*, 2022). These processes are the responsibility of maintenance, which has the greatest knowledge of the operation of equipment and machinery.

At a basic level, maintenance means convection and compensates for the gaps between the required and realized functions through reactive, preventive, improvement and modernization measures (Ylipää *et al.*, 2017). However, given technological advances, understanding maintenance as repair has become insufficient. Researchers and practitioners have begun to present maintenance holistically, i.e., in the context of the entire company and the creation of added value, rather than just a narrow slice of the business requiring cost reduction.

Ahuja and Kamba (2008) emphasized that “maintenance must be managed as a process rather than by an obsolete maintenance department and evaluated from a much broader rather than a narrow and insufficient perspective of cost and internal efficiency.” Various approaches and concepts have developed in this regard: preventive maintenance (PM), productive maintenance (PM), Total Productive Maintenance (TPM), terotechnology, total quality maintenance (TQMain) or reliability-centred maintenance (RCM) (Sherwin, 2000; Al-Najjar, 1996; Nakajima, 1988).

The TPM philosophy developed by Nakajima (1988) is particularly important in this regard. It can be pointed out that TPM, along with lean management and total quality management (TQM), is a key pillar of value-adding management, and their everyday basis is total employee involvement (Nagarajan and Ravi, 2017). TPM verifies the efficiency of a company's machinery, equipment, processes and employees to increase efficiency and productivity, resulting in a competitive advantage in the global market (Tobe *et al.*, 2017). TPM covers three areas: total, productive, and maintenance.

The first, it seeks to ensure effective teamwork to share knowledge and experience and solve problems. This approach is also intended to eliminate accidents, defects and failures. The second area emphasizes minimizing losses, identifying difficulties in executing significant operations, and providing products or services that meet and exceed customer expectations. The third area focuses on restoring equipment or machinery while carrying out various activities, which impacts their longer life cycle (Ylipää *et al.,* 2017).

At a basic level, TPM is designed to improve equipment efficiency by eliminating losses and accelerated equipment degradation, autonomous maintenance activities, improving maintenance efficiency and prevention, involving people from all departments that plan, design, use or maintain equipment, and ensuring or improving safety and environmental protection. Developed TPM focuses on the value generated by equipment or together equipment and people throughout the production process or service delivery, reducing or eliminating 16 losses (Mohanty *et al.,* 2022).

Ahuja *et al.* (2008) presented an eight-pillar approach to implementing TPM, including development management, office TPM, safety, health and environment, education and training, quality maintenance, planned maintenance, focused improvement, and autonomous maintenance.

Thus, maintenance should be treated as a profit rather than a cost centre in modern environments. Three key metrics are used to check the degree of completion of a critical TPM task. These are Mean Time to Repair (MTTR), Mean Time To Failure (MTTF), and Mean Time Between Failures (MTBF). They serve several functions, including supporting prevention by allowing planning for downtime or part replacements, importing the effectiveness of an organization's maintenance services, and checking progress in successively reducing the time spent fixing failures (Nurprihatin *et al.,* 2019).

MTTR is calculated as the failure time divided by the number of repair incidents. To calculate MTTF, first determine the difference between available operating time and failure time and divide the resulting difference by the number of repair events. MTBF, in turn, is the sum of MTTR and MTTF (Pintelon *et al.,* 2000). These metrics are the starting point for a key tool for assessing maintenance (TPM) and are a way to monitor the actual performance of equipment and its capabilities under optimal operating conditions, i.e., OEE (Nakajima, 1988). MTBF and MTTR are also key components of a modification of the OEE measure, i.e., total effective equipment performance (TEEP) (Szeląg-Sikora *et al.,* 2019)

OEE is gaining prominence in manufacturing companies by measuring achievements, often without mentioning TPM (Nachiappan and Anantharaman, 2008). The OEE value indicates the magnitude of technical losses (6 Big losses). Knowing the areas of these losses and their reasons can be monitored and corrected through OEE to improve equipment efficiency and optimize processes and profitability. A distinction is made between availability losses (planned and unplanned stops), performance losses (micro and slow stops), and quality losses (start-up rejects, production rejects). They define the OEE structure, where OEE = availability * performance * quality (Szeląg-Sikora *et al.,* 2019).

Availability is when a piece of equipment is used throughout production. It is a comparison of actual production utilization time with planned time. Assuming that the planned equipment utilization time is unchanged, the factor that affects the change in the size of the availability factor is mainly the duration of unplanned downtime - related to direct machine failures, shortages of production components or external factors (e.g., power outages) (Throat and Mahesha, 2020).

Performance measures how well a machine's production capabilities are utilized. Its magnitude can vary depending on many different reasons - the skill of the machine operator, the needs of the machine's use, the number of workers operating the machine simultaneously, etc. Utilization losses do not infrequently prove to be the explanation for any losses that are difficult to explain and measure and, by nature, the most challenging area to measure (Throat and Mahesha, 2020).

Quality is the ratio of the output volume proper (without quality deficiencies) to total output. Another interpretation is the proportion of time that equipment produces quality products over the entire production period. The issue that can be problematic in this ratio is determining from which point one can speak of a lack of quality. This will depend on the products produced and vary from organization to organization.

However, a clear line should be drawn to collect data to calculate the OEE indicator between a defective product and a product that meets customer expectations. The deciding factor in classifying a product into one of these groups may be, for example, whether the product needs a minor correction or whether it needs to be wholly re-manufactured (Throat and Mahesha, 2020).

Nakajima (1988) indicated that the ideal OEE total is 85%, with 90% in availability, 95% in achievements, and 99% in quality. However, many researchers deny the targets above, claiming they are difficult to achieve under typical conditions. They insist that realistic results are those between 30% and 80% useful as an acceptable target. It can be considered that Nakajim's proposed targets may be achievable under certain conditions and given specific procedures for its calculation.

Thus, the higher the calculated results, the closer the efficiency is to the ideal (Wijesinghe and Illankoon, 2022). In addition, although there are uniform formulas for calculating OEE and its elements, many measures are modified by adopting other benchmarks or not considering other losses (Wudhikarn, 2016). It is worth noting that while OEE is about equipment, the losses it generates are also the result of human interaction.

3. Research Methodology

This section presents the practical application of OEE through a warehousing case study focusing on automated packaging. The empirical study was conducted in a company's warehouse (supply centre), where sporting goods and clothing were distributed. In addition to shipping items to stationery shops, it provides e-commerce services for individual customers. An additional service it provides is the so-called Click Collect, i.e., the possibility to order items from the online shop and pick them up at a unique point - usually a company outlet or stationery shop. The service is provided mainly to one of the Central and Eastern European countries.

The warehouse building is divided into three cells: a low storage department, a high storage department and an e-commerce zone. The flow occurs between all three cells by established procedures and the system in place. Depending on the type of order, the goods leave the warehouse in different forms. Those prepared for dispatch to the shops for onward sale are transported using in-house reusable carriers. On the other hand, orders for individual e-commerce and C&C customers are packed in cartons or plastic packaging.

Observation of the automated packaging process in a warehouse in an e-commerce zone in February was used as the research method. The observation lasted 8 hours daily (i.e., for one of two shifts). On February 06-12, the observation lasted from 2:30 to 22:30 p.m.; on February 13-15, it lasted from 6:00 a.m. to 2:00 p.m. The total duration of the observation was 80 hours. The information obtained through eyewitness observation was continuously entered into MS Excel, which automatically calculated the OEE measure used in the TPM framework using formulas prepared in advance.

The observation measured the downtime of two key pieces of equipment in the automated packaging process, without which packaging cannot occur - the carton and the I-Pack machine. In addition, the correctness of the packages and cardboard bottoms produced was verified. Their total number at the end of each shift was also counted. The data obtained made it possible to calculate indicators, and in-depth observation and analysis of machine stoppages made it possible to find the most common causes and verify their effects. It is worth noting that the idea of automatic packaging did not appear in the company until 2019.

This involved adapting equipment that supports automatic packaging, emphasizing the I-Pack packaging machine. Previously, packaging was done manually, so the efficiency of the process depended on human resources. A worker at the packing station would receive a finished order and a shipping label in an open plastic carrier. Her/his job was to assess the volume of the order, select the appropriate carton, fold it, pack all the items, seal the carton, affix the shipping label, and bring the package to the correct pallet location so that subsequent workers could continue the flow of the package.

This process had to be preceded by several others for this to be possible. Immediately before the packing stage, another employee had to sort the items into the correct orders, print the labels and transport the ready-to-pack orders to the correct shelving location. Appropriately beforehand, someone else also had to retrieve the articles from the low and/or high storage departments.

Moreover, the packer also had to be adequately prepared, so he or she should organize the materials necessary to do the work in advance, such as different-sized cardboard boxes, tape, carton filler and plastic packaging for small items. It was an arduous process and fraught with defects, and the aesthetic qualities of the packaging left much to be desired.

4. Research Results

4.1 Equipment in the Process of Automatic Packaging in the Studied Company

Five pieces of equipment used in automatic packing in the warehouse include a carton, a barcode and shipping label printer, a roller conveyor and an I-Pack packaging machine. Automatic packing in the warehouse is done with some interference from human resources, although the company is trying to limit it.

The roller conveyor performs multiple functions (transporting boxes, creating a buffer zone for finished carton parts, locking the position of the carton, and moving the carton to the dispatch area). This device is integrated with sensors that enable the automatic flow of cartons and the reporting of carton production demands.

The carton, however, is crucial in automated packaging, although the I-Pack packaging machine is the most important in this regard. The carton machine starts the whole process, producing the bottom of the box (two types).

The dimensions of the carton base do not differ in the two models. The carton forms the bottom shape and glues the walls together using hot glue. The formed bottom falls onto the belt at the bottom of the carton and travels on, giving way to the next bottom being produced. The carton's maximum output achieved at the company surveyed is 23 cycles/min.

On the other hand, the I-Pack packaging machine fills the bottom of the carton with articles, which, in effect, becomes a finished package for the potential customer. This machine reduces the volume of packages by lowering the height of the carton to the level of the articles inside. In addition, it reinforces the package thanks to folds, and in the final stage, it glues the lid.

The activities of the above-mentioned equipment provide comprehensive order processing in the packaging process and enable the production of the final product - packages. However, for the functionality of the equipment to be maximized, care must be taken to ensure both their full integration and the best possible performance of each individual device. The Maintenance Department plays a key role in this area.

4.2 Metrics of Maintenance for two Key Warehousing Equipment: The I-Pack and the Carton Machine

Considering the similar conditions in the studied company in warehousing to manufacturing operations, the OEE was used to measure the efficiency of two key pieces of automated packaging process equipment: *the I-Pack and the carton machine.*

Observations and interviews conducted in the company warehouse under study provided data to calculate OEE for the TPM method. The downtime data for the I-Pack packaging machine is presented in Table 1.

Table 1. *Data and MTTR, MTTF and MTBF indicators for I-Pack machine*

Days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
TOTAL	0:35:31	0:12:13	0:57:50	0:15:32	0:46:21	3:21:24	0:37:15	0:30:33	0:08:18	0:45:18	
Total (in minutes)	35,52	12,22	57,83	15,53	46,35	201,4	37,25	30,55	8,30	45,30	$\bar{x}$:
Number of total downtimes	23	11	40	7	21	14	22	10	9	15	**17,2**
Number of downtime due to machine fault	3	9	35	6	18	8	17	9	7	11	**12,3**
Share of downtime due to machine fault in total downtime	13,04 %	81,82 %	87,50 %	85,71 %	85,71 %	57,14 %	77,27 %	90,00 %	77,78 %	73,33 %	
MTTR	**11,84**	**1,36**	**1,65**	**2,59**	**2,58**	**25,18**	**2,19**	**3,39**	**1,19**	**4,12**	
MTTF	**159,99**	**653,33**	**13,71**	**80,00**	**26,66**	**59,98**	**28,23**	**53,33**	**68,57**	**43,63**	
MTBF	**171,83**	**54,69**	**15,37**	**82,59**	**29,24**	**85,16**	**30,42**	**56,73**	**69,76**	**47,75**	

Source: *Own collaboration.*

The company released the following data on the I-Pack packaging machine. Design unit time for processing a package:

$800\, unit/h \approx 13{,}333\, unit/\min \approx 0{,}075\, min/unit$. Shifting time fund: $8\, h \cdot 60\, min = 480\, min$. Planned downtime: 30-minute meal break.

In addition to the information above, data on the number of parcels processed and defects were needed to calculate the OEE index. Deficiencies are all those parcels that deviated qualitatively from the standard and required additional intervention or repackaging (parcels not glued, torn, soiled with hot glue, etc.). Deficiencies were counted manually, while all packed parcels were calculated using the indications of the I-Pack packaging machine, which counts each processed parcel. The results of collecting this data are presented in Table 2.

Table 2. *Number of packages packed by I-Pack machine*

	Days	*afternoon shift*							*morning shift*		
		1	2	3	4	5	6	7	8	9	10
SHIPPING	Indication of the beginning of the change	1 832 639	1 837 047	1 840 625	1 847 015	1 851 042	1 855 076	1 858 844	1 860 522	1 864 492	1 866 555
	Indication at the end of the shift	1 834 686	1 838 391	1 844 454	1 849 068	1 853 317	1 856 656	1 860 522	1 862 616	1 865 611	1 868 635
	Number of parcels shipped	**2 047**	**1 344**	**3 829**	**2 053**	**2 275**	**1 580**	**1 678**	**2 094**	**1 119**	**2 080**
	Number of deficiencies	3	7	37	15	11	14	22	8	6	19

Source: *Own collaboration.*

The above data made it possible to calculate the OEE (see Table 3).

Table 3. *OEE for I-Pack machine*

Days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AVAILABILITY										
Shift working time fund (min)	480	480	480	480	480	480	480	480	480	480
Planned stopping time (min)	30	30	30	30	30	30	30	30	30	30
Operating time (min)	450	450	450	450	450	450	450	450	450	450
Unplanned machines stop (min)	35,52	12,22	57,83	15,53	46,35	201,4	37,25	30,55	8,30	45,30
Net operating time (min)	414	438	392	434	404	249	413	419	442	405
AVAILABILITY (%)	**92,11**	**97,29**	**87,15**	**96,55**	**89,70**	**55,24**	**91,72**	**93,21**	**98,16**	**89,93**
PEFORMANCE										
Number of parcels processed (pcs)	2047	1344	3829	2053	2275	1580	1678	2094	1119	2080
Design unit time of packaging (min/pc)	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075	0,075
PRFORMANCE (%)	**37,04**	**23,03**	**73,23**	**35,44**	**42,27**	**47,67**	**30,49**	**37,44**	**19,00**	**38,55**

QUALITY										
Number of deficiencies (pcs)	3	7	37	15	11	14	22	8	6	19
QUALITY (%)	**99,85**	**99,48**	**99,03**	**99,27**	**99,52**	**99,11**	**98,69**	**99,62**	**99,46**	**99,09**
OEE										
OEE (%)	**34,07**	**22,28**	**63,20**	**33,97**	**37,73**	**26,10**	**27,60**	**34,77**	**18,55**	**34,35**

Source: *Own collaboration.*

Calculations related to carton machine downtime durations are presented in Table 4.

Table 4. *Data and MTTR, MTTF and MTBF ratios for the carton machine.*

Days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
TOTAL	0:11:32	0:23:48	0:30:49	0:39:44	0:15:09	0:21:21	0:16:09	2:14:12	0:00:45	0:13:53	
Total (in minutes)	11,53	23,80	30,82	39,73	15,15	21,35	16,15	134,2	0,75	13,88	$\bar{x}$:
Number of total downtimes	9	11	14	8	7	2	5	24	1	8	**8,9**
Number of downtimes due to the cartoner	9	10	13	8	7	2	4	23	1	7	**8,4**
Share of downtime due to cartoners in total downtime	100%	90,91 %	92,86 %	100%	100%	100%	80,00 %	95,83 %	100%	87,50 %	
MTTR	**1,28**	**2,38**	**2,37**	**4,97**	**2,16**	**10,68**	**4,04**	**5,83**	**0,75**	**1,98**	
MTTF	**53,33**	**48,00**	**36,92**	**60,00**	**68,57**	**239,99**	**120,0**	**20,87**	**480,0**	**68,57**	
MTBF	**54,61**	**50,38**	**39,29**	**64,96**	**70,73**	**250,67**	**124,03**	**26,70**	**480,75**	**70,55**	

Source: *Own collaboration.*

As with the I-Pack machine, MTTR, MTTF and MTBF rates were calculated based on downtime directly attributable to the carton machine. The shift time fund and 30-minute meal break remain the same, but the carton machine's projected unit time to produce a carton (bottom) is slightly different at:

$1380\ unit/h \approx\ 23\ unit/\mathrm{min}\ \approx 0{,}04348\ min/unit$. Assuming that the buffer zone is equally filled at the start and end of the shift, the number of elements produced by the carton machine will equal the number of packages packed by the I-Pack machine. Only the number of deficiencies, i.e., incorrectly folded elements (unstuck, torn), will differ. For the carton machine during the period under study, these numbers are presented in Table 5.

Table 5. *The number of elements produced by the carton machine*

Days		*afternoon shift*							*morning shift*		
		1	2	3	4	5	6	7	8	9	10
CARTONS	Number of elements produced	**2 047**	**1 344**	**3 829**	**2 053**	**2 275**	**1 580**	**1 678**	**2 094**	**1 119**	**2 080**
	Number of shortages	6	3	2	26	2	4	2	79	2	4

Source: *Own collaboration.*

The method of calculating the OEE is presented in Table 6.

Table 6. *OEE for carton machine*

Days	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
AVAILABILITY										
Shift time fund (min)	480	480	480	480	480	480	480	480	480	480
Scheduled stopping time (min)	30	30	30	30	30	30	30	30	30	30
Working time (min)	450	450	450	450	450	450	450	450	450	450
Unplanned machine downtime (min)	11,53	23,80	30,82	39,73	15,15	21,35	16,15	134,2	0,75	13,88
Net operating time (min)	438	426	419	410	435	429	434	316	449	436
AVAILABILITY (%)	**97,44**	**94,71**	**93,15**	**91,17**	**96,63**	**95,26**	**96,41**	**70,18**	**99,83**	**96,91**
PEFORMANCE										
Number of parcels processed (pcs)	2047	1344	3829	2053	2275	1580	1678	2094	1119	2080
Projected unit packing time (min/piece)	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043	0,043
PEFORMANCE (%)	**20,30**	**13,71**	**39,71**	**21,76**	**22,75**	**16,03**	**16,82**	**28,83**	**10,83**	**20,74**
QUALITY										
Number of deficiencies (pcs)	6	3	2	26	2	4	2	79	2	4
QUALITY (%)	**99,71**	**99,78**	**99,95**	**98,73**	**99,91**	**99,75**	**99,88**	**96,23**	**99,82**	**99,81**
OEE										
OEE (%)	**19,72**	**12,96**	**36,98**	**19,58**	**21,96**	**15,23**	**16,19**	**19,47**	**10,79**	**20,06**

Source: *Own collaboration.*

5. Conclusions and Discussion

For both the I-Pack machine and the carton machine, one conclusion indeed comes to the fore: the utilization of both machines is abnormally low. This is evidenced by one of the components of the OEE index, the utilization rate, the average value for the I-Pack machine is 38.42%, while for the carton machine, 21.15%. During the research, an attempt was made to find the reason for such a low value of this indicator.

According to employees, the low utilization rate was mainly influenced by the time of the year: February had been the weakest month for years in the company's warehouse regarding e-commerce sales and shipments. In 2021, this slump was also exacerbated by the situation in Poland and activities related to the COVID-19 pandemic. By government decision, the 2021 winter holidays for all Polish provinces were held from January 4 to 17, a distant date range from the time of the study.

Due to the pandemic situation, people's mobility was also severely restricted, so sales of items related to winter trips, such as to the mountains, fell. It is worth noting, however, that customers who decided to engage in winter sports in February 2021 were likely opting to purchase items that I-Pack technology could not handle anyway. This is particularly true of skis, sledges, snowboards, ski poles, high-volume ski jackets and pants, ski boots and other items whose size is a disqualifying factor. This leads to another conclusion explaining the low use of I-Pack technology in the company's warehouse during the period under review.

This solution is not universal and does not fully meet the needs of the warehouse. Due to the high restrictions on the maximum dimensions of packed items, I-Pack technology can be used in companies where the size of items is not as varied as in the case of the studied company. Even the manufacturer introducing I-Pack technology mentions that it is recommended for shipping books or CDs.

On the other hand, the company offers very small goods (fishing rod hooks, swimming caps, table tennis balls) but also very large (treadmills, trampolines, bicycles). The expected increase in the use of the I-Pack machine will, therefore, come when customers choose to purchase smaller items, such as summer clothing, swimwear, beach shoes and the like.

Turning to the other two components of the OEE index, the quality and performance index, it can be said that their level is satisfactory. For the I-Pack machine, the average availability was 89.11%, while for the carton machine, it was 93.17%. The average quality coefficients, on the other hand, were even higher: 99.31% for the I-Pack and 99.36% for the carton machine. These results can attest to the high quality of the technology in question. Despite the meticulousness of the measurements, failures and quality deficiencies were rare.

However, it is worth remembering that these are measures appropriate for low machine utilization rates, and it cannot be assumed that if the machine utilization rate were very high, package quality and machine availability would be equally satisfactory. As mentioned, according to maintenance personnel, the frequency of failures increases as the degree of machine utilization increases.

Analyzing the causes of stoppages of the I-Pack machine and carton machine, most of the stoppages were caused by the direct fault of these machines. While in the case of the carton machine, the most common reason for stops was defective cartons (which, by blocking the carton machine, instantly caused it to stop), the reasons for I-Pack stops were already more complex.

According to the 80 h observations alone, it was possible to observe the following reasons for which the I-Pack machine stopped and required the intervention of a maintenance worker:

The packaging worker packed the articles in such a way that they protruded above the carton and the machine could not stick the lid on,

The packing worker packed the elements in such a way that they protruded above the carton and the machine soiled the articles with glue,

The cartons were too light and small, and the machine did not sense their presence in the carton machine,

The cartons were too heavy, and the carton tore while floating in the machine,

The element inside the box was only “a ball” that rolled inside the carton and moved the carton and removed it from the machine's sensor field,

The employee did not scan the barcode from the box, and the package was packed correctly, but without a shipping label,

The lid did not stick to the carton at all.

A few more words should be added to the conclusions of the collected data regarding MTTR, MTTF and MTBF ratios. The most important yardstick for assessing the quality of maintenance work is the MTTR indicator, i.e. the average time it takes to repair a failure. In the case of this indicator, except for two deviations, maintenance workers are very efficient in making repairs. In most cases, it is less than 4 minutes.

Another measure that can help evaluate the maintenance department is MTTF, or mean time to failure. With this measure, you can check, for example, whether preventive maintenance of a machine is being properly carried out. If one started to notice a downward trend in this time over a given period, one could conclude that machines are not being adequately cared for, as they are breaking down more and more frequently.

The MTBF indicator, on the other hand, is a combination of the two mentioned indicators and measures the average time between failures, so it also considers the pace of work of the Maintenance Department.

The OEE indicator data collected during the study can have broader applications. For example, knowing the performance of each piece of equipment can be used to make further decisions about expanding the automated packaging area of a warehouse.

According to maintenance staff, for example, one carton machine could handle two I-Pack machines, while a shipping label printer with a larger shipment can't cope with the pace imposed by the rest of the machines at their current volume. There is also the issue of employee productivity and the possible number of packing stations. Collecting the data used for OEE over a more extended period could help find the optimal number for each mentioned element.

Although OEE is mainly a measure that has its application in evaluating the efficiency of production machinery, the case study proves that, as much as possible, it is a measure that is also applicable to other areas of business, including warehousing. Its measurement and related measures improve the efficiency of the warehousing process, which, in the long term, can translate into an increase in the company's financial performance.

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