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Application of the OEE index in assessing the efficiency of vehicle use

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Abstract. Overall Equipment Effectiveness (OEE) is a Key Performance Indicator (KPI), which describes the efficiency of using technical resources. The index allows improving the efficiency of the production process, and also reflects the potential of the unused production capacity. In the presented case, new possibilities were proposed for the application of this model in public transport. First, the theoretical foundations of machine reliability, as well as the principles of comprehensive maintenance were presented. This discussion presents how to implement the OEE index to assess the effectiveness of vehicle use in a public transport company. Weaknesses were identified in the use of vehicles and changes were proposed to improve the OEE index.

1 Introduction

Nowadays, ensuring continuity of traffic is a key element in maintaining the competitiveness of enterprises in many areas of human activity. The reliability of machine work is increasingly important for human health, life and safety, as well as for environmental protection. Areas where maintenance is important are [1,2] e.g. power, gas and sewage plants, IT systems and telecommunications networks, instrument processes, continuous food production, manufacturing of cosmetics and chemical products, and maintenance of rolling stock in transport companies.

Initially, enterprises did not pay much attention to the issue of maintenance. Different self-developed approaches were applied, which most often focused only on quick disaster recovery rather than prevention. However, with the increasing level of complexity in manufacturing processes, unplanned failures have proven to be a source of significant losses, which companies cannot afford these days. The academia began to wonder how to prevent failures, instead of anticipating them, and then minimizing the effects of downtime. However, it wasn't until the late 20th century that a coherent, now popular concept of comprehensive maintenance was developed, Total Productive Maintenance (TPM). This concept emphasizes in particular modernization repairs and prevention, in order to prevent a failure and to minimize the risk of downtime. The application of the TPM-based approach has proved to be sound, and today is widely used, because, in the long run, prevention of failure is more cost-effective than anticipating unplanned events. The goal of TPM is to eliminate failures and to make operation of machines as effective as possible, involving every employee of the company, from entry-level to top-management. Equipment designers should also be involved in the maintenance

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management process, to anticipate preventive repair options. The issue of maintenance also has a broader context. It turns out that the TPM concept is closely related to TQM quality management, the principles of Word - Class Manufacturing and statistical modeling of reliability, which is described in the literature [3-5].

Maintenance KPIs have been included in the standard EN 15341: 2007 Maintenance - Maintenance Key Performance Indicators, developed by the European Committee for Standardization (CEN), which contains a unified set of measures [6-7]. The standard contains 71 indexes, along with a detailed interpretation of their elements. Due to their large number, they were ordered according to two criteria:

- types of decisions/actions taken by maintenance services:
  - economic indicators,
  - technical indicators
  - organizational indicators.
- decision levels that result in:
  - level 1 – indicators of the company's operations as a whole,
  - level 2 – indicators of the operations of the company's maintenance department,
  - level 3 – indicators of the activities of maintenance brigades and operational staff.

The OEE model is closely related to the TMP concept. In many manufacturing enterprises, the OEE model is widely used as a key indicator of overall equipment performance, which, combined with the increasingly popular Lean Management method, allows the company to effectively increase efficiency. First described in the 1980’s [3], the measurement of the overall equipment efficiency is the product of three components, i.e. availability, performance and quality (1).

$$\mathbf{OEE = availability \cdot performance \cdot quality} \tag{1}$$

Availability represents the total operating time, and can be reduced by losses caused by machine failures, and sometimes changeovers or machine configuration. **Performance** represents the overall production efficiency. It can be reduced by reducing the speed of the machine, internal breaks and other unplanned events that reduce the efficiency of the machine (but without stopping it). **Quality** is a resultant representing correctly manufactured products, free of defects.

The literature [1-5,8-10] lists many significant losses that may occur due to the machine's operation, and which can significantly impact all components of the OEE index. They are classified differently, but in general, six basic losses can be adopted, divided into three classification groups.

I. Losses in work time: failures or unplanned events occurring in the machinery and equipment; regulations and settings include changing parameters, changeovers, commissioning, testing, material shortages, operator’s ineptitude, etc.;

II. Losses in production rate: waiting for work, i.e. a blocked flow of elements, blockage of the line lasting more than 5 minutes; reduced work rate, i.e. wear and tear, poor quality of raw material, operator’s fatigue;

III. Losses in quality: repairable deficiencies; waste.

Before implementing the OEE index, it is important to understand its definition and to know its main factors, which affect the real time available for production. With the help of the OEE, the duration of the planned operation of machinery and equipment can be effectively determined, as it indicates the level of loss over a specified period of operation of the machine. Implementation of the OEE has positive effects, which can be expressed as follows:

- Improved machine performance,
- improved quality of manufactured products,

- increased machine availability,
- no unnecessary machine purchases,
- comparability of companies within the group in terms of the use of machinery [11-12].

2 Implementation of the OEE index in a public transport enterprise

The research was carried out in a public transport company operating in a medium-sized city. Przemyśl is a city located in south-eastern Poland, with total area is 46 km^2. The city's population is over 64,000, and population density is approx. 402 persons per square kilometer. Currently, the fleet of the municipal transport company consists of 40 vehicles:

- 10 Jelcz PR110 buses, manufactured in the years 1982-2001, after a recent general engine and chassis overhaul, to allow further use;
- 12 Otokar Vectio 250 LE buses, manufactured in 2010;
- 3 Solaris Urbino12 or Urbino 10 buses, manufactured in the years 2012-2013;
- 15 Autosan M12LF buses, manufactured in 2018;

The tests in question were carried out for one of the buses of each type in a randomly selected business week. Data on the availability of vehicles for use, punctuality of departures from selected stops and the number of passengers on the bus were collected. In the surveyed company, two drivers are always assigned to one bus, because the work lasts for two 8-hour shifts. Prior to starting the first shift, the driver is required to arrive earlier and inspect the technical condition of the vehicle. If a malfunction is found (e.g. inefficient lighting, low tire pressure, air conditioning, etc.), the bus is parked for service and the driver takes a substitute vehicle. After repair, the vehicle is returned to service.

According to the interpretation of the formula (1), the overall efficiency model described in the literature [12-13] is a product of availability, performance and quality as shown by the symbols in the formula (7).

$$OEE = A \cdot P \cdot Q \quad (7)$$

The availability component (A) is calculated using the expression (8), and can be used in an unchanged form to test the availability of vehicles.

$$A = \frac{t_a - t_s}{t_a}, \quad (8)$$

where:
t_a - time available for operating the machine (vehicle),
t_s - machine service time (e.g. failures, adjustments, downtime).

In a classic form, the performance component *(P)* refers to the ratio of production. In a production company, it is the product of the number of items manufactured *(P)* and the planned production cycle *(t_c)*, divided by the actual machine operating time *(t_r)*, as demonstrated in formula (9). Another way to determine the performance component is the ratio of the theoretical value of the production cycle time *(t_{cp})* to actual production cycle time *(t_{cr})*, as demonstrated in formula (10). For a transport company, the efficiency component should be calculated using the formula (11). It is the ratio of the actual number of passengers transported on the examined route between successive stops (p_r), to the number of seats available on the bus (p_t). For example, for the Jelcz PR110 bus, the total (theoretical) number of seats is 60, including 46 seats. Therefore, if the number of passengers on the bus at the examined stop was 60, then the vehicle's performance on this section was maximal. In practice, the calculation of this index takes into account the ratio of the arithmetic mean of the number of people on the bus along the entire route, to the number of available seats.

$$P = \frac{p \cdot t_c}{t_r}, \tag{9}$$

$$P = \frac{t_{cp}}{t_{cr}}, \tag{10}$$

$$P = \frac{p_r}{p_t}, \tag{11}$$

In the production processes, the quality component *(Q)* takes into account the quality of manufactured products, i.e. the ratio of the number of acceptable products (p_a) to the total number of products manufactured *(P)*, as demonstrated by the formula (12). A different interpretation has been adopted for transport. The most important quality criterion is the punctuality of departures from each stop on the entire length of the vehicle's route. In this case, the quality component is the ratio of the number of punctual departures $(n - n_f)$ to the total number of departures *(N)*, as demonstrated by the formula (13).

$$Q = \frac{p_a}{p}, \tag{12}$$

$$Q = \frac{n - n_f}{n}, \tag{13}$$

where:
(n_f) - number of faulty (late) departures;
(n) - total number of departures;

The calculation example is based on empirical data from the enterprise. The availability component of one bus includes its working time, as well as its breakdown time. It turned out that the Jelcz PR110 bus selected for the study remained in a failure state for 2 days a week. Due to the fact that the company works in two 8-hour shifts, also on Saturdays and Sundays, the sample calculations for the availability component are as follows:

t_a = *7 days * 2 shifts * 8 hours = 112 hours*
t_s = *32 hours*
A = 80/112 ≈ 71%

To calculate the full value of the performance component *(P)* during the week in question, data should be collected from all bus stops. An example calculation for one 8-hour work shift is as follows: 92 observations of the number of passengers on the bus between consecutive stops on the selected line (line 18) were made. The following numbers of passenger were recorded: 2, 2, 2, 4, 11, 6, 7, 7, 5, 4, 6, 6, 2, 2, 2, 2, 5, 5, 5, 8, 8, 15, 0, 7, 7, 10, 11, 11, 12, 11, 6, 5, 4, 12, 12, 11, 11, 9, 8, 8, 4, 2, 6, 6, 6, 0, 19, 23, 24, 25, 27, 33, 39, 40, 42, 43, 36, 36, 18, 7, 3, 10, 9, 10, 6, 7, 6, 6, 0, 5, 6, 6, 6, 6, 11, 12, 15, 17, 22, 30, 31, 15, 9, 7, 12, 7, 7, 7, 7, 5, 5, 0. The arithmetic mean of passengers was 11 people, the standard deviation was 10, with a large spread around the average. Please note that a full bus has never been reported; the Jelcz PR110 bus has a nominal capacity of 60 passengers, and only seating positions, i.e. 46 seats, were taken into account for the calculation of the value (P).

P = 10/46 = 0.16 ≈ 22%

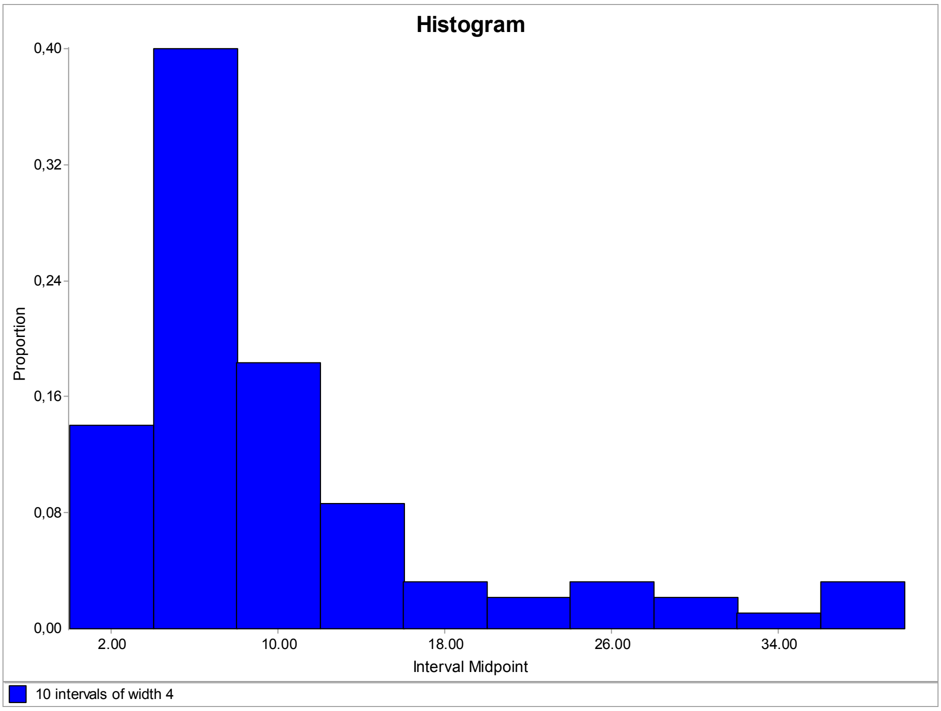

Fig. 1. Computer analysis of the number of passengers on line no. 18 during one work shift.

The value of the component (P) turned out to be very low, approx. 22%. This was confirmed by histogram analysis, which showed that on the route no. 18, there were less than 9 passengers on sections that represented 54% of the entire route covered in one work shift.

For an exemplary estimation of the quality component (Q) during one work shift, 92 observations were made at the same stops at which performance (P) was previously observed. There were 35 late departures per 92 scheduled departures, the quality component was 62%.

$$Q = \frac{92 - 35}{92} \approx 62\%$$

The values of the OEE index and its individual components during a randomly selected working week are presented in Table 1. One bus of each type used in the enterprise was selected for the study.

Tab. 1. Average values of the components of the OEE index for a single bus of each type during a random work week

Vehicle type	Availability	Performance	Quality	OEE
Jelcz PR110	71%	24%	68%	11.5%
Otokar Vectio 250 LE	86%	29%	69%	17.2%
Solaris Urbino12	86%	27%	67%	15.5%
Autosan M12LF	100%	25%	73%	18.2%

3 Conclusions

The OEE model can be successfully used to assess the level of use of vehicles in public transport. Based on the data from Table 1, a very low level of vehicle use was identified, mainly due to a small number of passengers, which significantly reduces the value of the performance index (24-29%). For each type of bus (also for old vehicles after refurbishment), the availability rate was relatively high, above 71 percent. The quality index concerned the punctuality of departures from the examined stops and was at an average level (68-73%). However, in the context of global standards set for production processes, which are 90% for availability, 95% for productivity and 99% for quality, respectively, the overall level of 85% of the OEE seems unattainable in public transport.

The method presented is appropriate as it demonstrates weaknesses in the economics of public transport. Recommendations for improving the OEE index are as follows: replacing buses with smaller ones or changing the routes, increasing the frequency of courses and improving punctuality, and in consequence, reaching the OEE at approx. 60% will significantly improve the company's profitability.

References

1. A. Kozieradzka (red.), *Podstawy zarządzania produkcją.* Politechnika Warszawska, Warsaw, (2016).
2. E. Macha, *Niezawodność maszyn.* Oficyna Wydawnicza PO, (2001).
3. S. Nakajima, TPM Tenkai. Japan Institute of Plant Maintenance, Tokyo, (1982).
4. Y. Takahashi, O. Takash, TPM, Total Productive Maintenance. Quality Resources, (1990).
5. S. Nakajima, Introduction to TPM: Total Productive Maintenance (Translation), Productivity Press, Inc., 1988, pp. 129, (1988).
6. PN-EN 15341:2007 Maintenance – Maintenance Key Performance Indicators, Polski Komitet Normalizacyjny, Warsaw (2007).
7. A. Grycuk, Przegl. Organ., **2**, 28-31, (2010).
8. A. Adamkiewicz, A. Burnos, Zeszyty Naukowe Akademii Marynarki Wojennej, **2** 189, (2012).
9. Z. Kowalczyk, M. Cupiał, Estimation methods of the agricultural equipment value with regard to evaluation of Alina carrot harvester. Contemporary Research Trends in Agricultural Engineering BIO Web Conf., 10 (2018).
10. E. Popardowski, D. Kwaśniewski, Technical-Economic Aspects Of The Eradication Of Energy Willow Plantations, in: Proceedings of 24th International PhD Students Conference (MendelNet 2017) / Cerkal Radim [et al.] (ed.), Mendel University, 808-813, (2017).
11. A. Loska, Komputerowo zintegrowane zarządzanie, **2**, 37-46, (2011).
12. K. Stecuła, Zarządzanie Przedsiębiorstwem **19**, (2016).
13. R. Oechsner et al., Materials Science in Semiconductor Processing, **5** 4-5, 333-339, (2002).