THE IMPACT OF SHUTDOWNS AND EQUIPMENT FAILURES ON THE EFFICIENCY OF THE ELECTROTECHNICAL SHEET PRODUCTION LINE

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Abstract

One quality that characterizes the management of manufacturing enterprises is the constant search for ways to improve the productivity of production processes. It is production that causes the main stream of materials, components, and parts to flow through individual departments and structures of a company. The task of logistics is to ensure a buyer to obtain the proper quality and quantity of a product in due time and place on the minimal cost of delivery. The use of production lines strongly depends on orders - orders for products. Production is concerned with short throughput times and high schedule reliability in order to on the one hand, fulfill customer demands and on the other hand, increase planning reliability. However, from the business perspective, it is preferred that the available production equipment is highly utilized and that there is the lowest possible WIP (Work in Process level). For the evaluation system used in the study TPM method. The TPM method most commonly employs three indicators: MTTR, MTBF and most typically - OEE. The first two are associated exclusively with technical issues of the examined production line. The object of the study was the production plant of transformer sheets. The article presents parts of research OEE performance indicator for many production lines. In particular, the impact of shutdowns and equipment failures on the sheet production capacity was examined.

Keywords: Efficiency, sheet production, TPM method

1. INTRODUCTION

The basic problems considered by industrial logistics are: displacement of materials and information, data storing and processing, problems of integrating the materials flow process, planning and control. One quality that characterizes the management of manufacturing enterprises is the constant search for ways to improve the productivity of production processes [1]. It is production that causes the main stream of materials, components, and parts to flow through individual departments and structures of a company. The task of logistics is to ensure a buyer to obtain the proper quality and quantity of a product in due time and place on the minimal cost of delivery [2]. The essence of lean approach is transformation of wastage (muda) into a value, thus determination of value is the first step during lean approach implementation. Main tools supporting the *lean* concept include [3]: JiT (Just in Time), Kanban, Jidoka, VSM (Value Stream Mapping), Heijunka and TPM (Total Productive Maintenance). The purpose of the TPM is to strive after maintaining continuous work of devices and machines executing specific tasks, which at the same time shows improvement of their functioning effectiveness. The main objectives for the implementation of the TPM method are: reducing the number of equipment failures, accelerating repair times of a unit or line, elimination of micro-stoppages, reduction of losses. The OEE (Overall Equipment Effectiveness) index is the primary measure for the TPM implementation effects [4,5]. The OEE is either overall equipment effectiveness or general equipment efficiency (machines, devices). This index shows what percent value of theoretically obtainable efficiency is characteristic for an examined device or line. The purpose of the TPM is to strive after maintaining continuous work of devices and machines executing specific tasks, which at the same time shows improvement of their functioning effectiveness.

The method is based on the use of human resources to analyse the causes of wastage and losses (muda) arising in the process and requires a systemic solution to the problems that cause downtime of machinery and equipment [4,6].

The TPM identifies 6 main losses (in three subgroups) [3]:

- time losses (availability: losses due to failure, losses for exchanges of die and adjustments),
- efficiency losses (performance: losses for dead time and micro-downtime, losses due to process speed drop),
- losses due to defects (quality: losses due to occurrence of rejects and corrections, tart-up losses).

In the article [7] was presented parts of research OEE performance indicator for many production lines. Average score index for the whole plant was OEE = 64.96 %. The OEE coefficient is strongly dependent on the operation of the production line, but its value depends on the method of calculation methods and data collection. Currently, the plant has been modernized several production lines: line of normalizing and pickling, line of primary mill (WS1), lines of decarburization.

2. RESEARCH OBJECT - SHEET PRODUCTION LINES

A production system of electrical sheets (SES) is composed of many subsystems:

$$SES = \langle L1, L2, L3 \ldots L13 \rangle \quad (1)$$

The technological process is carried out on 13 production lines:

L1 - Line of normalizing and pickling (LN) - preparing for the cold rolling,

L2 - Line of primary mill (WS1) - Sendzimir mill,

L3, L4, L5 - Lines of decarburization (A, B1 and B2) - reduce the carbon content (up to 12 ppm),

L6 - Line of final rolling (WS2) - Sendzimir mill (thickness min. 0.23 mm),

L7 - Line of sheet straightening (B3),

L8 - Line of sheet coating (B4) - layer of magnesium oxide MgO,

L9, L10 - Lines of annealing (new furnaces: LOI - 20 pcs., old: IPSEN - 10 pcs.),

L11, L12, L13 - Lines electro-coating layer (C1, C2, C3),

Sheet production scheme is shown in **Figure 1**.

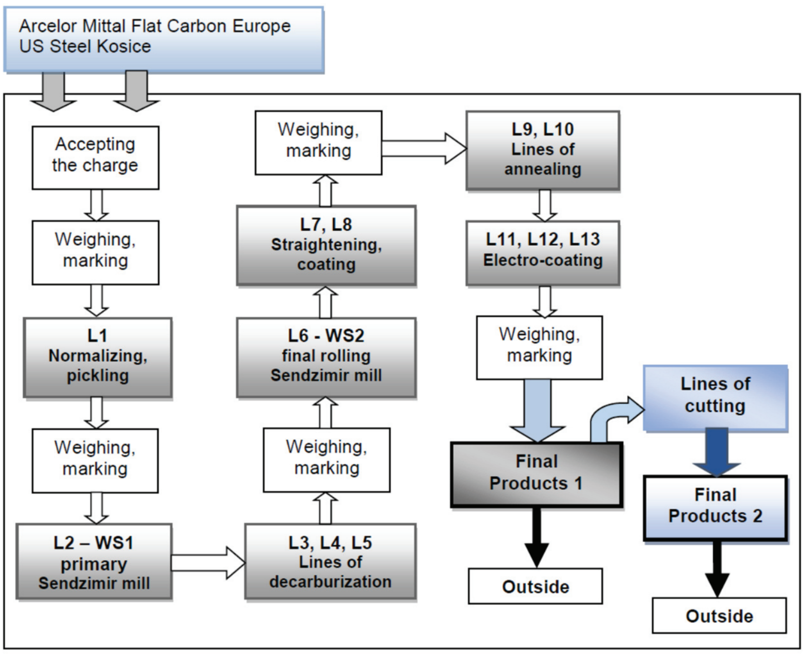

Figure 1 Scheme of electrical sheets production system SES

OEE (Overall Equipment Effectiveness) index research was carried out for all 13 lines. The final products of the plant are electrical sheets. All parameters and tolerances are in accordance with EN 10107:2005. The offer of the plant contains four of the final product thickness: 0.23 mm, 0.27 mm, 0.3 mm and 0.35 mm; magnetic induction - 1.85 T (Tesla).

Load (100,000 -120,000 Mg/year): hot-rolled sheet with a thickness of 2.0 ÷ 2.5 mm and a width of about 1,000 mm in the form of rolled coils.

Suppliers: Arcelor Mittal Poland (Krakow), Arcelor Mittal Germany, U.S Steel Czech Republic (Košice).

On the basis of data on annual production and available working hours, the efficiency of each line was calculated (data for the one year of operation from ERP -IFS). The results are summarized in **Table 1**.

Table 1 Efficiency and processing times of individual lines [own study]

Line	Production volume (Mg)	Work time (h]	Efficiency (t/h)	Unit time (h)	Average unit time of the process (h)
L1	90,359.26	5,400	16.73	1.02	1.02
L2	92,511.76	6,246	14.81	1.12	1.12
L3	40,316.00	6,783	5.94	2.79	1.17
L4	23,601.50	5,610	4.21	3.95	
L5	23,921.30	5,501	4.35	3.82	
L6	84,614.40	5,903	1.,33	1.10	1.10
L7	40,673.30	6,645	6.12	2.57	1.29
L8	42,455.70	6,958	6.10	2.58	
L9	48,599.60	7,071	6.87	2.26	1.39
L10	36,813.90	7,834	4.70	3.30	
L11	23,797.95	6,757	3.52	4.40	1.38
L12	28,518.20	7,705	3.70	4.19	
L13	31,915.71	7,845	4.07	3.81	

The unit time was defined as the quotient of the charge mass and the line efficiency. To calculate the unit time, the average mass of the batch material on each line was used (**Table 2**):

Table 2 Average mass of the batch [own study]

Line	L1	L2	L3-L5	L6	L7-L8	L9-L10	L11-L13
Average mass (Mg)	17	16.6	16.6	15.75	15.75	15.5	15.5

The comparison of the efficiency of individual processes is shown in **Figure 2**.

When comparing the performance of all processes (**Figure 2**), one can notice a decrease in the efficiency of each subsequent process. The decisive advantage of such production is the lack of a situation in which, at some stage of the process, the lack of input material forces the stoppage of the line due to the low efficiency of the previous line. The disadvantage is the overproduction, and hence - the filling of inter-operation buffers.

Production on the normalization and pickling line is distinguished by the highest efficiency from all lines. Within an hour, this line can process nearly 2 Mg more material than the next cell - Sendzimir No. 1 rolling mill, and almost 5.5 Mg more than the lines of the last technological process. It is connected with overproduction, as a consequence of which interoperational buffers are filled, the capacity of which is limited.

In practice, there are situations that force the production to stop on the line. These include, among others: line component failures, sheet breakage, crane failure.

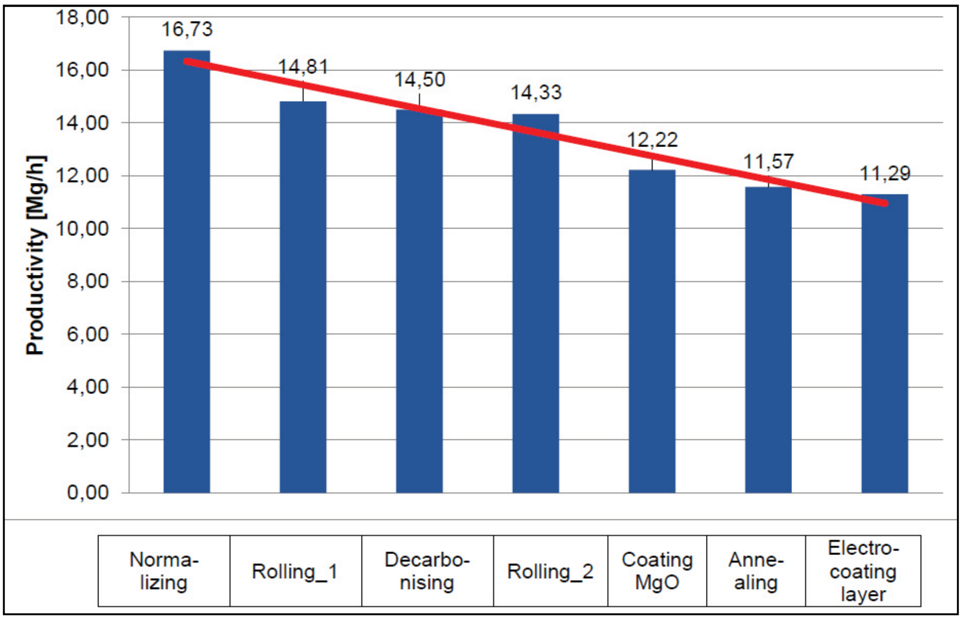

Figure 2 Comparison of the efficiency of processes

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Continuity of production and differences in the efficiency of subsequent production cells in the plant are the factors that require the existence of inter-operation buffers in which the stock is collected at each stage of material processing. The stored inventory are strategic, which in turn translates into a high level of customer service. At each stage of the sheet metal processing, a certain material is produced, which in the event of failure ensures continuous production. Differences in the efficiency of individual production cells make the inter-operation buffers fill with different speeds. The buffers with the largest capacity are located next to the lines with the highest efficiency, ie before the No.1 and No.2 rolling mills. Their capacity is sufficient to maintain production continuity in the event of a planned stoppage or L1 line breakdown for approximately 48 hours.

3. ANALYSIS OF THE OPERATION OF SES SYSTEM

The analysis of the production process shows that the main losses are:

- overproduction,
- unplanned stops,
- generating waste.

Overproduction problems are discussed in the previous chapter. Unplanned outages are the biggest problem because they have no control over them. For the selected year of system operation, the time of work and stops of each line was calculated, and their summary is shown in the graph (**Figure 3**).

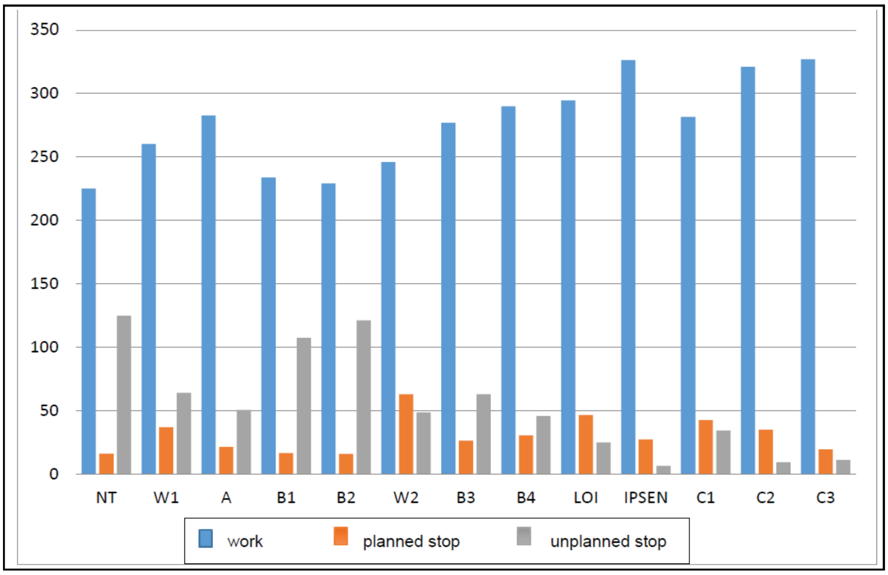

Figure 3 Times of work and stops of the line expressed in days

In many cases, a stopover is of an organizational nature or is caused by an activity that cannot be bypassed, such as replacing the solution or preparation for voltage decay. However, there are lines where the total unplanned downtime is significantly higher and it reaches up to 30-35 % of the net operating time. The lines with the lowest availability for this reason are the NT line and lines B1 and B2, and the most common reasons for unplanned shutdowns are: sheet metal failure and drive failures and other devices. In this situation, a TPM system should be implemented, including the maintenance of traffic to the production process. Examples of reasons for stops are summarized in **Table 3**.

Table 3 Exemplary reasons for shutdowns [own study]

Lines	NT	A, B1, B2	B3, B4	LOI	IPSEN	C1, C2, C3
Failures	Power failure, failure of the shot-blasting machine, failure of the welding machine - adjustments, tearing off the sheet	Drive failures, cutting of tears, extinction of the furnace, breaking the sheet	Tearing off the sheet, cutting defects, adjusting, failure of the drive, replacement of the coating rollers	No hood, no batch	Damage to the chamber / trolley	Sheet breakage, brush replacement, replacement of the furnace rolls, replacement of breakers, cutting defects, damage to the heater

The production process of electro technical transformer sheets for many reasons generates relatively large amounts of scrap. The first of these reasons is the need to remove the joints that must appear on each circle several times. Apart from this part of the waste, which are cut edges and welds there are also many defects on the surface of the sheet. They may be caused, for example, by poor selection of process parameters, a defect of machine elements, but also by inadequate quality of ordered substances used in the process as well as feed defects. Hot-rolled coils are ordered from 3 suppliers: Arcelor Mittal Poland in Krakow (AMP), Arcelor Mittal Eisenhüttenstadt in Germany (AMEH), U.S. Steel in Košice (USSK). The amount of waste in 2018 augmented with the increase in the share in the production of coils from Košice and reached the maximum for the A line - 238.8 Mg, (for the B2 125.6 Mg and 101.1 Mg lines for the B4 line). These losses were caused by a serious edge defect that had to be cut off. The conducted analysis also showed a break in the supply of coils from the Krakow smelter. These coils had defects at the level of chemical composition in this period, causing further serious defects in further stages of production. The yield achieved by the sheet division in 2018 is approximately 83.6 %.

All the losses mentioned above affect the assessment of the operation of the entire system. The OEE (Overall Equipment Effectiveness) index is the primary measure for the TPM implementation effects.

Table 4 shows the results of measurements obtained from the IFS system (ERP) for the time line and the stops planned and unplanned.

Table 4 The results of OEE indicators of selected lines

	NT	A	B1	B2	B3	B4	C1	C2	C3
Total operating time (h)	8,784	8,784	8,784	8,784	8,784	8,784	8,784	8,784	8,784
Time of losses (h)	2,996	1,212	2,575	2,909	1.509	1,096	826	223	268
Work time (h)	5,400	7,055	5,810	5,493	6.645	6,958	6,933	7,772	8045
AVAILABILITY	**64.31 %**	**85.34 %**	**69.29 %**	**65.37 %**	**81.49 %**	**86.39 %**	**89.35 %**	**97.19 %**	**96.78 %**
PERFORMANCE	**82.09 %**	**86.98 %**	**67.92 %**	**83.45 %**	**74.68 %**	**75.12 %**	**84.58 %**	**86.76 %**	**69.58 %**
QUALITY	**97.64 %**	**94.76 %**	**95.57 %**	**94.67 %**	**98.35 %**	**98.15 %**	**92.74 %**	**91.93 %**	**93.74 %**
OEE	**51.55 %**	**70.33 %**	**44.97 %**	**51.65 %**	**59.85 %**	**63.69 %**	**70.08 %**	**77.52 %**	**63.12 %**

The results of the calculation of OEE Overall Equipment Effectiveness shown in **Figure 4**.

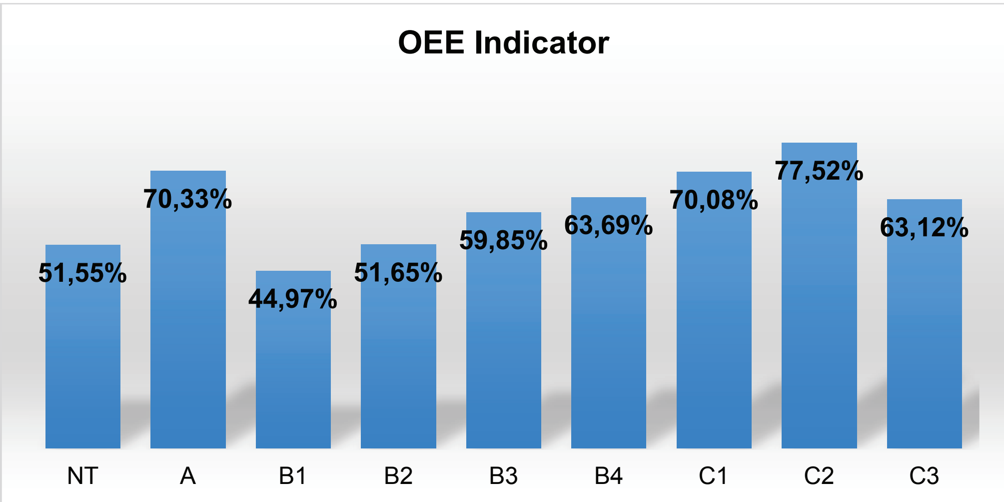

Figure 4 OEE indicator for all lines

CONCLUSION

The C1 line has the highest value of the OEE indicator (77.52 %). B1(44.97), NT and B2 lines have the lowest values of OEE, which is mainly caused by the number of unscheduled stops that took place on these lines during the year. These stops were mainly caused by: sheet breakage, drive / power failures, cutting defects, adjustments.

This OEE index shows what percent value of theoretically obtainable efficiency is characteristic for an examined device or line. A company is evaluated as high-quality if their OEE indicator exceeds the value of 80 %. Average score index for the whole plant was OEE_{SES} = 61.38 %. This is not a satisfactory result.

Line availability has the lowest index among the factors determining OEE, which is caused by very frequent unplanned downtime. The highest score for it has a quality factor, which for each line is over 90 %.

The production process of electro technical transformer sheets due to their complexity and the number of factors affecting the quality of the product requires continuous monitoring and thorough analysis. One of the possibilities to improve productivity is the implementation of lean methods - that is, continuous elimination of wastage in ongoing processes.

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