RESEARCH IN LOGISTICS & PRODUCTION

DETERMINING MAITENANCE SERVICES USING PRODUCTION PERFORMANCE INDICATORS

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Abstract. Increasing efficiency of machines and strong competition between companies, popularized the use of measures for maintenance service, designed to increase efficiency and reduce the costs of the machines usage. These indicators, help to achieve the reliability of production centers, eliminating potential events associated with electric, hydraulic and pneumatic failures. The aim of the work was to investigate the dependence of performance indicators used by the maintenance services, with the number of parts produced on automated production lines. Then assessed the relationship between the productivity of the line and the ratio of effective production time and how much time is spent on resolving the failure. Interpretation of measurement helped to make the joint improvement activities in the publication described production plants.

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1. INTRODUCTION

The role of maintenance and financing their proper functioning are an indicator of a well-functioning production company. Based on statistical data and knowledge of operators, organization is looking for the possibility of determining the limit damage's symptom, so as to obtain maximum efficiency in the use of machines (Bojar & Żółtowski, 2011). In terms of available methods, it is possible to use pattern recognition, analysis and correlation of events, statistical data analysis and monitoring of alarm thresholds, with the aim to achieve reliable production centres, eliminating future production problems associated with failures of electrical, hydraulic and pneumatic systems (Żółtowski, 1996).

The aim of the paper was to investigate the dependence of performance indicators used by the maintenance services, and the number of parts produced on automated production lines. The article analysis the average repair time and mean time between failures in two factories producing furniture. The collected data provide a description of the work of four double-end tenoner lines, with similar technical parameters and purpose of usage. Based on the obtained information, the line stops reasons assigned to three groups. The first concerns the operational efficiency in terms of technical and organizational – technical. The second group is focused on preventive measures carried out by the machine operators and maintenance service workers. The third group of downtime, categorized the activities dependent on the current methods of management organization and accepted standards for technological processes (Loska, 2013).

The paper is organized as follows. The second chapter describes the theoretical aspect of the work. The third chapter describes the utilization rates of production equipment as well as their effectiveness in relation to initiated improvement activities, based on the data used in the publication of two furniture production plants. The fourth section characterizes one of the four production lines and shows the relationship between the productivity of the line level with effective production time and the time that is devoted to the elimination of the fault. The fifth chapter describes interpreted indicators and improvement actions implemented jointly in the production plants. The sixth chapter is a summary and conclusions.

2. MEASURES OF OPERATION EFFECTIVENESS ASSESSMENT

Efficiency is understood as a property of the operation object (or system) conditioning the level of the tasks realisation of the object or system under certain operating conditions and within a certain period of time. Operating efficiency can be defined as the quotient of the effects achieved in a given period of duration of a specific operation state of the object to the expenditures to achieve these effects (Antosz & Sadnicka, 2015). Inherent in assessing the effectiveness of the enterprise it, is to build a system for measuring performance, so use a variety of measures and indicators, known collectively as KPI (Key Performance Indicator). These measures, are used to evaluate the key measures implemented in different functional areas of the company and indicate their effectiveness in relation to the objectives of the organization. In the area of maintenance for enterprise indicators and metrics can be divided into the following categories (Loska, 2013):

- model of reliability,
- operation of object in terms of technical point of view (in the form of probabilities, related to certain classes of states (e.g. a function of reliability in terms of the exponential distribution, the intensity of the damage, the technical readiness coefficient)),
- operation of objects in terms of organizational and technical points of view (measures received from both the identification of the technical condition, as well as the activities of organizational and economic services supplies, for example. MTBF, MTTR and MFOT),
- model of operational efficiency OEE (Overall Equipment Effectiveness),
- organizational and technical model – KPI.

Their primary function is, among others (Adamkiewicz & Burnos, 2012), to show the current and historical values, performance characteristics and the relationships between them, enabling the comparison of the values obtained from the design values and the values obtained from observations of other operating systems, diagnostics implemented maintenance actions, the realization of continuous process improvement by finding and eliminating significant deviations from assumed value of the project, track changes and progress in the system of exploitation, motivating and settlement of technical and managerial staff with the achieved results, and so on.

3. PERFORMANCE INDICATORS USED BY THE MAINTENANCE SERVICES IN DESCRIBED ENTERPRISES

The purpose of described companies is a joint production of pine box furniture, targeted at the general audience. Pine, due to the availability and its characteristics is a competitive product against the solid wood furniture of other species through the use of mass production. Modern technologies allow securing raw material staining wood surfaces so as to make the durability and quality, which greatly increases the usability of pine itself. Plants located next to each other have their own organizations, and depending on the number of orders and the adaptation of machine parks, produce identical or different elements of requested goods.

3.1. Operational efficiency model OEE

One of the most commonly used measure in the described enterprises assessing the efficiency of the maintenance, production and logistics is measurement of production equipment efficiency – OEE (Szwedzka, Jasiulewicz- Kaczmarek & Szafer, 2015). Model of operational efficiency OEE is a key model of assessing the effectiveness of the use of production equipment used in the TPM strategy (Total Productive Maintenance) (Nakajima et al., 1988), and for many manufacturing companies is a basic indicator of machines and devices efficiency. OEE describes three basic areas: availability, efficiency and quality of products (Loska, 2013).

The essence of OEE is based on comparing the use of the machine for perfect use, which occurs when production and its preparation are carried out according to plan, continuously and the maximum possible speed with the maximum expected quality. Calculation of OEE and its value is the starting point for all activities related to the improvement of the value stream in terms of machinery and equipment, allowing measuring their effect after implementation.

In this article, the indicator will not be analysed and was used to indicate the efficiency measures described in enterprises only.

3.2. Mean Time Between Failures (MTBF)

MTBF, is the most widely used indicator of reliability measurement and informs about the arithmetic mean of times between failures of the system. Determination of MTBF assumes that the system is ready to work after failure and enabled for use immediately after removal of the fault (Pourjavad, Shirouyehzad & Shahin, 2011). An analysis method shown in equation 1 (Fig. 1).

$$MTBF = \frac{Total\ time\ in\ availabe}{Number\ of\ failures}$$

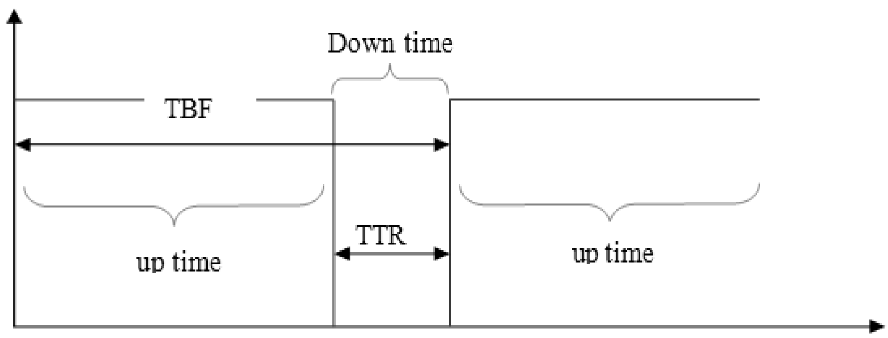

Fig. 1. Calculation of MTBF (TBF – Time Between Failures, TTR – Time To Repair)

3.3. Mean Time to Repair

MTTR is the most widely used measure of the effectiveness of maintenance. This indicator measures the average time that is required to perform corrective actions on all moving parts of the system (Equation 2, Fig. 1) (Pourjavad, Shirouyehzad & Shahin, 2011).

$$MTTR = \frac{Total\ Time\ To\ Repair}{Number\ of\ Failures}$$

Indicator provides information about the time of repair and maintenance, including, inter alia take into account time needed: to properly diagnose the cause of the accident, for ordering and delivery of the components necessary to repair failures, to restore the device operational status, for the replacement of damaged parts, time required to access the affected part, etc.

4. INTERPRETATION OF KEY PERFORMANCE INDICATORS AND THEIR IMPACT ON THE PLANNING OF THE MACHINERY OPERATION

4.1. Characteristic and evaluation of tested objects effectiveness

Double-end tenoner lines are used for formatting end edge processing of elements. The machines are equipped with automatic feeders, double-end tenoners machine for along grains processing, turning unit, double-end tenoner for across grains processing, conveyor, two automatic arterial drilling machines, turning unit and stacker. Elements such as the feeder, stacker and duble-end tenoner are numerically controlled and change of setup is done by selection of appropriate program. Only the work of drilling machine requires operator intervention, i.e. exchange of drilling chucks with drill spindles. Each of the tested line runs at 30-50m/min, in three shifts mode (Fig. 2). Each line is supervised by two operators, whose task, among others, is adjusting setups for new element processing and preventive technical service of the line (Szwedzka, 2014).

Formatting lines are major production equipment for pine box furniture. Beside thickness calibration and lacquering treatment, lines perform all machining operations on pine glue board elements. Their reliability has a key influence on the effectiveness of all remaining stages of furniture production.

In order to determine the operational performance line are used ratios for determining the production time of one particular element. Double-end tenoner lines setup time is determined on the basis of carrying out a series of measurements.

Since it is not always a constant value, the average setup time line is divided by the size of the batch and then added to the processing time of each piece at a workstation. Taking into account the quantities produced, processing times and time settings can be used, determines the need of line usage.

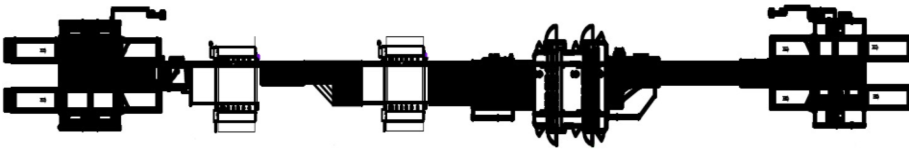

Fig. 2. Double-end tenoner line (formating line) for panels processing (in order: feeder, double-end tenoner, turning unit, double-end tenoner, conveyor, drilling machines, conveyor, stacker)

Efficiency of operated double-end tenoners can be categorized into three levels (Tab. 1). From the hardware level (technical one) machine performance technical barriers are being removed through a variety of investments for improvements or reparation. From the logistics (preventive level) continuity in the availability of materials by changing the organization of the flow of these materials and supervision over efficiency of machines and transport is provided. From the planning (management level), seeks to eliminate activities not directly related to the production process.

Table 1. The average percentage of downtime share for 4 formatting lines

Downtime cathegory	Charcteristics	Double-end tenoner line			
		Plant A		Plant B	
		M1	M2	M3	M4
Technical level	failures directly affecting the efficiency of the equipment, ie .: electrical, pneumatic, mechanical, IT, double-end tenoner segments, drilling machines, feeders and stackers, technical – undefined	7.12%	8.43%	10.11%	6.12%
Preventive level	total downtime indirectly influencing the efficiency of the equipment, ie.: settings calibration, machine cleaning, preventive maintenance	8.19%	20.97%	11.2%	16.34%
Management level	actions that could in the future be carried out without stopping the line by coordination of actions with line operators, ie.: a lunch break, production meetings, lack of material on the line	7.54%	5.95%	6.86%	6.36%

Information regarding lines downtime contained in Table 1 is the key information from the obtained data. Their categorization allows for the preliminary and the general interpretation by comparing similar characteristics or periods for operated lines. Further and detailed analysis of downtime is based on the KPIs used in the enterprise. Measures depending on the machine type, its purpose or age are used to assess their performance and are a benchmark in undertaking maintenance and repairs actions or investments.

4.2. Measuring the efficiency of machines based on MTTR and MTBF indicators

In the article contained two indicators based on which maintenance departments of company analyse operated lines. The measurement was carried out according to common assessment criteria, providing the same picture for the two companies. The MTTR indicator, counted on the basis of failures recognised on technical level, so those which are directly related to the state of the suitability of the system, by making a detailed analysis of its condition, and the MTBF indicator (Tab. 2).

Table 2. Measures of effectiveness used in manufacturing plants

		MTTR (minute)					
Line		**Month**					
		I	II	III	IV	V	VI
Plant A	M1	48.96	36.87	44.55	31.46	85.35	57.20
	M2	50.39	53.91	50.73	44.89	48.49	51.99
Plant B	M3	38.99	39.00	59.57	98.22	120.67	49.40
	M4	52.46	33.99	38.99	26.85	53.05	63.90
		MTBF (minute)					
Line		I	II	III	IV	V	VI
Plant A	M1	298.02	221.21	225.49	215.02	133.05	101.89
	M2	268.98	261.22	229.00	258.30	212.44	242.94
Plant B	M3	189.16	264.96	224.70	198.21	175.41	166.96
	M4	336.27	417.28	344.01	236.36	228.07	224.43

Summarizing the information contained in Table 2, lines 1 and 2 at the factory A is operated at a similar level as the line 3 and 4 of the plant B. Based on the type of manufactured product range can be inferred that the lines have similar technical problems. In order to search for a correlation between the received values of the indicators and produced assortment. Collected information on the monthly performance of linear meters for each line for a period of six months presents Tab. 3.

Table 3. Running meters of elements processed on double-end tenoner lines

Running meters for double-end tenoner lines (monthly)							
Line		**Months**					
		I	**II**	**III**	**IV**	**V**	**VI**
Plant A	M1	306 685	314 344	294 101	335 687	23 166	242 061
	M2	271 216	354 039	262 893	328 549	266 004	318 762
Plant B	M3	337 011	424 869	406 297	521 217	305 231	391 011
	M4	255 007	351 313	294 465	293 765	242 259	306 672

To identify the relationship between the productivity of the line with respect to the effective production time and the time that is spent of the breakdown, used Pearson correlation coefficient (Tab. 4).

Table 4. Correlation coefficient of MTBF and MTTR between the number of items produced on the lines

Pearson coorelation			
Lines		**MTTR to curent meters**	**MTBF to curent meters**
Plant A	M1	-0.965	0.613
	M2	0.193	0.534
Plant B	M3	-0.009	0.395
	M4	-0.407	0.519

The resulting ratios may, however, provide a lot of valuable information. They can be used as a primary tool to determine the ratio of each failure to total failures or for machines effectiveness planning with the theoretical assumption of line availability time. Modification of plan based on data MTBF can shorten line calibration time or increase the time required for maintenance of machines without additional machine stop times.

5. INTERPRETATION OF EFFICIENCY MEASURES IN ENTERPRISES

Since the dependencies between variables have weak correlation, the compound of the general data between the calculated sums of the value of the index in relation to his individual characteristics can be analysed. In case of machines failures, data already collected can show the components of the machine that is the most critical and where to plan corrective actions or repair. High frequency of occurrence of a failure in the sub-assembly can also indicate control points of produced element until failure removed or to take action to eliminate the source of occurrence.

For further analysis, data regarding customer claims obtained from the sales department were used (Fig. 3).

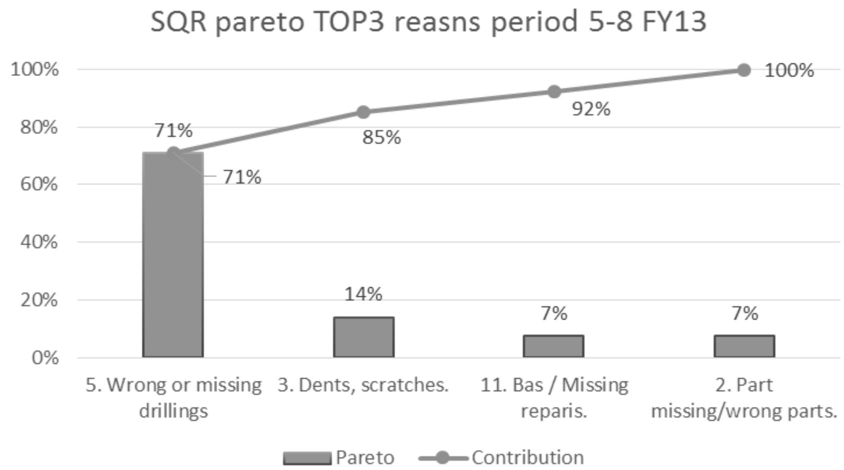

Fig. 3. Pareto analysis of the percentage share of defects of products returned by customers

The cause of complaint was the impossibility of furniture assembling due to wrongly performed frilling operation. The main causes of product returns related to: offset of holes, shallow drilling, wrong diameter, collision of drillings, holes on wrong side. Drilling machines used in lines were analysed (Tabs. 5, 6, Fig. 5).

Table 5. Downtimes for double-end tenoner lines and downtimes caused by drilling machine only

total technical downtime [min]				**downtime of drilling machine[min]**			
Line number				**Line number**			
M1	M2	M3	M4	M1	M2	M3	M4
2 203.15	1 965.24	2 105.43	1 469.00	1 645.96	1 345.20	1 125.47	568.00
2 027.71	1 940.93	1 326.03	985.63	1 836.49	8 65.68	956.32	452.00
1 648.38	2 282.90	2 561.36	1 247.80	1 243.26	1 298.00	1 504.00	752.36
1 446.98	1 256.88	4 714.40	2 389.47	1 345.00	729.13	2 540.23	1 001.63
4 011.36	1 309.30	6 757.30	2 440.10	2 899.12	769.29	4 201.74	958.58
3 775.45	3 119.50	2 667.85	3 642.47	1 140.85	2 068.00	1 542.00	1 938.25

Table 6. Correlation coefficient of MTBF and MTTR with the number of items produced on the lines

Pearson correlation to the total break down at the lines			
M1	M2	M3	M4
0.508	0.964	0.99	0.951

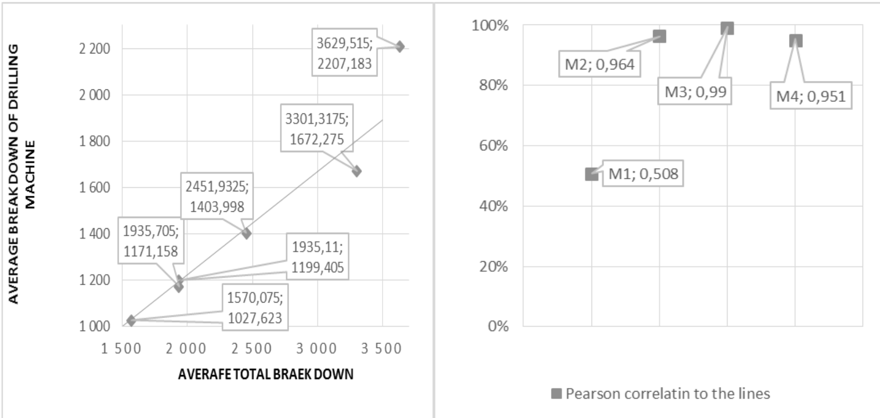

Fig. 4. Dependencies of line and driling machines breakdowns with trend line for avarage drilling machine breakdowns and plot for the Pearson correlation (source: own)

As shown in Table 5, the ratio of dependence highlights high weight of influence on the technical performance of all lines producing pine components being a part of finished product. In the case of group of machines, each failure pf drilling machines causes system disability, and such a line cannot produce. At described above line speeds may seem that the ratio of failure is not high, however, assuming that the one line produces about 5 running meters per minute, the loss due to drilling machine failures, assuming stop times of 1000 minutes a month will give 5000 running meters of ready elements missing. The loss of such, production can take as calculated waste or lack of one line, but in observing the growing trend of downtime due to problems with drilling machines, and a mirrored their potential value because of two lines in each plant, the company decided to take common preventive actions. Confirming the validity of the failure tendency, to reduce the level of quality as a result of a breakdown in drilling operation, plants have decided to appoint a joint committee made of the operators, foremen and maintenance workers. Commission with the tools used in the company to identify the problem (method 5 Why and Ishikawa diagram) conducted an analysis of the causes of non-compliance (Fig. 5)

During analysis, particular attention was focused on the technical aspect of the device, because the analysis of the human factor to the long downtimes, often grounds on the management method. Striving to fulfil production plan in case the machine is repaired long time and cannot produce moving task for another shift, causes frustration both the operator and the other people responsible for the process execution. A proper understanding of the failure causes can develop a strategy for the repair of machines and focus more efforts on the process of drilling by the maintenance services, operator, but also quality controllers, who can often make correct drilling measurements. Based on the knowledge and experience, interpretation of the most commonly caused cases of failure drills has been made. Conclusion shows Table 7.

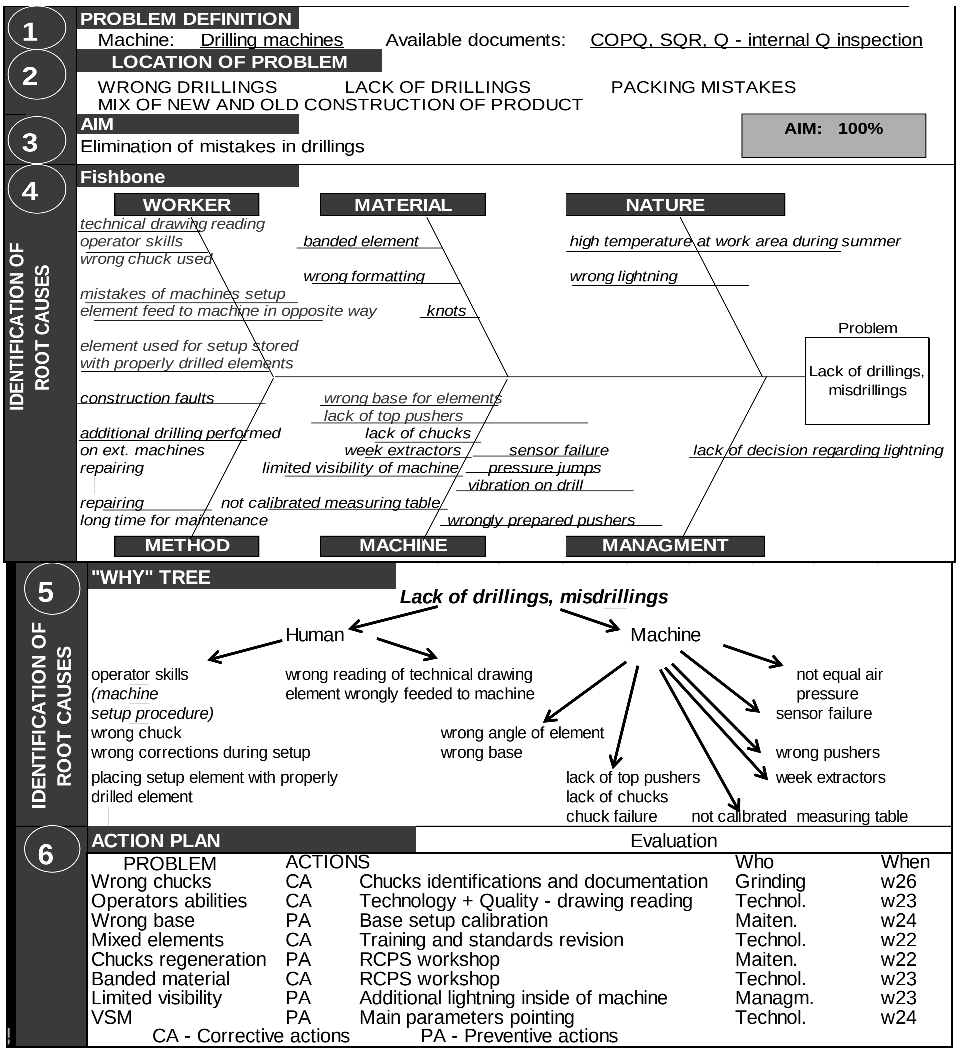

Fig. 5. Root Cause Problem Solving form in described organisations

Table 7. Reasons of wrong or missing drillings

Wrong or missing drillings			
	Root case	**Reason**	**Action**
human aspect	Mistake during chuck assembling	abstractedness	proper and readable chucks marking
	Rush during machine setup	pressure from foreman side reg. plan realization	training
	mixing test elements with others	abstractedness	pointing a place for test elements storing
	wrong interpretation of technical drawing	pressure from foreman side reg. plan realization	training
	wrong positioning of pallet with elements for feeding	abstractedness	clear and readable marking of pallet
Machine	lack of special chuck allowing drilling in one cycle – standard chuck have spindles in 32mm distance	distance between holes is not equal to multiple of 32mm so processed element has to be drilled in two cycles	new, product dedicated chucks purchase
	difficulties with machine calibration – setup of movable machine parts in x,y,z space in relations to 0,0,0 point.	the difficultness causes offset of all drilling chucks, requiring many manual adjustment of chucks position during setup	include setting to zero operation in preventive actions to be performer by experienced operator
	frequent pneumatic clamps damages – problem with right position of element during processing	element not located in proper place in the machine or is lifted when drilled from bottom side what causes problem with depth of holes or their absence or element too heavy and impacts front clamps wit big force, damages them, or changes their position, what causes dislocation of drillings	guarantee compressed air supply on minimum required level by air supply system modification
	chucks damages – chuck is a system of sprockets for rotation transmission, sprocket damage causes that spindles are not rotating	Damaged sprockets are nailing drill bits into the panel instead of drilling, drill bits are breaking or falling off	regular chucks inspection, every each 80 working hours.
	sensors failures or sensors dirty	amount of dust and chips can block number of sensors located underneath working area	additional inspection of dust extractors
	compressed air supplies problem – periodical low pressure – chucks cannot be lifted to requested height	Pneumatic element of drilling machine are not lifting to request position or they do it too slowly causing problems of drilling quality or elements stacking, too high air consumption	guarantee compressed air supply on minimum required level by air supply system modification
	not enough vacuum force of dust extraction system	amount of dust and chips can block number of sensors located underneath working area	additional inspection of dust extractors, implementation of additional stop time for machine cleaning

While part of the problem can be eliminated by purchasing special chucks and by proper supervision of their designation and service, the compressed air failures and pneumatic clams' damages can be reduced by slowing the speed of the line.

Large and heavy items from the pine glue boards, entering slowly to drill, with less force hits the clamps, extending their service life and efficiency at the same time. As a result, factories returning to three-shift production system has decided to slow down the line speed for large items that passed with big force on the chain conveyor caused damage to positioning clamps. The proposed improvement actions are currently in progress.

6. CONCLUSION

The production process is not only the manufacturing process, but also the process of preparation for the workmanship based on technical condition of the machines. Wide range of available indicators, not always have correlations among themselves, but helps to determine the appropriate corrective strategies.

Enterprises that use indicators should clearly and precisely define their scope. Exact analysis can help avoiding extending a working time with another shift, what leads very often to 4-brigade system of work what is very inconvenient for workers. In a situation where these machines are the bottlenecks in the production process, it becomes a key aspect for the enterprise performance. Therefore proper selection of measures and their assessment of the consequences can bring relaxation and systematization of jobs. It can lead to a change of perception in managing group, increase effectiveness and capacity what allows for new products implementation.

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BIOGRAPHICAL NOTES

Katarzyna Szwedzka is a doctor degree student at Faculty of Engineering Management in Poznan University of Technology. She came to University with extensive experience in industry. Her research interests are production engineering and maintenance. She is the co-author of a few publication of industry concept so far.

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