THE IMPACT OF MODERNIZATION ON THE PRODUCTIVITY OF A MULTI-STAGE PRODUCTION OF TRANSFORMER SHEETS

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Abstract

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 was examined the impact of modernization of the line on the efficiency.

Keywords: Productivity, equipment modernization, efficiency indicator OEE

1. INTRODUCTION

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 [1].

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 [2]: VSM (Value Stream Mapping), Jidoka, Heijunka, TPM (Total Productive Maintenance). 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 [3]. 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 OEE index is most often computed using simple formula:

OEE effectiveness index = availability x performance x quality x 100 [%]

$$OEE = A \times P \times Q \times 100\ [\%] \qquad (1)$$

Where:

A - Availability: practical availability, availability ratio
P - Performance: efficiency of performance, performance ratio
Q - Quality: quality factor

TPM method has been used to improve productivity in plant production of electrical sheets. In the article [4] was presented parts of research OEE performance indicator for many production lines. Average score index for the whole plant was OEE_{SES} = 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 - Sendzimir mill (WS1), lines of decarburization.

2. TPM IMPLEMENTATION AFTER MODERNIZATION

The final product of the plant is the electrical sheets. All parameters and tolerances are in accordance with EN 10107:2005. Offer plant contains four of the final product thickness [mm]: 0.23, 0.27, 0.3 and 0.35 mm. A production system SES of electrical (transformers) sheets is composed of many subsystems:

$$SES = \langle L1, L2, L3 \ldots L13 \rangle \tag{2}$$

L1 - NT: Line of normalizing and pickling
L2 - WS1: Line of primary mill - Sendzimir mill
L3 - A, L4 - B1, L5 - B2: Lines of decarburization
L6 - WS2: Line of final rolling - Sendzimir mill
L7 - B3, L8 - B4: Lines of straightening and coating
L9 - LOI, L10 - IPSEN: Lines of annealing (new furnaces: LOI - 20 pcs.)
L11 - C1, L12 - C2, L13 - C3: Lines electro-coating layer

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

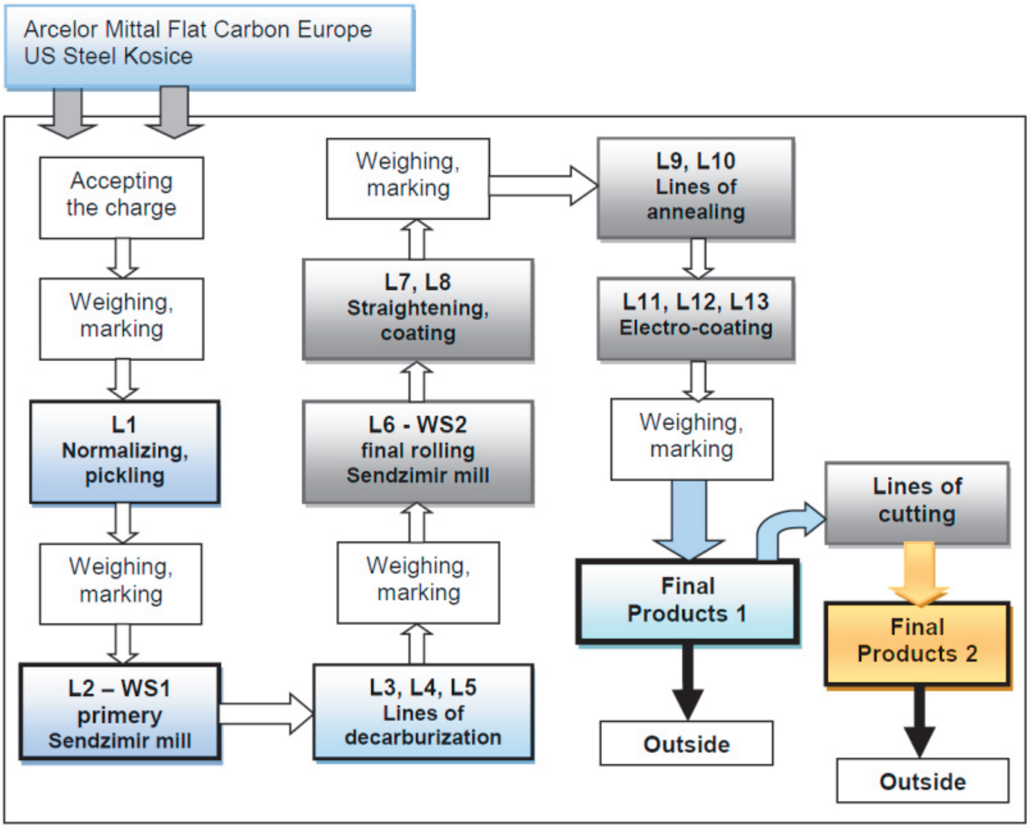

Fig. 1 Scheme of electrical sheets production system SES

For all 13 lines was carried out research performance indicators OEE (Overall Equipment Effectiveness). In the case of the primary rolling mill (Sendzimir mill WS1) to improve the rolling coefficient OEE_{WS1} = 27.53 % would first seek to improve the availability of the index as it has a small value. This is a very bad indicator for immediate improvement. Improving the value of this ratio can be achieved not by eliminating unplanned downtime, but the analysis of the causes of their occurrence and to find the reasons that cause it stops. It was assumed that the indicator should be equal to 75 %. The **Table 1** shows calculation results of the OEE indicator for each production line. In the table indicates results OEE effectiveness index below 55 percent (line L2 - WS1, line L6 - WS2, line L7 - B3, line L11 - C1, line L12 - C2). The results of the calculation of OEE Overall Equipment Effectiveness for L2: Line of primary mill - Sendzimir mill (WS1) shown in **Fig. 2**.

Table 1 Indicator OEE for each production line

No.	Line	Availability	Performance	Quality	OEE [%]
L1	NT	92.95	84.17	97.27	76.11
L2	WS1	63.37	43.44	100.00	27.53
L3	A	96.60	88.62	95.28	81.55
L4	B1	88.99	81.81	95.25	69.35
L5	B2	95.87	83.79	95.28	76.62
L6	WS2	73.32	80.00	100.00	58.98
L7	B3	92.53	59.56	99.00	54.56
L8	B4	92.43	60.34	98.96	55.19
L9	LOI	97.52	88.67	100.00	86.47
L10	IPSEN	97.46	87.78	100.00	85.55
L11	C1	87.60	66.10	92.83	53.75
L12	C2	88.08	71.62	92.85	58.57
L13	C3	78.52	80.98	94.77	60.26
				Average OEE	**64.96**

Overall Equipment Effectiveness for mill WS1: $\boldsymbol{OEE_{WS1}} = A \times P \times Q$ = 63.37 x 43.44 x 100 = **27.53 %** (see **Fig. 2**).

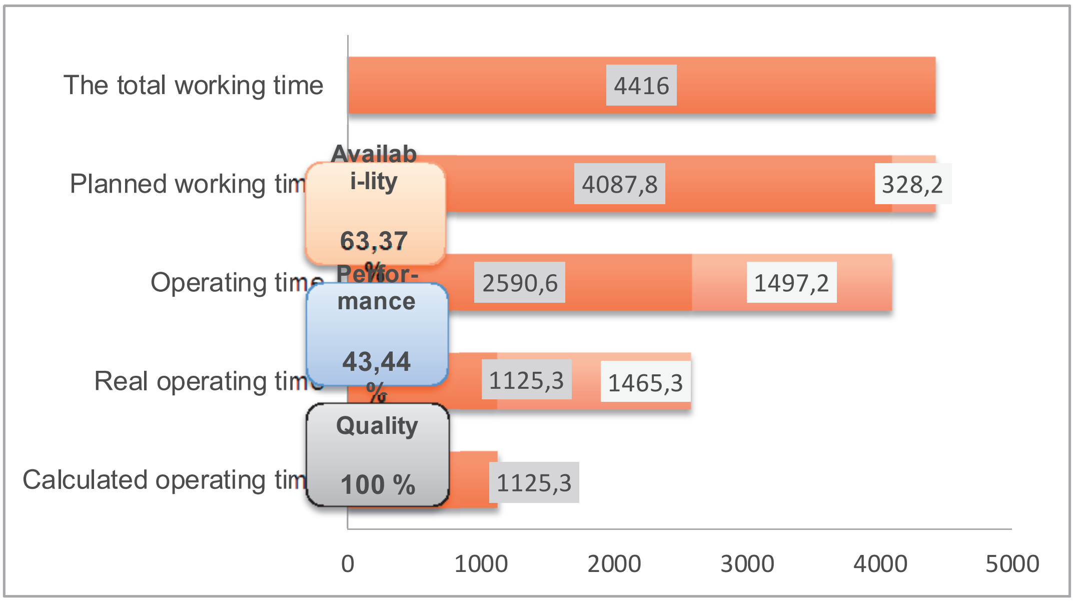

Fig. 2 The results of the OEE calculation WS1

3. LOGISTIC OPERATING CURVES (LOC) FOR WS1 LINE

Logistic Operating Curves (LOC) [5, 6] show the variations of different parameters of production process, like for example Output Range (ROUT) or Throughput Time (TTP), according to value of Work in Process (WIP). An analysis of the process, using this method may be conducted for three reference processes:

- Production and testing
- Transport
- Storage and supplies

For WS1 an analysis was conducted for ROUT and TTP.

Throughput time (*TTP*) is the time between finishing, which occurs before the observed process, until the end of the observed process.

$$TTP = t_{ope} - t_{prope} \tag{3}$$

Where:

t_{ope} - End of current operation
t_{prope} - End of previous operation or

$$TTP = TIO + TOP \tag{4}$$

Where:

TIO - Inter-operation time
TOP - Operation time

Output Rate ($ROUT_m$) is a ratio of the sum of Work Content (WC_m) and the duration of the reference period. It is also connected with utilization (U_m) (which can be understood as performance):

$$U_m = \frac{ROUT_m}{ROUT_{max}} \tag{5}$$

Where:

U_m - Mean utilization
$ROUT_m$ - Mean output rate
$ROUT_{max}$ - Maximum possible output rate

In the **Fig. 3** the ideal and real logistic curve for ROUT (ideal OROC and OROC), and real logistic curve for TTP (TTPOC) are shown as an example of conducting using LOC.

According to OEE, in case of WS1, first actions aiming improving the process should be aimed on increasing the performance (in LOC analysis, the parameter connected with performance is ROUT). An ideal OROC pictures the dependence between ROUT and WIP in a perfect process. When the level of WIP is relatively low, function ROUT (WIP) grows linearly. The coordinates of inflection point represents the maximum level of Output Rate that is possible to reach on the station ($ROUT_{max}$) and the ideal minimum WIP ($WIPI_{min}$) - above this value, the level of ROUT is constant.

In reality, a great number of factors has an influence on a production process, so it cannot be conducted perfectly. The shape of real OROC includes their impact on the process. For low values of WIP, the real curve is similar to the ideal one - it grows linearly. In the second interval, there is significant incompatibility between those two functions. Grey area marked on a diagram is a WIP buffer, which is the value by which the $WIPI_{min}$ must be increased in order to avoid disrupting the continuity of the flow caused by interruptions on the entrance to the process. In the last interval, the real curve is asymptotically closing to the ideal one.

The curve below the OROC is the function of TTP. This parameter acts differently than ROUT. For low WIP it is constant at its minimum value, which is limited by technology and inter-operation times. After passing some border value by WIP, it grows linearly.

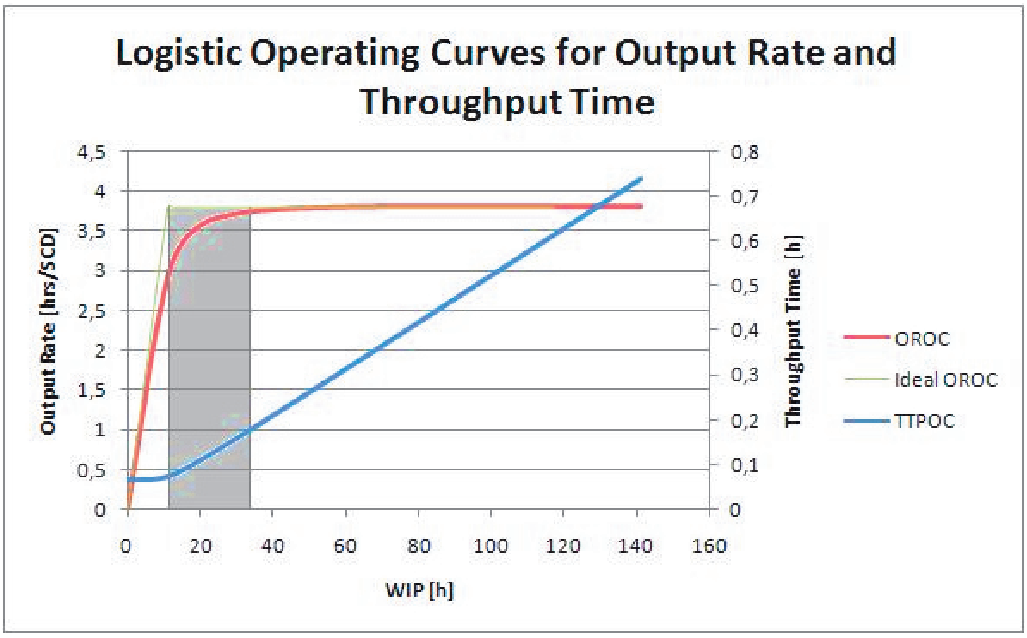

Fig. 3 LOC for output rate and throughput time

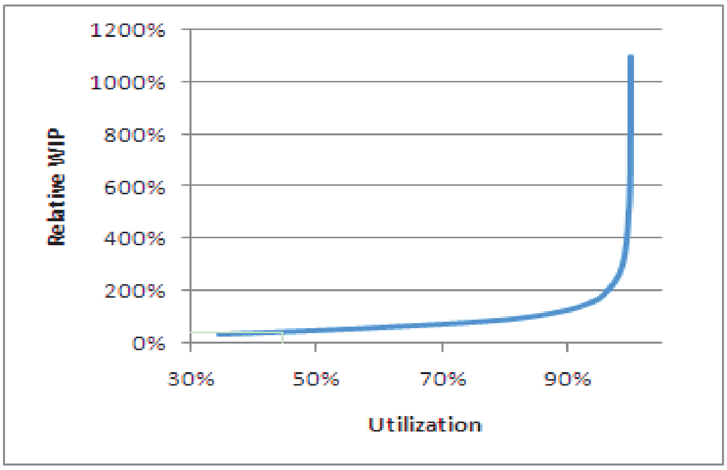

Fig. 4 The dependence between utilization and WIP for WS1

The **Fig. 4** shows the dependence between the utilization (here identified as performance) and a relative WIP *(WIP_{rel} = WIP_m / $WIPI_{min}$)* for WS1. The interpretation of this function allows us to state, that to achieve the utilization on the level of 88%, the relative WIP should be at least around 118 %, and so the WIP_m = 15.10 h. According to OEE, in a primary process, the utilization for WS1 was 43.44 %. That means, that the WIP_m = 5.67 h.

Referring those values to OROC, it can be easily seen, that current WIP value contains in the I interval. If the main goal is to increase the utilization, it may seem right to increase WIP, first to create the proper WIP buffer, and secondly to move its value to the third interval, where its potential changes won't significantly influence the output level. In this case, the fact of influence of those actions on the TTP also have to be considered. Simply increasing WIP will cause increasing the Throughput Time.

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The variance and mean of the work content determine the logistic potential of the shop.

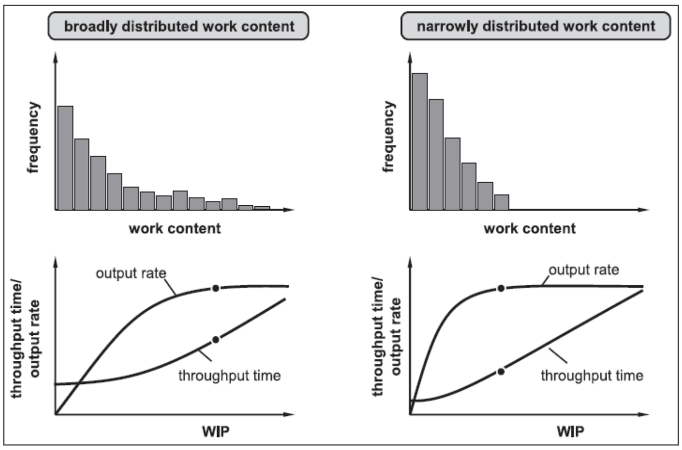

Fig. 5 Fifth Law of Production Logistics [6]

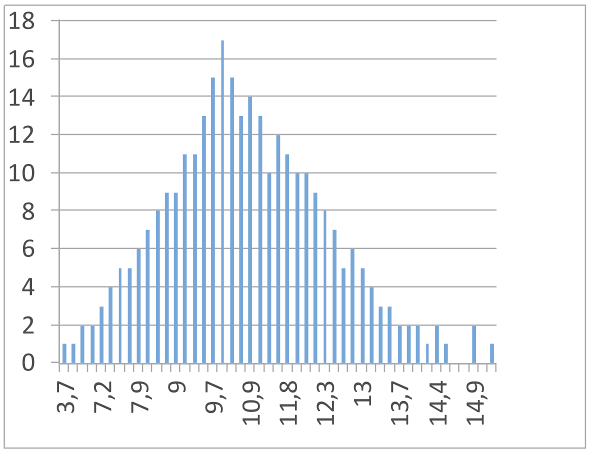

Fig. 6 Distribution of WC for WS1

The **Fig. 6** shows the distribution of Work Content WC:

$$WC = LS \times t_p + t_s \quad (6)$$

Where:

LS - Lot size
t_p - Processing time per piece
t_s - Setup time per lot for WS1 (measurements for 300 lots)

The distribution may be considered as wide. According to 5PLP, homogenizing the Work Content could allow reaching the greater values of $ROUT_m$ without any changes to WIP. Although, in this case, as in the previous one, any actions connected with changing ROUT impacts the TTP.

4. CONCLUSION

For a production process, in every area, number of different aims may be appointed and some of them may be contradictory to one another (i.e. from the productions` standpoint, achieving the minimum throughput times and rarest changes in production schedule is most profitable, while from the economy's standpoint, maximal utilization of equipment is crucial). Representation of measurements connected with mentioned aims, as a function of one parameter - WIP - allows to evaluate the influence of actions taken in purpose to achieve one of assumed goals, on other reference processes, or other parameters of the process.

Calculating the OEE allowed to point the area of for which the need of changes is the biggest. Using LOC as a complementary method of analysis gives the possibility to concretize the direction of planned actions and evaluating their impact on other aspects of the process proceeding, and by that, it allows to determine the sense and the range of implementing assumed changes.

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