

Application of OEE Coefficient for Manufacturing Lines Reliability Improvement

Arkadiusz Gola

Institute of Technological Systems of Information
Lublin University of Technology, Faculty of
Mechanical Engineering
Lublin, Poland
e-mail: a.gola@pollub.pl

Aleksander Nieoczym

Department of Machine Design
Lublin University of Technology, Faculty of
Mechanical Engineering
Lublin, Poland
e-mail: a.nieoczym@pollub.pl

Abstract—This paper describes how to use the OEE index to analyze the reliability and efficiency of the production line. The survey provides an indication of machines that generate disturbances in the operation of the system and is based on the three parameters: availability, performance and quality. In the present study, the operation of a filling line for alcoholic beverages was analyzed. The analysis helped to find the weakest points of the line. The machine which caused the longest downtime was identified. Finally, structural modifications were proposed which would increase the reliability of the machine.

Keywords-OEE; overall equipment effectiveness; manufacturing line; reliability, improvement

I. INTRODUCTION

Flow production involves a continuous movement of items along a production line, where each machine performs a specific operation or set of operations. In order to achieve the assumed productivity, each machine should be characterized by a specific operational reliability index (reliability) [1-2]. This parameter is also referred to as time between repairs or as time to recovery [3]. For example, if the reliability of a single machine is 90%, i.e. its probability of working is 0.90, and the line consists of 30 machines, the reliability of the entire line is $0.9^{30} = 0.042$, i.e. 4%. If the reliability of the machines is increased via a 10-fold reduction in failure, the following reliability of the line is obtained: $0.99^{30} = 0.74$. Reduced reliability and thus a reduced efficiency of the production system may result from machine production errors, operating errors, and non-compliance with usage requirements [4-5]. Another cause of reduced reliability of a production line is downtime of a machine or a set of machines due to a defect in the finished product caused by defective input material or errors in the manufacturing process [6-8]. To avoid such problems, production lines are configured so that the production machines are separated by control points [9]. These points are where the production rate is stabilized and defective products are eliminated. The probability of failure is also dependent on the skills and competencies of people [10]. In the initial phase of machine use, failure rate is higher because workers and/or maintenance and repair personnel lack sufficient skill and practice. After this period, the

machine enters the most stable period of operation, which continues until the natural end of its useful life [11].

Because the reliability of a single machine affects the reliability of the entire system and has a direct impact on productivity, it is necessary to use a measure allowing to identify the machines that generate disturbances in the operation of the system. One such measure is the Overall Equipment Effectiveness (OEE) indicator [12]. OEE is used to measure the reliability of equipment based on three important metrics: Availability (A), Performance (P) and Quality (Q) [13]. The value of OEE is used to draw conclusions about the causes of decreased reliability of a production line as well as to formulate preventive measures [14-15]. OEE has a numerical value, which is not only a benchmark for controlling and monitoring the performance of production equipment, but also an indicator that determines the direction of qualitative changes in the production system and changes targeted at increasing efficiency [16]. It is similar to assessment of a process using process capability index (eg. [17]). Corrective actions based on OEE are also taken to improve the organization of work and management of human resources and also to change a company's image [18]. Very often corrective actions are prompted by the desire to achieve business performance at world-class level [19-20]. To obtain a comparative value, OEE is compared with the values given in the standards of the Japan Institute of Plant Management (JIPM) [21].

The methods for calculating OEE are often modified so that the results reflect the specific character of a particular branch of industry [22-24]. In the electronics industry [25] for example, a two-dimensional research methodology for measuring and analyzing productivity, called Overall Equipment Productivity (OEP), has been introduced. In [26] Design of Experiments (DOE) method used in collecting data for the analysis of OEE is described. It has been shown, based on DOE, that in order to improve OEE, greater emphasis should be placed on factors that affect performance.

Performance and reliability of production systems have been considered in relation to various branches of industry. Lonkvic and Nieoczym describe the impact of the design of a working tool and the method of controlling its operation on the performance of a robotic work station [27]. Samociuk et al. present a multi-faceted analysis of the reliability of the storage of ammonia [28]. Reliability has

also been discussed in reference to the process of designing machines [29-30]. Studies in this area combine input design data which determine the operating parameters of a machine with kinematic, dynamic and strength analysis.

Sometimes FMEA parameter is used to find correlations among the severity of failure, failure rate and failure detection [22]. In the study mentioned, thirty two research hypotheses have been tested and detailed proposals regarding the use of FMEA to improve OEE have been presented. The results of tests conducted after the integration of OEE and reliability of the investigated system are presented in [24]. The concepts of Failure Rate and Failure Ratio have been introduced. The integration of these two factors is aimed at improving the quality of maintenance.

II. INDICES OF OPERATIONAL RELIABILITY

OEE value ratio is calculated as the product of three components and is expressed by the formula [9]:

$$OEE = A \times P \times Q \quad (1)$$

where: A – Availability, P - Performance rate, Q - Quality.

An OEE score of 100% means that the system has achieved one hundred percent availability, performance and quality. This is unattainable in practice, and the lowering of the particular underlying metrics results in lowering the OEE. Managers may set their own OEE targets or use JIPM guidelines, which give the following values of the component indicators:

- availability 90%,
- performance 95%,
- quality 99.9%,

what gives an overall OEE score of 85.41%.

An OEE score obviously requires proper interpretation. The detection of critical points in production lines and taking measures to increase the reliability of the individual machines is what OEE is calculated for.

The relationship between FMEA and OEE requires that indices of operational reliability of the investigated production line be calculated. These indices include [31]:

- Failure rate (k_a) – number of failures during an operational period:

$$k_a = \frac{N_a}{N_o} \quad (2)$$

where: N_a – number of failed production line components [pcs], N_o – number of production line components [pcs].

- Failure intensity (ω) – anticipated number of times an item will fail in a specified time period:

$$\omega = \frac{n_u}{N_o} \quad (3)$$

where: n_u – number of failures of all line components [pcs], N_o – number of production line components [pcs].

- Mean stop time of a line due to failures (T_{pm}):

$$T_{pm} = \frac{\sum t_{pi}}{n_u} \quad (4)$$

where: t_{pi} – stop time due to the i-th failure of the line [h], n_u – number of failures of all line components [pcs].

- Mean operating time between failures (T_{rm}) – the expected value of the random variable defining the operating time of an item between two successive failures:

$$T_{rm} = \frac{T_c - \sum t_{pi}}{n_u} \quad (5)$$

where: t_{pi} – stop time due to the i-th failure of the line [h], n_u – number of failures of all line components [pcs], T_c – useful life of the line [h].

- Line downtime coefficient (k_p):

$$k_p = \frac{\sum t_{pi}}{T_c} \times 100\% \quad (6)$$

where: t_{pi} – stop time due to the i-th failure of the line [h], T_c – useful life of the line [h].

- Availability coefficient (k_g) – defined as the probability of finding the system in the operational state at any point of time t in the adopted model of reliability:

$$k_g = \frac{T_c - \sum t_{pi}}{T_c} \times 100\% \quad (7)$$

where: t_{pi} – stop time due to the i-th failure of the line [h], T_c – useful life of the line [h].

III. AN ANALYSIS OF OPERATION OF A PRODUCTION LINE IN AN INDUSTRIAL SETTING

The focus of the analysis was a filling line for the production of high-proof alcoholic beverages. The line consisted of the following machines and auxiliary equipment:

- A depalletizer for unloading new bottles from pallets and placing them on a conveyor belt.
- A laning conveyor for funneling a wide mass of bottles onto a single-lane conveyor.
- A rinser for washing the bottles (usually with technical alcohol).
- A filler for filling and capping the bottles. Filling takes place in the so-called sanitation zone endorsed by HACCP.

- A bottle buffer for collecting bottles downstream of a labeller; this device eliminates downtime in instances such as when labels are being replenished.
- A label applicator for applying labels and excise stamps.
- A single-lane conveyor for transporting bottles between label applicator and bottle separator.
- A bottle separator for automatic funnelling of bottles into separate rows before they are fed into a packing machine.
- A cardboard packaging machine for packing filled bottles into cardboard boxes; the machine first forms and then glues cardboard boxes to fit the dimensions of the product.
- A palletizer for stacking cartons on pallets.
- A wrapper for wrapping pallets with foil.

Line operation was tested for 4 weeks during which time the line ran seven days a week on a single-shift schedule. The information on the functioning of the line and operation events was obtained from the Line Performance Card, the Monitoring Section and the Maintenance Department. The Performance Card was used to record the following data: brigade number, time and date of production, line performance, failure code, failure type, code of material defect, downtime code, and downtime type.

Gathered data allowed to calculate values of the indices of operational reliability (tab. 1 and 2) and to make graphical analysis of obtained results (fig. 1-4).

TABLE I. RELIABILITY INDICES FOR PRODUCTION LINE OPERATION IN EACH WEEK OF THE STUDY

An indice for production line reliability	Week			
	1	2	3	4
Failure rate k_a	0,45	0,45	0,45	0,45
Failure intensity ω	1,5	1,6	1,55	1,2
Mean stop time of a line due to failures T_{pm} [s]	720	1013	1150	1023
Mean operating time between failures T_m [s]	5520	4190	5354	7378
Line downtime coefficient k_p [%]	11,54	19,45	17,67	12,17
Availability coefficient k_g [%]	88,46	80,55	82,33	87,83

TABLE II. OEE SCORES IN THE FIRST WEEK OF OPERATION OF THE LINE BROKEN BY DAY

	Week 1	Week 2	Week 3	Week 4
Day 1	82	59	60	83
Day 2	82	51	71	81
Day 3	84	62	64	77
Day 4	71	66	48	92
Day 5	76	67	70	79
Day 6	65	60	49	68
Day 7	72	71	70	77

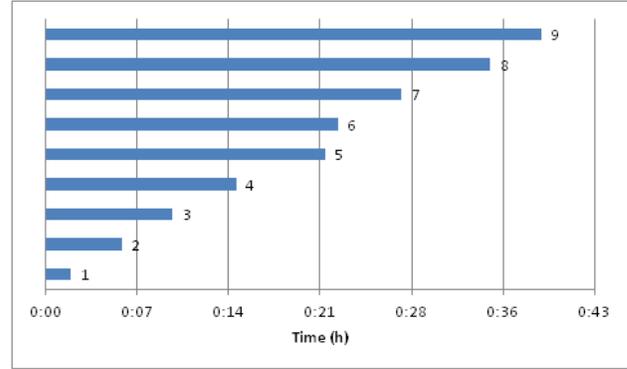


Figure 1. Downtime by machine in the first week of operation: 1 – depalletizer, 2 – machine for capping the bottles, 3 – palletizer, 4 – filler for filling, 5- conveyor, 6 – washing machines, 7 – other, 8 – cardboard boxes, 9 – cardboard packaging machine

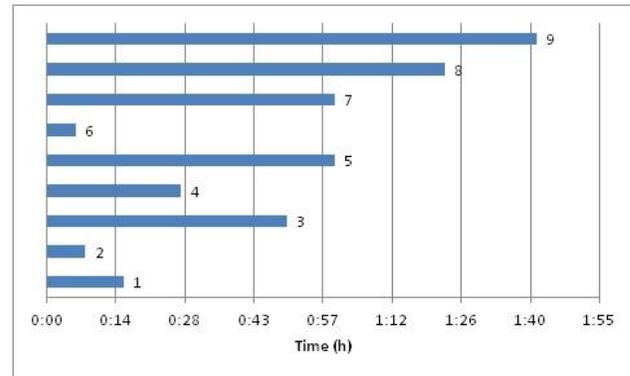


Figure 2. Downtime by machine in the second week of operation: 1 – depalletizer, 2 – machine for capping the bottles, 3 – palletizer, 4 – filler for filling, 5- conveyor, 6 – washing machines, 7 – other, 8 – cardboard boxes, 9 – cardboard packaging machine

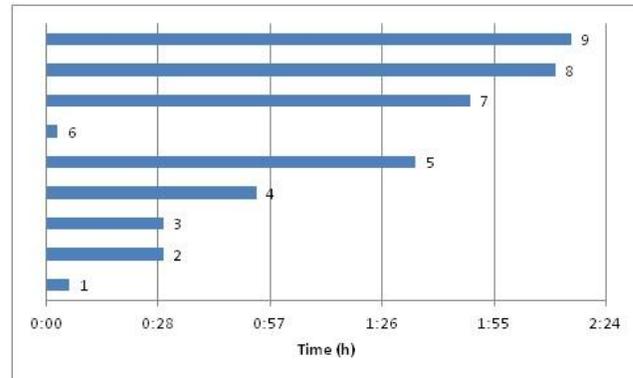


Figure 3. Downtime by machine in the third week of operation: 1 – depalletizer, 2 – machine for capping the bottles, 3 – palletizer, 4 – filler for filling, 5- conveyor, 6 – washing machines, 7 – other, 8 – cardboard boxes, 9 – cardboard packaging machine

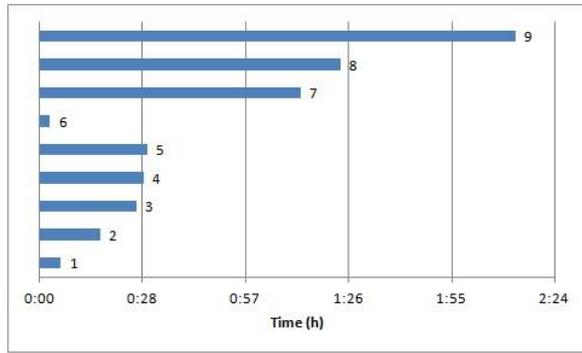


Figure 4. Downtime by machine in the fourth week of operation: 1 – depalletizer, 2 – machine for capping the bottles, 3 – palletizer, 4 – filler for filling, 5- conveyor, 6 – washing machines, 7 – other, 8 – cardboard boxes, 9 – cardboard packaging machine

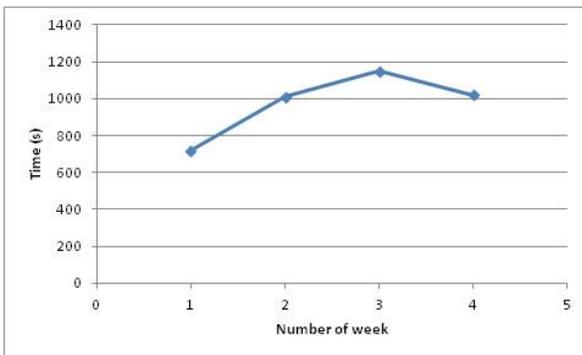


Figure 5. Mean stop time due to breakdowns during the four-week study

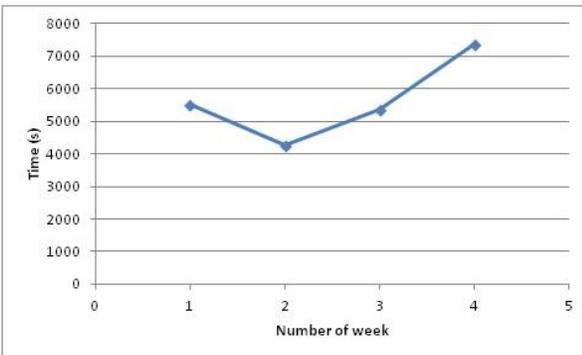


Figure 6. Mean stop time between failures during the four-week study

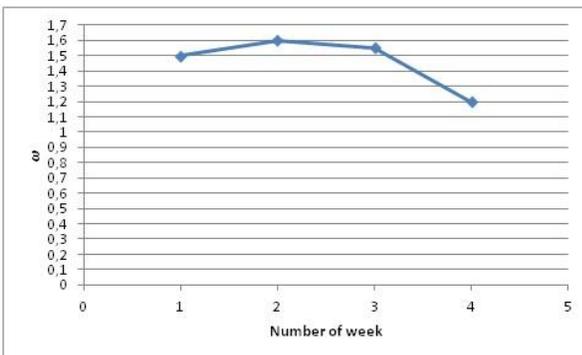


Figure 7. Failure intensity ω during the four-week study

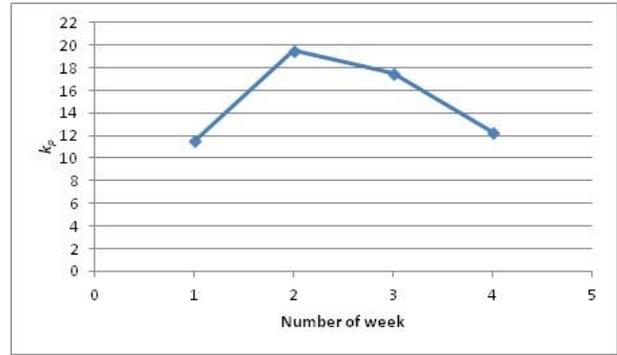


Figure 8. The values of line downtime coefficient k_p during the four-week study

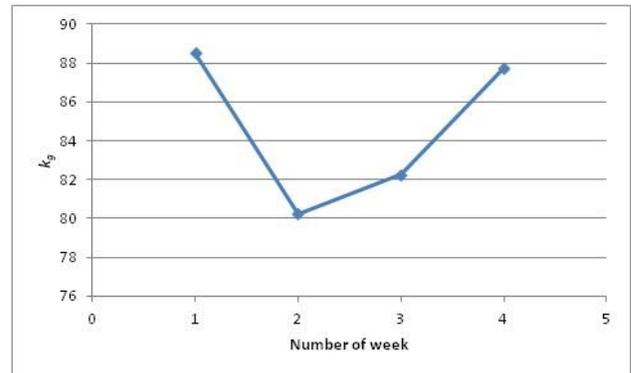


Figure 9. The values of line availability coefficient k_g during the four-week study

The impact of the individual units comprising the vodka production line on its failure rate can be assessed on the basis of the number of failures and downtimes of these units. Indicators of reliability can be used to pin down weak links in the system, i.e. units that

- fail most frequently,
- cause long downtime.

A weak link is a unit that meets the following criteria:

- it sustains two or more failures per operation time,
- it has at least a 10% share in overall line stop time.

The line operation data and data on operation events allow one to calculate the values of reliability parameters and perform graphical analysis of the results. Downtime due to failure increased at 3 and 4 weeks. The devices that generated the longest downtime were the packaging machine and the label applicator. The downtime caused by the packaging machine during the four-week analysis was as long as 6 h 49 min which represented 25.43% of the overall downtime. The total number of failures or adjustments of all machines was 117 h, of which 23.93% were failures or adjustments of the packaging machine.

During the four-week study, the largest number of events involved adjustment (23 events) and five were associated with a failure of the packaging machine.

The analysis allowed us to identify the devices which failed most frequently. Next, the failure-prone assemblies were identified and analyzed in detail. The analysis showed

that the packaging machine caused the longest downtime of about 10% during the operation of the line and sustained the largest number of failures. This device was selected for further analysis of life cycle, to eliminate the large number of line outages.

Based on the analysis of the operation of the filling line, it was found that the packaging machine generated the longest downtime. The operation of the packaging machine was analyzed in order to identify the critical points of the device. A schematic representation of the operation of the device was analyzed and the way it operated was observed during the production process. Observations showed that the component that caused the greatest problems was the cardboard-blank magazine (Fig. 10). The feeding system is designed to move horizontally oriented cardboard blanks toward a roller which collects them. The main problem during the operation of the magazine is that several blanks are fed at a time which causes downtime of the line. So it is not failures that generate the most downtime but adjusting of the magazine. For the magazine to operate smoothly, the blanks must have strictly defined dimensions conforming to a standard model and cannot be damp. When the humidity in the production hall increases, so does the number of problems with feeding of the blanks. A situation like that was observed at 3 and 4 weeks of collecting data regarding the reliability of the line. At a higher humidity, the blanks are lightly glued together which leads to double-feeding.



Figure 10. Cardboard-blank magazine

The blanks magazine was selected as the critical point of the machine and the entire line. To improve the operation of the line, and thus improve its performance, a decision was made to re-design the magazine. While the required feeding rate of 40 cartons per minute was maintained, the following major changes were proposed: the cardboard blanks were now to be positioned vertically and collected by pneumatic suction cups.

A schematic design of the modernized cardboard-blank magazine is shown in Figure 11. The blanks are placed vertically on a board (1) and pressed down by the guiding mechanism (2) to a stop positioned next to the feeding arm (4). A positioner (3) is used to set the blanks in the axis of the cardboard-blank magazine. The width of the positioning mechanism can be adjusted with adjusting handles so that

the dimensions of the magazine match the format of the cardboard blanks. The designed magazine is equipped with a pneumatic blank collection system.

The blank extraction mechanism (Fig. 12) is driven by a three-phase electric motor (1) which drives a shaft (4) via a chain transmission. In turn, the swinging movement of the arm (8) with pneumatic suction cups for extracting cardboard blanks is actuated by a pull rod (5) and a drive belt (7).

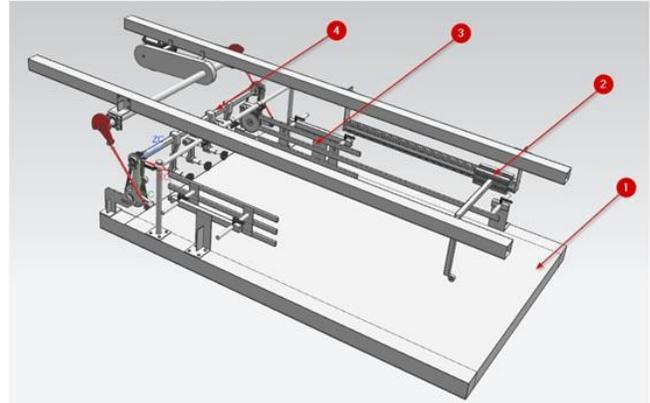


Figure 11. A schematic design of the modernized cardboard-blank magazine: 1 – board, 2 – guiding mechanism, 3 – positioner, 4 – blank collection system

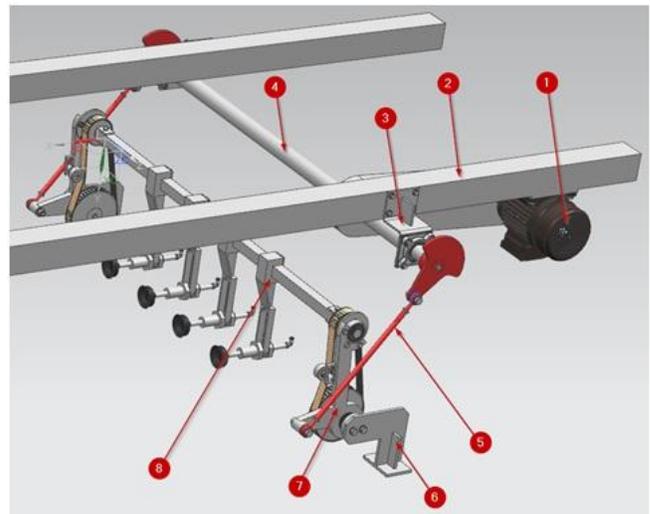


Figure 12. Blank collection system: 1 – electric motor, 2 – main frame, 3 – support of drive shaft, 4 – drive shaft, 5 – pull rod, 6 – support of transmission, 7 – belt transmission, 8 – arm.

IV. CONCLUSIONS

OEE is one of the most important metrics describing the performance of equipment used in a company. An OEE rating provides a basis for creating strategies for the improvement of production processes. It allows production managers to identify "bottlenecks" and technical and organizational problems in the company. OEE can also be used to evaluate already implemented improvements and calculate the benefits of process improvement and elimination of the individual problems.

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