SHAPING OEE AND EPEI INDICATORS IN MEDIUM SIZE ROLLING MILL PLANT

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Abstract

In the article there is an analysis of OEE (Overall Equipment Effectiveness) and EPEI (or EPEx - Every Product Every Interval) indicators of medium size rolling mill plant in one of the raw materials steel mills. Analysis of OEE and EPEI covered period of 12 months. OEE indicator, alongside MTBF (Mean Time Between Failure), MTTR (Mean Time To Repair) and MTTF (Mean Time To Failure) is one of the parameters of TPM method (Total Productive Maintenance). OEE is an assessment of the overall efficiency of the production system equipment. OEE consists of three elements: availability rate, performance rate and quality rate. EPEI indicator is used to assess flexibility of production structure. It indicates production frequency of various final products. Optimized value of EPEI indicator helps to meet clients' demands and keep the minimal maintenance of resources at the same time.

Keywords: Medium size rolling mill plant, OEE, EPEx

1. INTRODUCTION

The production of raw steel has varied greatly throughout the last 20 years. During 2005 and 2009 production has decreased drastically. The first decrease is a result of restructuring. The second marks the economic crisis lasting from 2008 to 2009. A smaller demand for steel is also a result of technological progress in engineering materials in the field of ceramics and polymers within the last two decades [1]. Nowadays in order to remain competitive on the market, smeltries must adjust their production to a constantly changing environment [2] t. This change takes place on a global scale (e.g. economic changes within countries) and locally - varying demand for the quantity and variety of final products [3]. Manufacturing a greater variety of final products in small (short) production series - requires the production systems to be flexible and to adapt almost instantly to the quickly changing customer requirements [3, 4]. This article presents the results of analysis concerning the adaptability of a subsystem within a raw steel smeltry. The adaptability has been determined with the EPEI indicator for a period of one full year. With the optimally adjusted EPEI indicator customer demands may be satisfied while simultaneously keeping a minimal supply level [5].

The analyzed facility has a production capacity of circa 5 mln Mg of steel annually. It is comprised of the following production units: Plant Blast; Steel and Half-Products Plant (Steel Plant and COS); Large and Medium Rolling Mill. The Large Rolling Mill produces heavy sections over 200 mm in height, v-sections, double T-bars, channel-bars, also locomotive and tram rails. The Medium Rolling Mill manufactures medium sections such as angle bars, channel-bars and double T-bars not exceeding 200 mm in height. The Medium Rolling Mill has been analyzed in regards to its systems adaptability.

The main goal of this article is to conduct the adaptability analysis of the Medium Rolling Mills` productions structure and determining a minimal EPEI indicator pointing the smallest frequency of changes for the assortment being manufactured. This article contains the necessary data gathered in order to achieve the assumed results. The article also depicts graphs showing the changes in the OEE indicator within the timeframe of one year for the considered facility [6].

2. LEAN MAITENANCE

The Lean Six sigma philosophy means careful planning, organizing and realizing in a ,,modern" industry organization. The Lean philosophy utilizes many tools and techniques [6]. One of them is TPM (Total Productive Maintenance) defined as comprehensive maintenance of production flow [6, 9]. This system focuses on the stability of production processes as well as maximizing effects in regards to availability, efficiency and quality of the manufactured products. The basic indicator for the TPM method is OEE (Overall Equipment Effectiveness), making it possible to locate the areas stopping production [8, 9]. The first stage of analyzing the Medium Rolling Mill was to establish the OEE indicator for each day. **Figure 1** depicts a graph of available time changes (red line) within the span of fifty weeks and comparing it to the effective worktime (green line) in the same time.

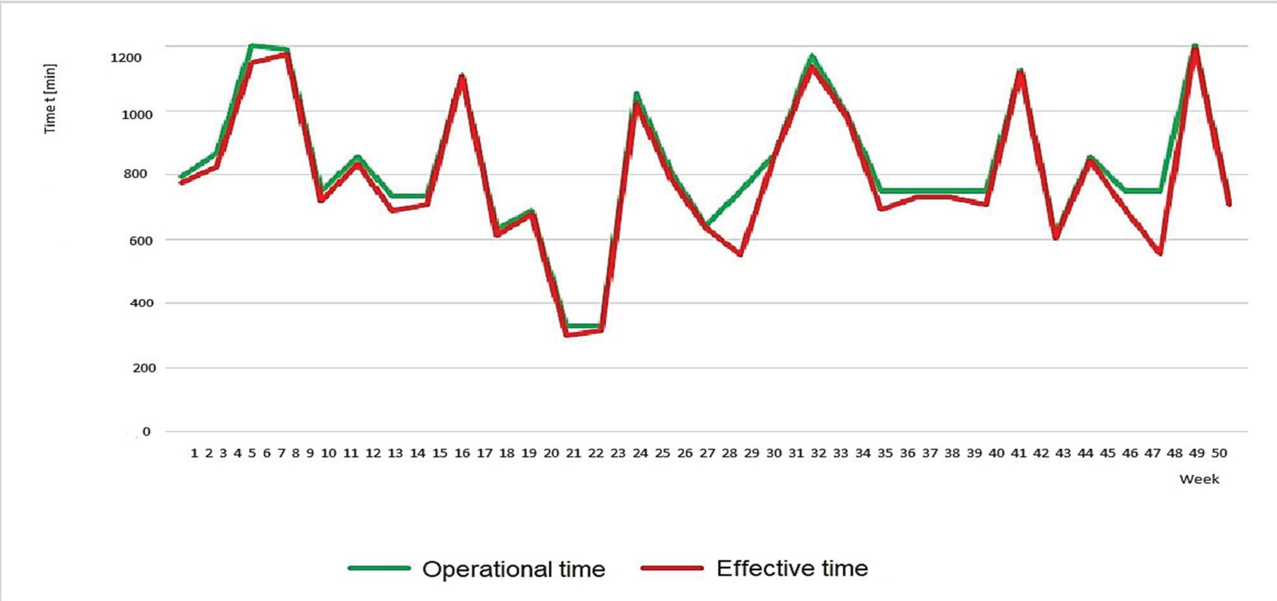

Figure 1 Comparing available time to the effective worktime

Analysis of the diagram shows that the smallest amount of the produced assortment occurs between the 20 and the 23 week. During this time the least diversified number of products was manufactured, furthermore the company experienced the longest standstill of the year due to a malfunction.

2.1. OEE - Overall Equipment Effectiveness

The plant operates 24 h per day in a triple shift system. The employee break time is 20 minutes per shift, plus 10 minutes dedicated to 5S. The remaining 7.5 h is the nominal available worktime. The nominal available worktime is the time the machine may operate during an eight hour shift. This time is calculated by subtracting the time dedicated for employee breaks, planned rearming, filling in reports and clearing up the work station from the gross time. The planned rearming time is established after the production schedule has been approved and synchronized with customer orders. The rearming time is the decisive factor in prioritizing tasks. Remaining standstills are in the unplanned group and directly affect the OEE indicator. Within one year the average unplanned standstill time equaled 6.9 h per month. The average monthly product rotation equaled 44 various assortments.

Table 1 depicts the planned production and the effective production for each separate month. Calculations have been made in developed forms to enable efficient calculation of availability, efficiency and quality indicators.

Table 1 Planned and actual production and average OEE per month

LP	Month	Planned production	Actual production	Loss in production	Variety assortment	Average OEE
		[Mg]	[Mg]	[%]	[art]	[%/m-c]
1	January	34 390	33 710	2	44	86
2	February	33 960	33 505	1.3	42	90
3	March	33 570	32 865	2.1	45	89
4	April	33 070	32 310	2.3	46	82
5	May	35 260	29 990	14.95	29	69
6	June	34 870	34 150	2.1	46	82
7	July	35 370	34 760	1.72	45	86
8	August	33 260	32 860	1.2	44	89
9	September	35 110	34 530	1.65	46	88
10	October	34 380	33 500	2.56	47	83
11	November	33 820	33 320	1.48	45	87
12	December	34 840	32 230	7.5	48	91
13	Sum or average	Sum 411 900	Sum 397 730	Av. 3.405	Av. 44	Av. 85.2

The OEE indicator is a measure of machine utility effectiveness. It is assumed that world-class manufacturers reach an average level of 85 %. For our calculations the average annual OEE indicator equals 82.6 %. This can not be compared to the above mentioned 85 % as it only represents one of the chosen subsystems - The Medium Rolling Mill, as opposed to the entire plant. The OEE level in the discussed example depends on the quality of the material delivered from previous stages (i.e. Steel Plant and COS). **Figure 2** depicts OEE levels for one exemplary month.

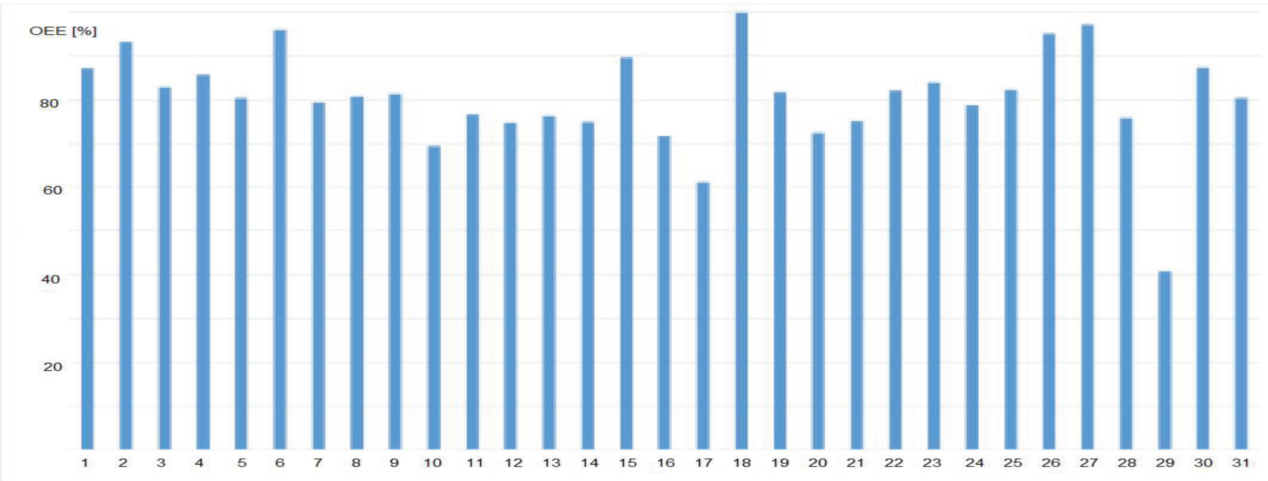

Figure 2 OEE gauge chart for each day for an example of one month

The presented diagram depicts major fluctuations in the OEE indicator in the scope of a month. The cause of this were two malfunctions, quality loss and machine availability decrease. The lowest value was logged on the 29 day of the month. This was due to low-quality slabs batch (400 Mg) - after rolling the material displayed cracks on the surface. Such losses have a negative impact on the entire systems` production process.

2.2. EPEI - Every Product Every Interval

The EPEI indicator describes the flexibility of the process by determining the frequency of product sequences being in demand within a unit of time. The processes` flexibility drops as the EPEI value raises. Flexibility of production systems is extremely important for setups designed to manufacture small bathes in short production series. The EPEI indicator is calculated for each stage of the production process. **Table 2** depicts a developed forhasanm improving calculations for the gathered data.

Table 2 Form of the indicator calculation EPEI

	I	D	D_D	$D^*i + D_D$	AWD/4	[%]	art/C/T	C/T	C/O
		[Mg/t]	[Mg/t]	[Mg/t]	[Mg/t']		[t''/Mg]	[t*/Mg]	[t*/part]
A	**1**	**770**	500	1270	317.5	4	-	-	-
⁞	⁞	⁞	⁞	⁞	⁞	⁞	⁞	⁞	⁞
C	**1**	**1120**	200	1320	330		-	-	-
	Sum	**33 960**	**…**	**33 960**	**8 490**	**100**		Razem	**19120**
			Operating time			O/T		450	[min/shift]
			Daily operating time			O/T_D	3*O/T	1350	[min/d]
			Efficiency			OEE		**0.9**	
			Number of posts			r		**1**	
			Execution time			Pe/T	∑ADD*C/T		[min/d]
			Flexibility			EPEx		0.6	[m/art]

Calculations for the EPEI indicator have been made basing on the below algorithm separately for each month. Formula (1) determines flexibility on the rolling process.

$$EPEI = \frac{\min\left(\sum_{i=1}^{n} C/O_i\right)}{E/T_X - \sum_{j=1}^{k} ADD} \tag{1}$$

where: $\min\left(\sum_{i=1}^{n} C/O_i\right)$ - is the minimum rearming time sum value obtained by the optimal sequence of planning product processing order while simultaneously assuring full rotation of products; E/T_X - the effective available time within a defined (discussed) unit e.g.: day E/T_D, week E/T_W, month E/T_M, etc., which has been defined according to formula (2); $\sum_{j=1}^{k} ADD$ - the accumulated machine workload time determined by current demand and technological takt times corresponding to each product - this value is calculated according to formula (3); i the number of necessary rearmings considering a full rotation of products - *i* = *1, 2, 3, …,n*; j - the number of various assortments being in demand in the discussed time unit - *j* = *1, 2, 3, …,k*.

$$E/T_X = T_{Net} \cdot OEE = \left(T_{Gross} - PD\right) \cdot OEE \tag{2}$$

where: OEE - Overal Equipment Efficiency; T_{Net} - nominal available worktime; T_{Gross} - nominal available standard hours, which is the total availability of the equipment (e.g.: 8 hours per shift); PD - planned downtime.

$$\sum_{j=1}^{k} ADD = \sum_{j=1}^{k} \left(C/T_j \cdot L_j \right) \tag{3}$$

where: C/T_j - standardized takt time *j* - of this product; L_j - demand for *j* - product in the discussed unit of time.

After applying formulas: (2), (3) and (OEE) formula (1) assumes the following form:

$$EPEI = \frac{\min\left(\sum_{i=1}^{n} C/O_i \right)}{\left(T_{Gross} - PD\right) \cdot OEE - \sum_{j=1}^{k} \left(C/T_j \cdot L_j \right)} \tag{4}$$

Table 3 presents EPEI indicator values for the cold rolling mill within the span of one year.

Table 3 Value Every Product Every Interval indicator

		January	February	March	April	May	June	July	August	September	October	November	December	Average for a year
1	Planned number of differentiated assortment	47	43	44	47	41	47	46	45	48	48	46	49	46
2	Indicator value EPEI [type of ass. asort./day]	1.1	0.6	1.33	0.9	-0.74	1.2	1.1 5	1.1	0.9	1.3	1.4	1.7	~1

If the EPEI indicator assumes negative value, then under current conditions it is not possible to realize the task schedule without additional resources (usually overtime is required). Our analysis takes under consideration a triple-shift worktime structure, therefore the planned task schedule for May has not been accomplished. The average annual EPEI value equals 0.995 with a minimal border -0.74 and maximum of 1.7. The varying flexibility of the process is proof of changing demand for assortment. Therefore for future calculations the instability in the form of standard deviation has been taken into account according to the following formula:

$$\delta_{EPEI} = \sqrt{\frac{\sum_{l=1}^{m} \left(EPEI_l - \overline{EPEI} \right)^2}{n}} \tag{5}$$

The EPEI standard deviation equals $\delta_{EPEI} \approx 0.59$. In order to determine the change dynamic of the EPEI indicator, future calculations should determine the probability of the random variable will differ from the average $\overline{EPEI}$ value by at least three standard deviations and the result be compared to the three sigma principle (±3σ) [10].

3. CONCLUSION

The analysis developed for the purposes of this article regard the Medium Rolling Mill, one of the subsystems of raw steel plant. The presented analyses allow to point out the factors contributing to efficiency, availability and product quality loss. Minimizing these will substantially improve production continuity and make the system more adaptable to dynamically changing orders. The current customer expects a differentiated product, ie available in different versions and variants. To meet these expectations, manufacturers are forced to produce products in small batches and at a low inventory level. However, such production is characterized by lower stability than mass production. The volatility and instability of the manufacturing process also introduces a component of uncertainty and risk decisions. The heavy industry deals in ,,bulk" orders placed by corporations a long term in advance. A significant rise in production assortment variety has been noted in recent years. Due to the complexity of the production process in the plant large amounts of supplies may not be stored. A large variety of final product assortment in the metallurgical sector requires an adaptable process. The adaptability of the production process is equal to that of the workstation operating in the manufacturing process, as the time between sequences increases along with the EPEI, thus lessening adaptability. Manufacturing variable final products in small (short) production series - requires high adaptability from production systems and near-instant reaction to dynamically changing customer demands. Assuring sufficient adaptability to the stream is a critical condition if orders are to be executed on time. The production limitations do not constrain the company, but systemize its actions on all order execution stages. Each system is in a certain state, and because production systems are of dynamic character, a continuous transformation, which causes transition from one state to another.

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