THE EFFICIENCY OF PRODUCTION EQUIPMENT IMPROVEMENT – A CASE STUDY

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Abstract The inherent aspect of assessing the effectiveness of improvement activities in enterprises is building a system for measuring performance, hence using a variety of measures and indicators. These measures are used to evaluate key activities carried out in various functional areas of the company and indicate their effectiveness in relation to the objectives of the organization. One of the measures most widely used in enterprises assessment of the efficiency of the maintenance, production and logistics is the efficiency of production equipment - OEE. The literature on OEE indicates the spectrum of its applications. It is used both as a operational efficiency measurement as well as a guide for managers for building internal cooperation between maintenance, production and logistics as well as initiating actions to increase the effective use of management at the disposal of production equipment. The purpose of this article is to show the possibilities of improving efficiency of production equipment working in the painting facility. Article consists of five chapters. The second chapter on the basis of the literature points indicators of efficiency used in enterprises concerning its equipment. The third chapter describes the production line, the analysis of OEE and defines the main problems. Section four – improvement actions and assessment of their impact on the value of the OEE. The fifth chapter is a summary and conclusions.

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1. OVERALL EQUIPMENT EFFECTIVENESS – BACKGROUND

Companies have different ways of measuring their manufacturing performance in order to achieve and maintain a competitive edge in the market. Overall equipment effectiveness (OEE) was proposed by Nakajima (1988) as an approach to evaluate the progress achieved through the improvement initiatives carried out as part of his proposed total productive maintenance (TPM) philosophy. OEE is the key measure of both total productive maintenance (TPM) and lean maintenance. OEE is measured in terms of six big losses, which are essentially a function of the availability, performance rate and quality rate of the machine (Fig. 1).

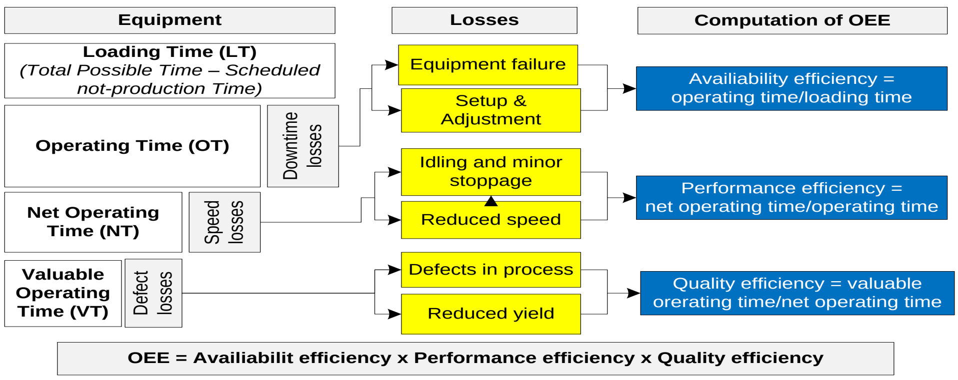

Fig. 1 Computation of OEE (for individual equipment) (Nakajima, 1988)

Though the OEE tool has become increasingly popular, it is only limited to measure productivity behaviour of individual equipment (Huang et al, 2003). This weakness of the OEE tool has led to its modification to fit different and broader perspectives in the manufacturing systems. Therefore, different modified formulations have emerged in the literature (Jasiulewicz-Kaczmarek, 2011).

De Ron and Rooda (2005) noticed that OEE includes losses, like for example blocking, which is a consequence of malfunctioning of an entire system and cannot be referred to any isolated machine. That is why, to get real equipment metric, authors suggested that All losses within production system, that do not depend on equipment itself should be excluded from OEE. Badiger and Gandhinathan (2008) modified OEE assessment methodology taking another factor into consideration –

utility. Inclusion of this factor leads to more detailed categorisation of equipment losses as equipment and process related, leading to specific identification of equipment losses in terms of availability and usability. Wang and Pan (2011) propose the simultaneous use of OEE and unit-per-hour machine rates to obtain complete data for the analysis of equipment processing rates. Nachiappan and Anantharaman (2006) proposed the overall line effectiveness (OLE) as an alternative metric to evaluate the efficiency of a continuous product flow manufacturing system. Unfortunately, OLE provides goods results only if applied to a continuous production line. To solve this problem, Braglia et al. (2009) proposed new parameter for pointing complete effectiveness of production line machines (overall equipment effectiveness of a manufacturing line (OEEML). The next solution was suggested by Muthiah et. al. (2008). They introduced the term of overall factory effectiveness (OFE), which is about combining activities and relationships between different machines and processes, and integrating information, decisions, and actions across many independent systems and subsystems.

Bamber et al. (2003) observe that OEE is often used as a driver for improving the performance of a business by concentrating on quality, productivity and machine utilisation issues and, hence, is aimed at reducing non-valued adding activities often inherent in manufacturing processes. The potential benefits (Badiger & Gandhinathan, 2006) of using OEE are unlimited. Plant and operations managers use OEE to measure performance at the machine, line and plant levels.

2. THE OBJECT FOR RESEARCH AND RESEARCH PROBLEM CHARACTERISTICS

The company is performing production of cabinet furniture, flat-packed made of glued boards where the components of the finished product are packaged in cardboard boxes with cardboard fillings, hardware, release paper, installation instructions, then stacked on pallets of cardboard, fastened together by tape and wrapped with foil. For each production line efficiency is assessed. The general model of OEE used in the enterprise is shown in Figure 2.

The availability metric was used to measure the total lost time when each of the machine were not operating because of breakdown, set-up adjustment and other stoppages. It indicated the ratio of actual operating time to the planned time available. Lost availability is measured in units of time. Performance efficiency was calculated as a function of both operating speed rate and net operating rate. The operating speed rate of equipment referred to the discrepancy between the ideal (theoretical) speed and its actual operating speed. The net operating rate measured the maintenance of a given operating speed over a period of time. This calculated the losses resulting from minor recorded stoppages, as well those that went unrecorded on daily shift logs. The quality rate calculation identifies quality losses, i.e. the number of items rejected due to quality defects occurring during processing. The Quality factor is the percentage of units which is produced and lies within the quality specifications. Lost quality is measured in units of product output.

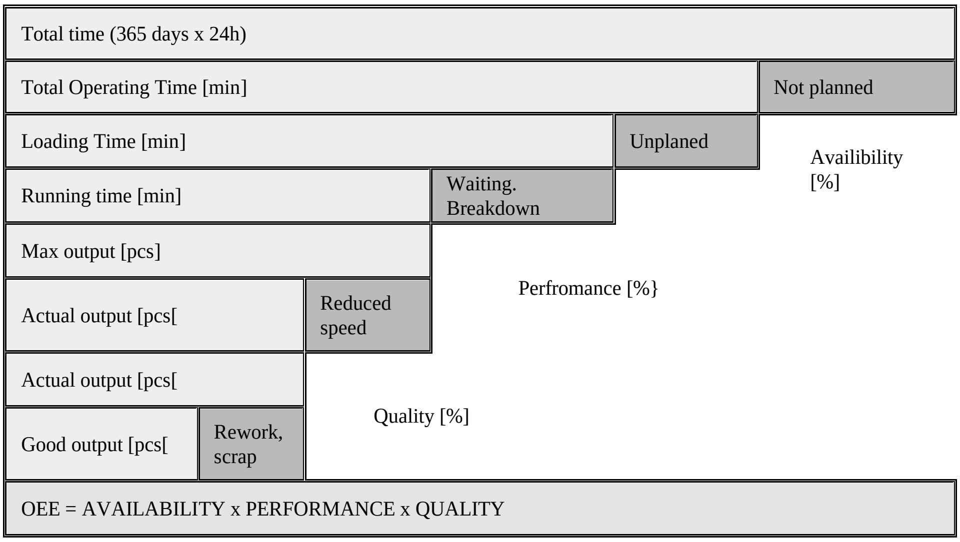

Fig. 2 The OEE elements connected with the losses

Simplified diagram of the manufacturing process of cabinet furniture production taking into account the value of the OEE is shown in Figure 3.

The presented diagram (Fig. 3) shows that the lowest value of OEE occurs in the area M1 (sanding), and under the M4 (lacquering line). The analysis covers the area of the M4. From the point of view of both the client (end customer) and organisation, the line M4 is a critical line. The efficiency of this line, on one hand, contributes to the quality of manufactured products (customer satisfaction), on the other hand, while it is not substitutable line, all failures results in downtime and generates losses for the company (Szwedzka, Lubiński & Jasiulewicz-Kaczmarek, 2014). The machine applies thin layer of lacquer by roller, and then cures the applied coating by UV lamp or UV light emitting diode (Fig. 4).

Coating materials are water-borne and in the presence of a suitable photo initiator and photochemical actions UV light energy at room temperature are becoming flexible chemically resistant paint coating of high hardness.

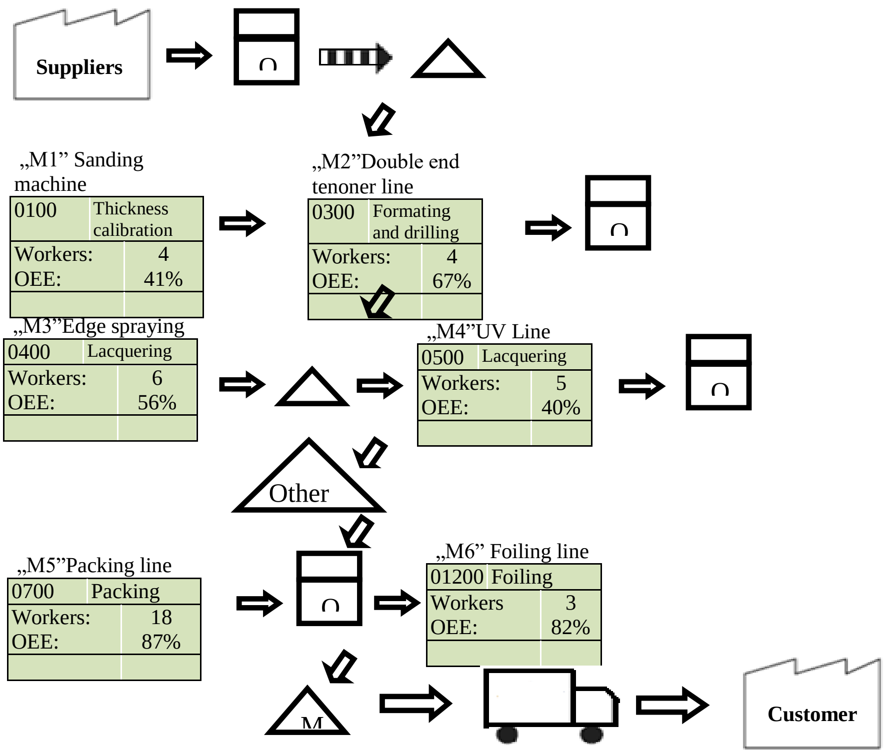

Fig. 3 Simplified diagram of the manufacturing process of cabinet furniture

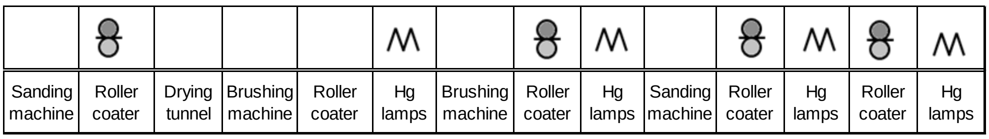

Fig. 4 Scheme of lacquering line

Analysing the value of the OEE line M4 concluded that the main cause of loss of its effectiveness are failures and associated downtime as well as repairs and waste material (manufactured defective items is approximately 13% of the total waste after staining surfaces for UV lines). The main reason of low OEE factor for the line was availability due to roller coater breakdowns, while the second reason was focused on the quality of manufactured parts. In order to efficiency improvement of the M4's line, all historical data and the number failures and for equipment included in the line were collected. Analysis of the M4 lacquering line work was carried out for a period of six months, a total of 250,000 minutes of theoretical working time zones in the system 4-brigade and were be analyzed as the first. Based on collected data the percentage of the failure of individual machines and equipment installed in the line M4 in relation to the total line failure was calculated (Table 1).

Table 1 Percentage share of machinery and equipment failure of lacquering line M4

Month	1 sanding machine	2 roller coater	3 drying tunnel	4 UV lamps	5 transporter and feeder	6 brushing machine	undefined
1	10,66%	23,21%	0,00%	6,93%	59,21%	0,00%	8,92%
2	28,59%	41,54%	0,00%	13,51%	16,36%	0,00%	7,46%
3	36,98%	29,98%	3,30%	13,95%	15,80%	0,00%	22,08%
4	24,70%	34,33%	0,00%	34,56%	6,42%	0,00%	0,00%
5	19,33%	38,19%	0,00%	25,71%	16,76%	0,00%	16,38%
6	13,95%	25,70%	1,22%	25,60%	33,53%	0,00%	2,74%

Follow-up results (Table 1) indicate that the most common cause of downtime is a failure of roller coaters (machine "2"). Roller coaters used for furniture treatment are simple mechanical devices which operate over the transporter and placed the application roller over it. They are armed with a pump to spread lacquer on a roller. Simplified model of single roller coater presents figure.5. Susceptibility to damage is low on parts that are fixed on machine, but the cylinder makes any damage associated with time-consuming operation of exchange and adjustments.

All components made from time of damage until it is detected needs to be treated again. The situation is complicated by the fact that all the elements are given and received with a line automatically or semi-automatically, so do not pass through the hands of workers. "Stamp" damage or damaged trace on the surface of the roller is difficult to observe the line speed from 25 to 40 meters per minute.

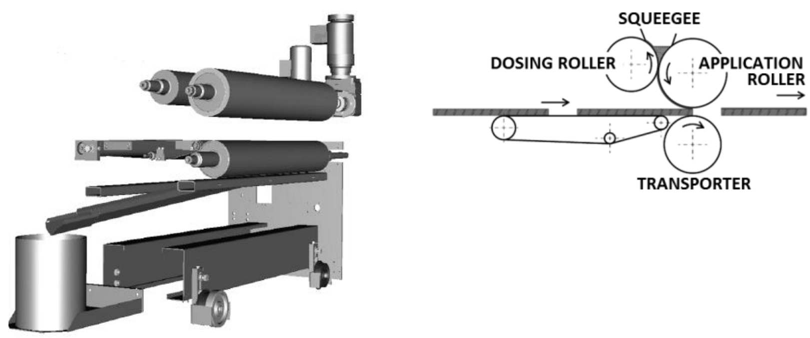

Fig. 5 Roller applicators scheme and way of the lacquer application process

YBY rollers, due to its porosity are key element in the coatings of elements and their quality influences not only the final parameters of the product (color and surface resistance), but also influence the cost of the process (the amount of material used). Rubber rollers having a hardness expressed in degrees Shore (°Sh'a), influencing the resistance of the surface of the element which is defined by norm as well as on the cost of the process. The most common causes of rollers damage are characterized in Tab. 2.

Table 2 The most common defects of treated surfaces due to rollers damage

Causes of appearance	Kind	Outlook
Sponge separation from rollers pin	Separation effect	Strips and strakes
Pigment concentration in pores	Blocked pores effect	Spilled sand effect
Constant work of the roller	Deformation of roller surface	Repeating strip pattern on surface of element
Two elements stacked one top of another under the roller	Cuts and holes	Repeating stamp effect on surface of element
Wrong roller height adjustment in relation to element thickness	Cuts and holes	Repeating stamp effect on surface of element
Crushing of outer layer roller during the contact with treated element	Roller surface wear effect	Various defects caused of foreign bodies
Two small diameter of roller blocking the possibility of right roller height adjustment	Not exact coverage of side chamfer of element, differences in color	Panther spots effects – discolouration, deviations in surface resistance on edges of elements

In the follow-up period, there were 80 failures of roller identified which result in 49 rollers classified for calibration and 31 pieces classified for regeneration. Calibration of rubber rollers, having a hardness of 20-95 Shore, is performed by pouring the rotating roller with dedicated liquid while grinding with pumice stone until a smooth surface achieved. A disadvantage of the calibration is reduced diameter of the roller so that it also changes its hardness. In the case of porous rollers (Pore 1-6), there is a less possibility of pressure to the treated part and to compensate the pore diameter there is necessity of increasing amount of stain used. In case of rubber rollers their hardness is increasing and makes right application of requested lacquer amount mere difficult. In both cases the operator has difficulties to obtain the appropriate parameters for the application of expected quantities of lacquering materials. It is usually lower than assumed in the technology specification and less stable to maintain right parameters. Measurements of parameters when using calibrated rollers are made more frequently, causing additional machine downtime because there is a risk of surface resistance reduction of furniture and very difficult to set proper color of the item. But it is a necessary step, which extends life of the roller and reduces manufacturing costs.

Regeneration of roller requires complete removal of damaged coatings and putting a new one. Seasoning for YBY rollers takes six weeks while for the rubber takes about four. Production of the roller outer layer consists of several stages, while maintaining the special operation regime. Shortening the period and accelerating sponge or rubber application on a metal pin, leads air bubbles inside the structure appearing, delamination of the layers and reduction of its utility functions.

3. THE CONCEPT OF IMPROVEMENT ACTIONS AND ASSESSMENT OF THEIR EFFECTIVENESS

The proposed solution is to partially replace the standard rubber rollers YBY and 20-95°Sh'a by polyurethane rollers. These rollers are the answer to the problem of rollers frequent replacement due to its damage when standard rubber coating used. Modern technical solutions allows to search for other solutions such as replacement of the roller core to reduce transport and storage costs, however, all of those solutions does not eliminate stop times for removing the cylinder UV line. Polyurethane has proven itself as a proper material in many industry sectors, and its use became widespread. Polyurethane is used in agriculture, industry and sport. The polymer is formed of two chemical materials: isocyanates and polyalcohol. Its properties can be adapted individually to the specific application by mixing additives such as catalysts, stabilizers, and many others depending on the use. Modern knowledge of polyurethane products can get the following benefits:

- Resistance to aging: reducing the effect of a worn roller surface;
- Flexibility: Depending on the polyurethane coating applied to the roller, pressure less than the thickness of the element 4 to 6 mm can be set, allowing to stain side chamfers;
- Equal hardness all over the place polyurethane layers: set hardness is unchanged even after calibration;
- Resistance to deformation: sharp edges or with continuous and high pressure does not deform or harm the roller;
- Higher quality of treated surface: better filling the porous structure of products and minimize the effect of fibres rising, what lowers the cost of intermediate sanding and total grams of lacquer applied.

Figure number 6, presents a typical roller coater armed with polyurethane roller.

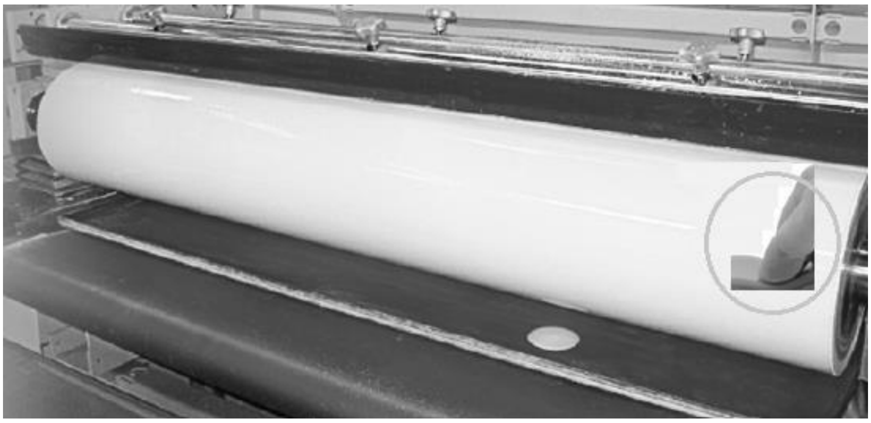

Fig. 6 Roller coater armed with polyurethane shaft (Szwedzka, 2014)

The proposed change of the roller resulting in the introduction of new materials, paint and modification of working methods with roller coaters depending on the stage in the process and the hardness of rollers. Simplified diagram of the process of elements treatment before and after the introduction of the proposed changes is shown in Figure 7.

Units in the line														
Standard setup	P120,150, 180	1YBY Pore2-3	50°C-90s	P.220	40°Sh'a-rubber	80 mJ/cm2	P.220	40°Sh'a-rubber	120 mJ/cm2	P.600	40°Sh'a-rubber	80 mJ/cm2	40°Sh'a-rubber	200 mJ/cm2
Preasure		↓ - 2,5-3,5mm			↓ -1mm			↓ -1mm			↓ -1mm		↓ -1mm	
Proposed solution	P120,150, 180	25°Sh'a-polyurethane (PUR)	50°C-90s	P.220	40°Sh'a-rubber	80 mJ/cm2	P.220	25°Sh'a-PUR	120 mJ/cm2	P.600	25°Sh'a-PUR	80 mJ/cm2	25°Sh'a-PUR	200 mJ/cm2
Preasuer		↓ - 2,5-3,5mm			↓ -1mm			↓ -1,5mm			↓ -2,5mm		↓ -1,5 -2mm	

Fig. 7 Standard solution comparison (roller +°Sh'a YBY) with the new (roller PU+° Sh'a)

Proposed solution has been implemented for three months test period in production line. Parameters of process were following guidelines presented in Figure 7.

4. IMPROVEMENT ACTIONS AND ASSESSMENT

OEE improvement was connected with a change in lacquering technology and new concept of roller coaters equipped with polyurethane rollers. As a result of the implementation of the new solution the company obtained the following benefits in the following areas:

Availability

1. Reducing stop times by reducing the failure rate of roller coaters. Before making changes average failure rate was 32.16%, while after the changes unreliability has reduced down to 15,19% (Fig. 8).

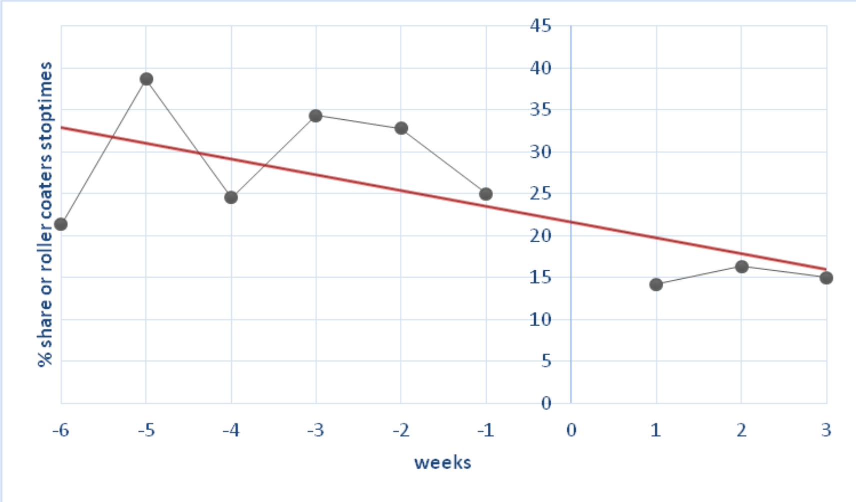

Fig. 8 The percentage of roller coater failures before and after described change

2. Trouble-free work of rollers reduced operating costs and energy for the proposed lacquering process per product. The use of water based stains is sensitive to a number of variables. The water content of the stain, the temperature of the drying tunnel and the proper surface preparation, affect the color of the final product. The introduction of the amended viscosity of staining material and use of rollers 25 ° Sh'a PUR in the production process maintains its continuity and eliminates the risk of changes in color intensity. Parameters set by operators do not change during working time, and surface preparation in accordance with requirements. Treatment does not require time-consuming adjustments during conversion to another dimension. It has fluent the flow of material and reduced the downtime of the machine.

   Given the above, the current value of availability factor is:

$$Avaliability = \frac{running\ time}{loading\ time} = 80{,}7\%$$

Quality

With a diverse hardness rollers, lacquering material spreads over the roller much faster. The result was a better distribution of lacquering material on the surface of the roller – especially at the edges of the rubber rollers that usually are not fully covered with lacquer accelerate what leads to the aging process as a result of increased heat dissipation while leading to the distortion of the rubber on its ends. Additionally rollers can be set below the thickness of a component, what allows for more complete staining of side chamfers. Elements treated that way (mainly narrow elements) are in most cases possible to be packed to box directly, reducing production waste.

The effect of the change was to reduce the number of non-conforming products by 30% with an increase in line capacity by 12%, which resulted in an increase in Quality factor in the formula for the OEE. Currently, the value is:

$$Quality = \frac{Good\ output}{Actual\ output} = 82{,}3\%$$

Performance

Decreased number of porous YBY2 and rubber rollers usage, by replacing them with polyurethane rollers reduced the number of damaged rollers targeted for calibration and regeneration, where:

$$Performance = \frac{Actual\ output}{Max\ output} = 84{,}9\%$$

In case of using stain on sponge rollers, there is an effect of separation of pigment and blocking the pores in the structure of the roller. Long-term use of roller coaters without flushing the roller with water and direct contact with blown warm air drying tunnel (eg. 6-8 hours), reduces the absorbency of sponges, which leads to the application amount increase. As a result of these actions roller needs to be sent for regeneration. Changing the viscosity of the paint material and usage of smooth rollers for color that is used for 60% of the products requires mandatory inspection by specified for standard inspection plan. Rollers YBY could not be eliminated from the process for other colors, which specifics limits the use of the smooth rollers is, however, the proportion of solids in a stain closes the pores less and reacts to heat not that much. Rubber rollers and their proper operating parameters reduce susceptibility to damage from sharp edges, reducing downtime due to failures.

OEE=Availability x Quality x Performance = 56,4%

Considering the above arguments we get longer working time, reduced downtime necessary to replace damaged rollers, reduced the number of items for repair, reduced the number of rollers for calibration or regeneration. OEE figure has increased from 40% to 56,4% what is almost 40% increase of efficiency.

3. CONCLUSION

Improvement actions taken brought an advantage for the company in many practical ways. The increase in OEE can be summed up in three dimensions components of the index, but the results achieved are disproportionate because they combine the cooperation of departments within the organization. Promoting measures for efficiency rising allows for a better understanding of their machinery parks as well as a wide cooperation between employees. The use of OEE (Overall Equipment Effectiveness) allows for accurate visualization of the process and detect its weak spots in the form of "bottlenecks" and areas of possible failure. It has indicated areas where activity should be taken to improve the process. The use of new rollers improved line efficiency and quality of processed components. The solution straight-tened out lacquering process and positively affected the life of the roller coaster for main of produced colors, constituting half of all lacquered elements in plant. Cooperation of many areas of organization reduced process costs of rollers reparation by lowering the amount of crashes on lacquering line in the company. Technologies using polyurethane slowly enters to large manufacturing plants. In this example, where managed to master the art of selection of the configuration settings resulting in better efficiency of the machine.

Identifying the weak points of the process, from the perspective of failure, would not be possible without the tools used by maintenance services.

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BIOGRAPHICAL NOTES

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