PLANT PERFORMANCE CALCULATION IN AUTOMOTIVE INDUSTRY USING ANDON SYSTEM

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Abstract   This article describes the way of exploiting an andon system to measure key performance indicators (KPIs) of manufacturing plant from the automotive industry. The performance measurement is conducted using four factors in two levels of performance aggregation. The first level constitutes the set of performance factors calculated for separated areas such as overall equipment effectiveness (OEE) to measure operational effectiveness and total effective equipment performance (TEEP) for analysis of capacity utilization. In the second level some global fators are proposed such as overall plant effectiveness (OPE) and total effective plant performance (TEPP) for global investigation of plant performance. Although OEE is well-known factor indicating different types of production losses it doesn't allow to look globally on the performance of whole production system. Therefore, a method of calculating global performance for whole plant in the form of OPE and TEPP is presented. These factors are investigated based on previous calculated OEE factors for smaller manufacturing areas. An andon system is used as information tool to monitor production losses needed to calculate mentioned KPIs factors.

Paper type: Research Paper

1. INTRODUCTION

Nowadays, many manufacturers seek possibilities to reduce production costs by means of Lean Production tools used to improve productivity. It implies using specified tools such as TPM, SMED, ZQC, etc. However, good diagnostics of what tool can be used depends on clarify information about the process execution obtained directly from the shopfloor. Gathering sophisticated production data and transformation them into appropriate information is a difficult task. Some external systems able to cooperate with operators, PLCs or even ERP software and calculate key performance factors have to be installed. Among many solutions, two kinds of systems seem to be relatively good to fulfil these requirements. It can be either manufacturing execution system (MES) employing mainly in process industries or andon system as a typical lean manufacturing tool broadly used in automotive industry.

 The latter system is more relevant for monitoring of production inside automotive plant. In this paper the main work is focused on the one of polish manufacturing plant which produces components of car power transmission. The name of this plant is withheld with respect of confidentiality policy. However, they decided to implement andon system as a tool which allows to provide valuable data about production losses in each separated manufacturing area and calculate key performance indicators (KPI's) from these areas. As a result, some conclusions about the efficiency and effectiveness of manufacturing plant are planned to be listed. Our work is involved of how to measure manufacturing system performance in terms of local (each separated production area) and global (whole manufacturing plant) point of view.

Typical installation of andon system is prepared for one selected production area. Andon system provides information about effectiveness in the form of OEE for selected production area. Every losses in operational time of production can be distinguished but these have limited range of influence on the performance measurement of manufacturing plant. Valuable information about performance of whole manufacturing plant requires complex installation for all areas as well as the methodology of how local performance obtained for each smaller production area can be translated into global performance of whole manufacturing plant. Thus, a methodology suited to the typical representative of manufacturing plant in automotive industry is worked out in this paper.

This paper is structured as follows. First, the literature review of performance measurement in manufacturing plants is provided. The description of OEE implementation based on production losses analysis is highlighted. Then, the implementation of andon system is described and the basic calculation of OEE using andon for selected manufacturing area is presented. Further, a methodology to develop global factors such as OPE and TEPP is carried out. Finally, results are showed and discussion is conducted to bring conclusions of the paper.

2. PERFORMANCE MEASUREMENT FOR AUTOMOTIVE INDUSTRY USING ANDON SYSTEM

2.1. Key performance indicators (KPI's): an overview

In this chapter, our focus is concerned on these group of performance indicators which follow by the idea of measurement of total production losses. It is a group of factors which indicate the effectiveness of exploited equipment in manufacturing environment. Basic factor in this field is OEE developed by Nakajima, 1988. OEE as a concept of TPM assumes achieving zero defects and zero breakdowns of equipment over specified period of time when equipment is planned to produce components. This period of time is consider as planned loading time and is depicted on Fig. 1 as a part of total production time (without both commercial and planned shutdown losses).
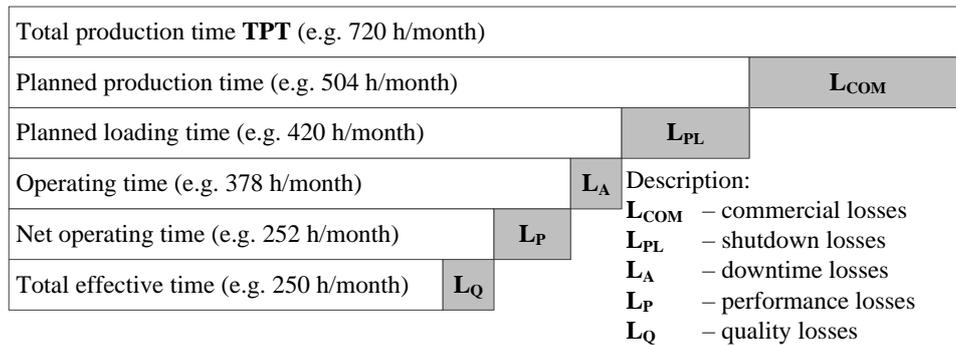
Total production time **TPT** (e.g. 720 h/month)		
Planned production time (e.g. 504 h/month)		L_{COM}
Planned loading time (e.g. 420 h/month)	L_{PL}	
Operating time (e.g. 378 h/month)	L_A	
Net operating time (e.g. 252 h/month)	L_P	
Total effective time (e.g. 250 h/month)	L_Q	

Description:
L_{COM} – commercial losses
L_{PL} – shutdown losses
L_A – downtime losses
L_P – performance losses
L_Q – quality losses

Fig. 1 A scheme of total production time

Planned loading time is the foundation for defining six big losses which can be categorizes into three-levels indicators, namely availability, performance and quality rates (Muchiri & Pintelon, 2008). According to TPM, availability indicates the level of equipment downtimes when it is planned to produce components. Every long-time losses including influences of manufacturing environment can be assign as downtime loss. These can be breakdowns, adjustments or even changeovers as well as downtimes affected by operator, recipe, facilities or material unavailability (SEMI, 2001). It means, that additional type of losses such as no materials, no operators or no energy can be translated into downtime losses though they are not directly involved with equipment. In turn, performance indicates how fast equipment is able to produce components. It means that any exception to the nominal speed of production without previous identified downtimes is a performance loss. Performance loss can be divided into speed loss by reduced speed of equipment as well as small stops regarding idle time or minor stoppage throughout pro-

cess execution. It is required to establish the time thresholds between speed loss, small stop and breakdown, individually for each manufacturing plant. Quality indicates the ratio of production good components in comparison with total components which are produced by equipment. Based on these three indicators OEE factor can be calculated as follows:

$$OEE = A \cdot P \cdot Q \tag{1}$$

OEE factor can be achieved by multiplying availability A, performance P and quality Q, respectively. Availability is calculated as a ratio of operating time to planned loading time. Performance is calculated as a ratio of net operating time to operating time. Quality, in turn, is calculated as a ratio of total effective time to net operating time.

For these calculation many procedures have been proposed in literature including Singh, Shah, Gohil & Shah, 2013, who developed their own software and hardware for basic OEE calculation, Ahire & Relkar, 2012, who worked out the methodology of correlating FMEA and OEE in process industry, Sohal, Olhager, O'Neill, & Prajogo, 2010, who provide cross-case analysis between several companies in order to find some similarities and proposed the framework of preparing reports based on OEE factor and finally Wang & Pan, 2011, who improved OEE and rates per hour (RPH) calculation by developing IT integrated system for automated data collection on bottleneck equiment.

Based on the basic OEE calculation prepared for TPM activity every manufacturing plant modifies the way of calculating OEE in order to identify individual problems and underlie improvements needed to increase their own productivity. However, with time, OEE calculation has become confused, since the extent of downtime reasons that have impact on OEE is individually selected by manufacturers. As stated by de Ron & Rooda, 2005, some capacity utilization losses such as no jobs, the absence of operators or even weekend breaks have become the part of OEE. This shortcoming resulted in enhancement of performance calculation. Therefore, new factors have been developed by researchers. Good example is TEEP factor introduced by Ivancic, 1998 which additionally includes aforementioned capacity utilization in the KPI calculation and OPE factor sometimes called OFE (Overall Fab Effectiveness) developed by Oechsner, Pfeffer, Pfitzner, Binder, Müller &Vonderstrass, 2003, to measure the performance of whole manufacturing plant.

The most dubious is the way of data acquisition and identification of possible time losses based on specific translations of equipment states without regarding real deviation of nominal process execution (de Ron & Rooda, 2006). As an alternative, some andon systems have been proposed to both collecting data of process performance and measuring productivity and effectiveness of equipment in manufacturing environment. In the next section, the utilization of andon system to calculate performance factors for automotive industry as a specific type of performance measurement is highlighted.

2.2. A framework of KPI's measurement using andon system

The key issue of performance measurement in automotive industry is to how production data can be gathered from manufacturing areas and transformed into performance factors such as OEE, TEEP or OPE. There is a need to find the simplest way of data entrance from the manufacturing area without taking much time of operators to record reports about shift or job execution as well as the actual state of this area. One of the possible solutions is to install so-called bolt-on firmware andon unit (one unit for each manufacturing area) which is able to collect data about cycle times for any piece produced based on the signals from sensors installed on the bottleneck machine inside manufacturing area. The scheme of such installation is depicted on the Fig. 2.
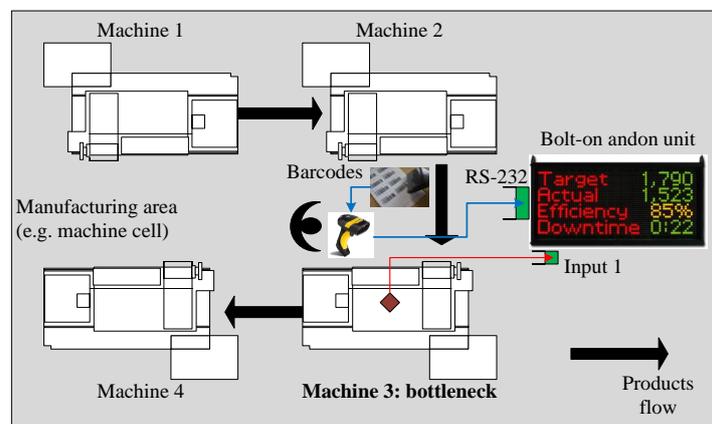

Fig. 2 A scheme of bolt-on andon installation in manufacturing area

Applied andon unit is an commercial product exploited as both a data collector for manufacturing area and a display panel for communication with operators. An operator as on Fig. 2 (who works inside manufacturing area) communicates with andon unit by barcode system using barcode scanner. The barcode system is used to inform andon unit about new jobs, starts and ends of changeovers, shift breaks, identification of shifts or even for downtime and scrap reasoning. On the other hand, andon unit is able to identify the downtime or runtime states based on the electrical signal representing actual cycle time of produced piece on bottleneck machine in comparison to ideal cycle time of product. Reports automatically generated for bottleneck machine are representative of whole manufacturing area, since every loss on bottleneck is treated as a loss for the whole area provided that products flow through all machines in the same way and no buffers occur inside the manufacturing area (Hadaś & Karaskiewicz, 2014). These conditions allow to calculate OEE factor directly by andon unit. However, the role of andon unit confines to OEE calculation based on the equation (1) to measure OEE for shift or job execution.

OEE factor indicates the effectiveness of manufacturing area under TPM assumption that manufacturing area is efficiently utilized when it is supposed to produce components. However, some additional losses can occur in automotive industry which seems to be hidden throughout total production time when manufacturing area is available to produce pieces. Looking towards global purpose of the manufacturing plant, machines should be utilized all times since they are expensive. Such suggestion induces managers to investigate real capacity utilization and eventually total effective equipment performance (TEEP) of invested manufacturing areas. For TEEP calculation, instead of traditional losses considered in OEE factor, some common losses for all plant or selected areas have to be included. These are shutdown losses which inform that no operators are available bacause of i.e. leave or the holidays and any commercial stops because of lack of orders. TEEP calculation follows by the equation:

$$TEEP = U \cdot \frac{G}{C_P}$$
(2)

Having andon unit to facilitate the calculation of TEEP factor on bottleneck machine, there is a need to monitor pieces that are qualified as good items ready for sales G (typically, this value represents demand over period of time), and the planned theoretical quantity of pieces that can be produced over planned loading time of bottleneck C_P. The period of time depends on the manager requirements. Typically, TEEP is calculated for one week. The last factor needed is capacity utilization U, which is calculated by dividing planed loading time by total production time (the planned loading time can be achieved by subtracting every commercial or shutdown losses from total production time, for better figure explanation see Fig. 1). For automotive industry, TEEP factor cannot be calculated by multiplying capacity utilization U and OEE factor, since traditionally production in automotive industry is planned to obtain daily demand.

The next enhancement of performance calculation includes whole manufacturing plant. Good analysis of plant performance requires calculation of KPIs which comprise profitability analysis apart from system effectiveness analysis, since manufacturing areas in automotive industry are not isolated but are combined by activities and material flow relationships between equipment and processes. Thus, firstly for traditionall overall plant effectiveness (OPE) the equation can be formed as follows:

$$OPE = \sum_{i=1}^{n} u_i \cdot OEE_i$$
(3)

Trivially, it is required to calculate OPE as an weighted average value of OEE for each manufacturing area i under restricted assumption that each manufacturing area produces components in separated way. Weight u_i represents the profitability

per each component and simultaneously the profitability of each manufacturing area. Weight u_i can be achieved using equations as follows:

$$u_i = \frac{d_i \cdot NP_i}{\sum_{i=1}^{n} d_i \cdot NP_i} \tag{4}$$

In the above equation the weight u_i for component is calculated based on the demand per component d_i and net profit per one piece of component NP_i. These two parameters are related to profitability of whole manufacturing plant. In the same way total effective plant performance (TEPP) is proposed to show global performance of manufacturing plant as follows:

$$TEPP = \sum_{i=1}^{n} u_i \cdot TEEP_i \tag{5}$$

The weight u_i is calculated for TEPP in the same manner as in OPE calculation.

2.3. Practical example and results

In the following chapter an example of KPIs calculation for one of automotive manufacturing plant is quoted. This manufacturing plant is organized in the form of '*factory within factory*', thus one of the so-called mini-factories is chosen to further analysis. This mini-factory is depicted on the Fig. 3.
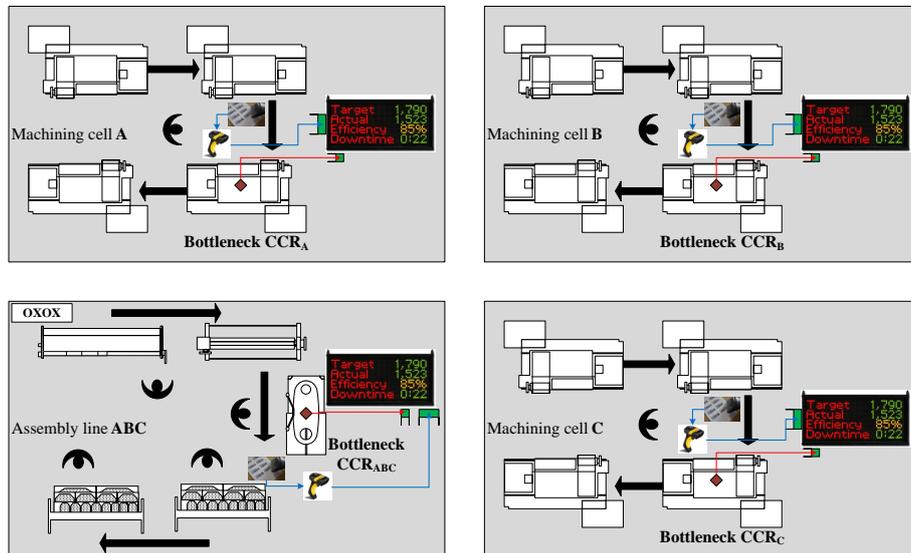

Fig. 3 Practical example: the scheme of mini factory for KPIs calculation

The mini factory consists of four dependent manufacturing cells. Three of them fabricate different parts named A, B and C in machining cell A, machining cell B and machining cell C, respectively. Parts from mentioned machining cells are then used in assembly cell ABC which shares assembly process between parts A, B and C. Some parameters about demand, nominal speed and time losses arisen in manufacturing cells and corresponding performance parameters in the form of OEE and TEEP are collected (Table 1). Data about time losses are reliable since are gathered from bottleneck by andon system in each manufacturing area. Ideal cycle time of process execution on bottleneck machine is known and the demand per each component produced is also given. In this example, KPIs calculation is respected for one week.

Table 1 Parameters and individual KPIs for mini factory

Parameters	Machining cell A	Machining cell B	Machining cell C	Assembly cell ABC
Ideal cycle time on bottleneck machine in seconds per piece	120	180	240	45
Demand in pieces per week	3900	2700	1800	8400
Ideal working time consumption in hours	130	135	120	105
Total production time in hours per week	168	168	168	168
Shutdown losses in hours per week	24	24	40	48
Capability in pieces per week	4320	2880	1920	9600
Downtime losses in hours per week	4	3	2	3
Performance losses in hours per week	5	4	3	7
Quality losses in hours per week	3	1	2	1
Utilization	85.71%	85.71%	76.19%	71.43%
Availability	97.22%	97.92%	98.44%	97.50%
Performance	96.43%	97.16%	97.62%	94.02%
Quality	97.78%	99.27%	98.37%	99.09%
OEE	91.67%	94.44%	94.53%	90.83%
TEEP	77.38%	80.36%	71.43%	62.50%

Since components from three machining cells flow to the same assembly cell ABC, the equations (3) and (5) cannot be directly applied. It is required to calculate aggregated performance factors in two stages. At first, OEE_{MA} and $TEEP_{MA}$ factors for machining area should be calculated based on equations (3-5). Afterwards, plant performance factors such as OPE and TEPP can be calculated as follows:

$$KPI = \frac{KPI_{MA} + KPI_{AS}}{2} \qquad (6)$$

Equation (6) is typical KPI's value of arithmetic mean between machining *MA* and assembly *AS* areas. Table 2 depicts component parameters as well as the results of plant performance factors in the form of OPE and TEPP.

Table 2   Parameters and plant KPIs for mini factory

Parameters	Component A	Component B	Component C
Net profit in zloty per piece	25	24	28
Net profit by component in zloty per week	97500	64800	50400
Component weight	45.84%	30.47%	23.70%
OPE			88.85%
TEPP			60.85%

3. CONCLUSION

Valuable measurement of performance indicators requires relevant and reliable tool able to provide gathering production data directly from manufacturing area. Good example is andon system which has been also exploited to calculate OEE for manufacturing area based on production losses happened throughout process execution. Moreover, it can be successfully applied in automotive industry as a specific case of manufacturing components. However, for more profound analysis of operational losses in the form of KPIs, some evolution of OEE calculation should be individually provided for every manufacturing plant.

In this paper, a new way in calculating performance factors for automotive industry, based on gathering data by andon system is described. Two-level analysis for measuring performance of separated manufacturing areas (from one place in manufacturing area which is a bottleneck) as well as for whole manufacturing plant is proposed. In the first level such factors as OEE and TEEP are calculated which represent operational effectiveness of manufacturing area for its productivity in the sense of TPM action and capacity utilization, respectively. The second level new factors such as OPE and TEPP are described for operational benefit of manufa-cturing plant based on both performance analysis of all manufacturing areas and net profit of produced components.

It can be concluded that performance measurement has evolved to include other production losses investigated to determine a total plant effectiveness in automotive industry. The practical framework of KPIs measurement combined with andon system has been carried out in this paper. It is powerful tool able to provide valuable information for management. It enables managers to make decisions about implementation of appriopriate lean tools to consequently improve productivity.

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BIOGRAPHICAL NOTES

Paweł Wojakowski is an Assistant Professor at Cracow Univeristy of Technology. He teaches subjects involved production management such as "Design of Manufacturing Systems" and "Lean Manufacturing". His research interests are focused on lean production systems, scheduling under uncertainty and inventory control problems. He is a member of The Polish Association for Production Management as well as a member of DAAAM Association. His work is directly affected real-world problems in cooperation with many polish manufacturing plants such as Grupa Kęty, Silgan White Cap Poland, TQMsoft from 2009.