Application of the Six Sigma Method for Improving Maintenance Processes – Case Study

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Abstract: The article presents an implementation attempt of the DMAIC method used in the Six Sigma concept for the improvement of production processes connected with maintenance. Thanks to the tools included therein (process map, FMEA, SIPOC chart) we were able to define the: problem, i.e. which types of breakdowns cause the most machine stoppage; precise structure of the failure removal process and its needs, owners, resources, client-supplier relationships in particular sub-processes; source causes for overly long stoppages. Learning the process and the causes of malfunctions allowed us to develop improvement procedures aimed at minimising the fault removal times. The procedures developed have been implemented in the company alongside a control plan, which will ensure supervision and their efficient functioning in the future.

1 INTRODUCTION

1.1 Maintenance

Processes connected with maintaining technical resources used in production in good condition are some of the key elements which affect the efficiency of production processes, which directly influences the company's competitiveness on the market (Żurakowski, 2004). Thanks to an efficient machine park, a production company can supply its goods to the customers in required quantity, quality and within the agreed deadlines; it becomes a reliable and trustworthy partner for its clients. A key element to the production process is the availability of machinery and equipment. Availability (operational time) of machines and equipment which take part in the production process is limited by several elements, which can be classified into two main groups: stoppages caused external factors and stoppages caused by internal factors. External factors do not depend on the technical condition of the machinery or the way it is operated. These factors include stoppages caused by e.g. media supply shortages (water, electricity, communication), but also weather conditions which make operation impossible (temperature in the production hall). Internal stoppage factors depend on the way the machines are operated and their technical condition. These include stoppages caused by breakdowns, inspections and renovation works, but it is also the time needed for refitting or calibration of the machines, launching them after a stoppage, introducing improvements, training new employees, etc. An example division is presented in Figure 1.

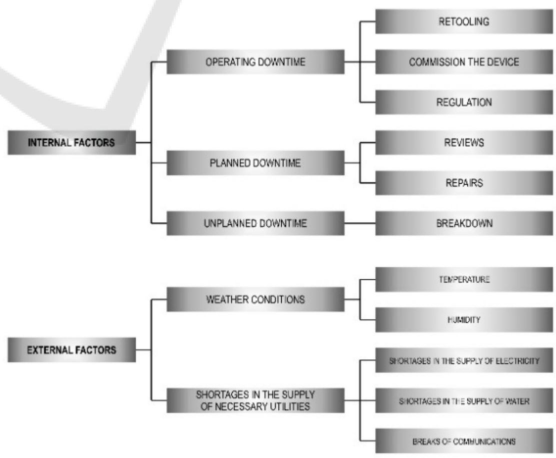

Figure 1: Factors affecting machine unavailability (based on Zasadzień and Midor 2015).

From the availability period we can also distinguish the unused time (the period when the machine is not working despite being operational), which depends on planning, production quantity and

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organisation. It is not considered as either external or internal factor, as the machine is available for work at the time.

The occurrence of a breakdown of a machine involved in the production process can cause delays, endanger its operators or the natural environment; it increases the risk of crossing delivery deadlines or decrease in product quality. The probability of stoppages caused by breakdowns can be minimised by introducing advanced maintenance strategies, which include preventive maintenance based on inspections and preventive renovation, or predictive maintenance, based on monitoring the technical condition (condition based maintenance) (Legutko, 2009). Even the most technically and organisationally advanced preventive measures cannot reduce the probability of a breakdown to an absolute zero.

A breakdown is a sudden and mostly unforeseen occurrence, which is why the process of its removal is very complex; it is necessary to act in a rush and reorganise working schedules. It consists of administrative, organisational and technical activities. Reducing the breakdown removal time, and therefore reducing the downtime of the machine directly affects the efficiency indicators of the production process. It is, therefore, important to skilfully direct the main and auxiliary processes connected with the company's activity in order to efficiently use the working time, materials, machines and equipment (Mikler, 2005). The maintenance department often operates based on no precisely defined schedule and its priorities are set on the fly, usually with not enough human and technical resources available, which is why the skills of managing working time and using it efficiently are especially important here (Midor, Szczęśniak and Zasadzień, 2010; Mączyński and Nahirny, 2012).

Stoppage caused by a breakdown can consist of active and passive time, as presented in Figure 2.

The length of the downtime period caused by a breakdown can be composed of elements whose duration depends on the organisation and management of the maintenance department (administrative delay, waiting for personnel and spare parts), i.e. the so-called support capability, as well as on ease of maintenance, i.e. the ease with which a given machine can be brought back to an operational condition. Ease of maintenance depends primarily on the qualifications and competence of employees, the machine's structure, its technical condition and location. Shortening the downtime caused by a breakdown consists in, for the most part, shortening the passive and/or active time of the breakdown removal process.

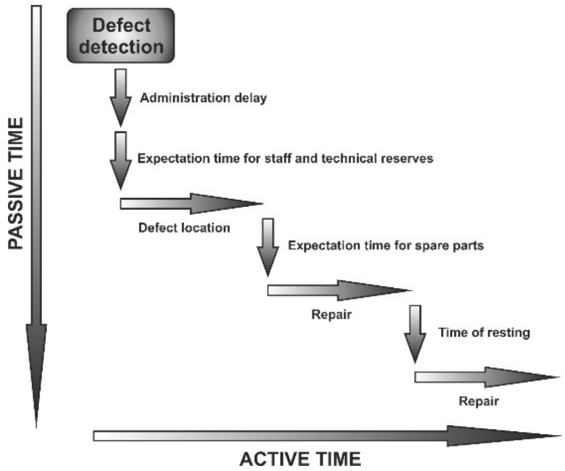

Figure 2: Time in the defect removal process (based on Mikler, 2005).

1.2 DMAIC

Strategies for improving production processes have been described in literature many times (Sahno and Shavtshenko, 2014; Soković et al., 2009). Currently, we have at our disposal such methods and concepts of quality management as: PFMEA, TQM, Six Sigma and others (Tague, 2005; Andrássyová, 2013). Apart from those, many less complex tools, such as the Pareto chart, Ishikawa diagram or 5 WHYs (Midor, 2014) are also used with much success.

One of the elements of streamlining the production process can be the DMAIC (Define - Measure - Analyse - Improve - Control) method, rooted in the automotive industry and successfully utilised in process improvement in accordance with the Six Sigma assumptions (Krzemień and Wolniak, 2007; Wojraszak and Biały, 2013). Six Sigma is a complex and flexible system for achieving, sustaining and maximising business achievements. It is characterised by the understanding of customers' needs and organised use of facts, data and statistical analysis results, and is based on management, streamlining and constantly creating new, ever better solutions with reference to all the processes taking place in the company. Furthermore, it is aimed at minimising the costs of bad quality while simultaneously increasing customer satisfaction (Truscott, 2003)). The method is used to eliminate the causes of defects, losses they incur and any problems related to quality in the aspects of production, services and management. To solve these problems, the method employs quality tools and statistical techniques (Eckes, 2000).

When implementing the DMAIC method, a number of auxiliary quality improvement tools and methods are used. The improvement cycle using the DMAIC method consists of the following elements (Dreachslin and Lee, 2007; Bargerstock and Richards, 2015):

- Define. In this stage a team is created which will be responsible for the implementation of the method. The defining phase must identify the following elements: determining the problem (description of the problem, time of occurrence), scope of the project (elements of the process the team will work on), aim of the project (a tangible goal to achieve and sustain in the future).
- Measure. During the measurement stage parameters and places of measurement should be defined, i.e. the points of process quality and its costs along with a precise reflection of the actual state. Conducting measurements successfully requires a statistical outlook on the particular production processes and problems related to them. The measurement stage employs methods such as: descriptive statistics, summary charts, the SIPOC method and the process map.
- Analyse. During this stage of the methodology, by analysing the particular parameters of the process, the team will be able to determine the causes of the problem, which will then need to be eliminated or fixed. The results obtained during the measurement stage are used in order to investigate the correlation between causes of defects and process variability sources. In order to identify the causes of process variability, which are a significant factor in defect creation, the PFMEA analysis, the Pareto - Lorenz chart and the Ishikawa diagram are often used.
- Improve. Improvement can otherwise be understood as engagement in the course of the production process, i.e. reduction of the defect rate. It consists in searching for and evaluating potential causes of process variability and investigating their correlations. Learning the multi-factor relations allows for achieving the desired results.
- Control. The control stage takes place after finishing the new process implementation phase. The fundamental goal of Six Sigma is the constant observation of the improvements introduced to maintain a desired level of quality. In this phase of the DMAIC the measurement system and potential verification process are repeated to confirm the improvement of the process. Afterwards, measures are taken to appoint control over the streamlined processes; usually a so-called control plan is created.

As we can infer from the above description, based on the concepts of Six Sigma and Lean, the DMAIC method used in management systems relies on the principle of constant improvement and PDCA formulated by E. Deming (Deming, 2000) and required by the ISO 9001 series standards. A comparison of both concepts has been presented in the literature in many forms (George et al., 2005; Soković et al., 2010) (fig. 3).

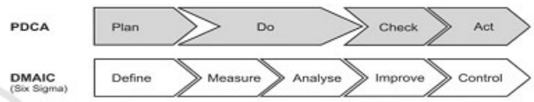

Figure 3: PDCA vs DMAIC.

The DMAIC methodology is used for improving production processes, successfully contributing to the reduction of the number of non-compliant products and reducing production costs. The author of this elaboration decided to introduce this method to processes auxiliary to the production process, i.e. to the maintenance process. The maintenance process, as every other process, has its inputs, outputs, clients, suppliers and can be described using indicators, similar to the production process. The case presented pertains to the breakdown removal process.

2 DMAIC IMPLEMENTATION

2.1 Define

In the company which is the subject of this study the key machines are the extruders producing HDPE (high-density polyethylene) pipes. Due to that fact, a total of 154 breakdowns of these machines were analysed in the period of 32 months. This allowed us to identify those components whose breakdowns caused the longest stoppages, as presented in Table 1.

As can be seen in the above table (Tab. 1), the breakdown that caused the longest downtime was the damaged connector of extruder head heater. In the examined period of time the downtime due to this failure lasted more than 130 hours (7 breakdowns of this type), and the average time of downtime was 18 hours, therefore, it was decided that the problem should be subjected to analysis. The aim was to reduce the total duration of downtime caused by this failure by reducing the average downtime duration and the number of breakdowns.

Table 1: Extruder component stoppages analysed.

Failure	Average downtime duration [h]	Total downtime duration [h]
Damaged heater supply connector	18.69	130.83
Incorrect caterpillar track haul-off	14.19	103.49
Pipe surface corrugation	10.19	71.31
Leak of oil from transmission gear	9.50	37.99
Crown brush failure	17.80	35.59
Error on controller display	22.83	2.83
No heating	0.98	20.64
Fuse blown	0.48	20.30
Destroyed basket for granulated product	18.60	18.60
No granules haul	1.61	12.88
Failure of ozone exhaust	0.42	7.48
Damaged frequency invertor	7.34	7.34
Leak of mass from the head	1.08	4.32
Leak in heat exchanger	3.81	3.81
No cooling	0.16	2.28
Saw failure	0.22	1.55
Printer failure	0.50	1.00
Clogged head sieve	0.44	0.88
Calibrator failure	0.24	0.72
Vacuum pump	0.21	0.21
Damaged air duct	0.03	0.03
Extractor failure	0.01	0.02
Drive system failure	0.02	0.02

2.2 Measure

Based on the information obtained from the production and maintenance employees, a map for the process of identifying and removing failures of the extruder head heater connector was created. The process map has been presented in Fig. 4.

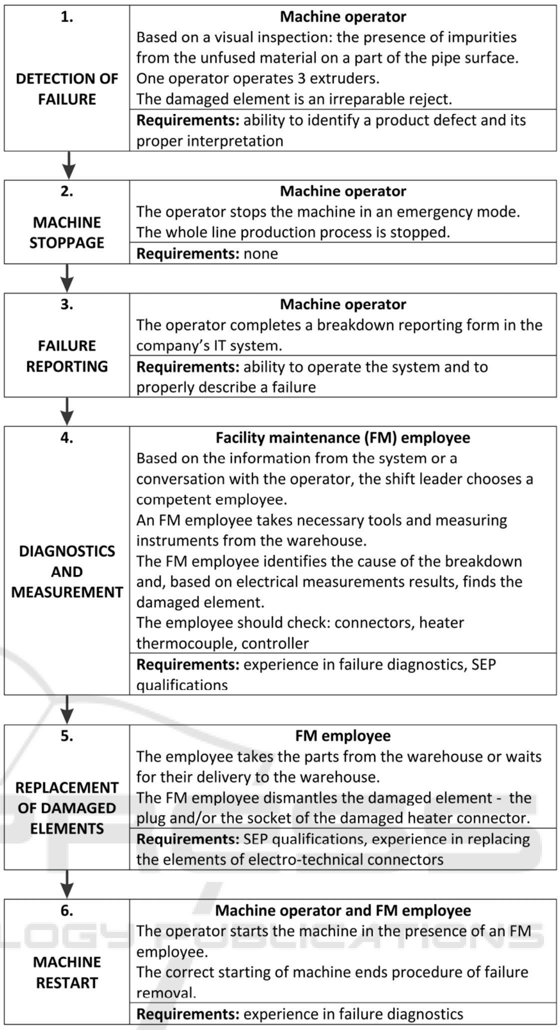

Figure 4: Failure removal process map.

2.3 Analyse

Based on the information collected in the process of identifying all the process steps and creating a process map, a modified PFMEA matrix was developed to identify potential causes and effects of delays during the process of removing a failure of extruder head heater and estimate their importance for the process. For the needs of the case study, a scale from 1 to 4 was adopted, where 1 means a positive situation and 4 – a negative one (Table 2).

Table 2: PFMEA matrix.

Process stage	Problem	Cause	Importance	Effect	Occurrence	Current prevention	Effectiveness of prevention	IOE
1.	Failure detected too late	Connector burnt during work	4	Line stoppage.	3	Observation of the product by the operator	4	48
				Possibility of further defects	1	Observation of the product by the operator	4	16
	Failure occurs after extruder refitting	Connector damaged in the process of refitting	3	Line stoppage	3	None	4	36
3.	Too long time of recording the failure in the system	Insufficient knowledge of the IT system	1	FM is not aware of the failure	3	Training of a newly employed worker	2	6
	FM does not know the failure details	Inaccurate description of failure	3	FM employee does not have the sufficient equipment	4	None	4	48
4.	Incorrect diagnostics	Having identified the cause of the failure, the employee does not control the remaining elements of the system	4	Long duration of failure removal	2	None	4	32
5.	Long waiting time for the parts	Lack of parts in the warehouse	4	Prolonged failure removal	1	None	4	16
		Long searching for parts in the warehouse	3	Prolonged failure removal	2	None	4	24
	Long duration of damaged elements replacement	Waiting for the head temperature to go down	4	Prolonged failure removal	4	None	4	64

The analysis conducted by means of the PFMEA tool revealed which of the analysed causes of the problems was the most important for the process of failure removal. Table 3 contains the analysis synthetic results.

For further works aimed at improving the process, problems whose IOE was at least 40, i.e. three most important items: waiting for the head temperature to go down, connector burnt during work – line stoppage and inaccurate description of the failure were selected.

Table 3: PFMEA analysis results.

Cause	IOE
Waiting for the head temperature to go down	64
Connector burnt during work – line stoppage	48
Inaccurate description of failure	48
Connector damaged in the process of refitting	36
Incorrect diagnostics	32
Long searching for parts in the warehouse	24
Connector burnt during work – possibility of further defects	16
Lack of parts in the warehouse	16
Too long waiting for the failure to be recorded in the system	6

2.4 Improve

At the further stage of analysis, improvement actions for all the important problems were proposed. Their synthetic summary has been given in Table 4.

Table 4: Improvement actions.

Cause	IOE	Improvement actions	Benefits	I	O	E	IOE
Waiting for the head temperature to go down	64	Introducing a system of doubled heads. A spare head is waiting at the quick replacement station.	No need to wait for the head to cool down. Replacement of the head for a cold one enables an immediate failure removal.	4	2	2	16
Connector burnt during work – line stoppage	48	Installing a system of product surface monitoring with software for image analysis.	No need for the operator to observe the pipe surface. Automatic alarm initiation in case of surface defects.	4	2	2	16
Inaccurate description of failure	48	Introducing a uniform base for failure reporting in the IT system and training of machine operators in failure identification.	FM employees receive reliable and precise information enabling their faster preparation for work.	3	1	2	6

The introduced improvement actions allowed a considerable reduction of IOE values for the analysed problems.

An estimation of the costs involved in the improvement actions has revealed that the cheapest solution is improving the process of failure reporting, as the enterprise has a possibility of modifying the IT system. Introducing a spare head at the extruder workstation required constructing and making trolleys for fast head replacements. Since the company manufactures its products on a mass scale, the expensive heads are stored in the company's warehouses. The most costly improvement action is introducing a system for product surface quality monitoring. It has been decided that such a system will be implemented in the places where operators have a hindered access, i.e. where observation of the process is difficult.

2.5 Control

After implementing the actions planned, the values of duration of downtimes due to failures of heaters in extruder heads are monitored on a regular basis and their causes analysed according to the schedule contained in Table 5.

Table 5: Process monitoring.

Element of control	Duration of downtimes due to heater connectors' failures	Elements of downtime duration
Control limit	Downtime duration <10 h	None
Frequency of control	1/half year	1/half year
Control system	Records in IT system	Failure removal reports
Control method	Figures	Charts
Response plan	Meeting with production managers	Meetings with FM shift leaders
Person in charge	FM manager	FM manager

At the last stage of creating a control plan, standardization (Table 6) was taken into consideration, aimed at maintaining the standards which the process of failure removal improvement is based on.

Table 6: Standardization.

Person in charge	Undertaken actions
Quality engineer	Instructions on head replacement using a fast exchange trolley
Quality engineer	Instructions for pipe surface control
Production manager	Operators' training in product surface observation
Quality engineer	Failure reporting instructions
FM manager	Training for operators in failure reporting and diagnostics

Training actions are undertaken in the event new workers are employed and any important changes have been made in the instructions and procedures.

3 CONCLUSIONS

The aim of the undertaken actions has been achieved. The duration of downtimes caused by failures of extruder head heater connectors was reduced. The period of results verification lasted 8 months. During that time there were two such failures and downtime duration decreased from 18 to 9 hours. This process will be further monitored.

DMAIC is a long-term method and despite being very extended and time-consuming, it guarantees proper identification of problems and their effects for the maintenance process. It ensures developing and implementing effective improvement actions and, what is most important, it guarantees that the implemented actions will be continued in the future.

The described case study has proved that it is possible to effectively use quality engineering methods and tools for maintenance process improvement. This allows increasing the availability of machines as well as shortening the duration of downtimes and failure removal.

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