Process Variation and the Total Productive Maintenance. Case Study in the Manufacturing Plant

Adrian Wojciechowski
Poznan University of Technology, Poland

One of the concepts decreasing the variability of the production processes is the Total Productive Maintenance. The aim of the article is to examine the impact of the TPM implementation on the reduction of process variation on the example of the production company. In the first part of the paper a short literature review in the context of the variability of processes and the characteristics of the TPM concept has been performed. Also a way of implementation of the concept in the production company has been presented. The second part contains the description of the applied research tools, it also presents research results and shows the final conclusions regarding the impact of TPM on the process variation in the studied company.

Keywords: process variation, Total Productive Maintenance, autonomous maintenance.

1. INTRODUCTION

The variability of the manufacturing processes is perceived by many authors and practitioners of the manufacturing companies management as the source of their main problems. K. Bhote and A. Bhote in their work entitled World Class Quality postulate a new paradigm, according to which, the variability in the industry is an evil and should be limited [1]. The literature describes a variety of tools and techniques to reduce variation. As a rule, they are related to the concepts of continuous improvement.

The aim of the study is to examine whether the implementation of the Total Productive Maintenance concept in the company reduced the process variation. The first part of the paper presented issues related to the variability of production processes, basic assumptions of the TPM concept and its implementation in the manufacturing company. The second part of the paper presented the details of methodology, research results with their interpretation and the final conclusions.

2. VARIATION OF THE PROCESS AND TPM

2.1. PROCESS VARIATION

As it has been mentioned in the introduction, variability of production processes is the cause of enterprises' problems. Too much variation results in the greater manufacturing waste and impacts the deterioration of operational results of the company, and this in turn translates into weakening of the market position of the given subject. In order to maintain and improve the competitiveness, enterprises should focus their actions on reducing the variability of processes.

Shewhart and Deming, quality management classics, define two types of variation: a common (chance) one and a special (assignable) one. Each process has its common variability, which is caused by unpredictable events, also called the chance causes. They are usually hard to determine and difficult to eliminate. While the special causes are easy to determine, are occasional, should be eliminated or limited. The use of statistical tools, including the control charts, allows to measure variation and identification of variation causes [3, 6].

K. Bhote and A. Bhote mentioned in the introduction indicate several sources of process variability. These include: poor management practices, incorrect specification of processes and products, poor component quality, inadequate quality management system, poor operational procedures, poor quality of suppliers, errors of operators [1].

High quality processes are processes, which are:
- stable,
- cantered,
- capable [7].

Understanding the variability requires the use of process capability metrics. The most popular ones include the indicator of the potential capability Cp (sometimes referred to as the spreading process indicator) and the indicator of real capability Cpk (also called the indicator of process centring). The use of process capability measures allows us to answer the questions: to what extent is the process capable to fulfil the customer's requirements, expressed by given specifications [2, 7]. As a rule it is assumed that the minimal referential value of the Cp and Cpk indicators commonly used in the industry is 1,33.

The variation of manufacturing processes can be limited by improvements related to the implementation of the philosophy and concepts of continuous improvement, such as: Total Quality Management, Six Sigma, Lean Manufacturing, Total Productive Maintenance. Particularly noteworthy and worth approximation is the concept of Total Productive Maintenance (TPM), which in its assumptions focuses on the man and machine. K. Suzaki defines TPM as the concept, which involves all employees and places an emphasis on respect for the man [8].

2.2.TOTAL PRODUCTIVE MAINTENANCE

This section will present the main assumptions of the TPM concept and the most important pillars of its implementation in the manufacturing company. The TPM concept sources date back to the sixties of the twentieth century, where on the Japanese grounds, the Nippondenso Corporation Ltd. company, belonging to the Toyota group, implemented a rule, which states that the maintenance of machines in a good condition rested on the production workers. The consequences of this decision was the reduced failure rate and higher productivity of the plant. In 1971 Seiichi Nakajima determined the basic assumptions of the TPM concept. These included: extending the life cycle of machines and increasing the productivity of the whole company [11]. The TPM encyclopaedia released by the Japan Institute of Plant Maintenance (JIPM) determines the basic goal of TPM, which is the focus on the reduction of losses by the complete elimination of accidents, failures and quality defects [10]. S. Nakajima defines *TPM* as maintaining productivity by all employees of the plant within functioning of small groups. In the abovementioned definition three elements are important: ensuring overall productivity, comprehensive maintenance of the system by focusing on prevention and improvements, involvement of the whole crew [5]. According to the Japanese standards, the construction and implementation of the TPM model in the organisation should be based on eight pillars:
1) autonomous maintenance,
2) planned maintenance,
3) focused improvement,
4) training and education,
5) quality maintenance,
6) early management,
7) Office TPM,
8) safety, health and environment [4,9,10].

It is worth noting that all TPM pillars play a significant role in the design of the whole system in the enterprise. Interactions between them and the ability to develop cooperation between groups of people managing the individual pillars are extremely important. Nevertheless, it seems that one of the most significant pillars include the autonomous maintenance and focused improvement. The aim of autonomous maintenance is to prevent the forced deterioration of the machine by focusing on the reduction of chronic losses and removal of abnormalities in the production process. On the other hand, the task of the pillar of focused improvement is the identification of losses in the whole system and their removal by the project approach [11]. Due to the desire to reduce the losses, the TPM concept plays an extremely significant role in reducing the volatility of production processes, which was mentioned in the first chapter.

2.3. TPM IMPLEMENTATION IN MANUFACTURING PLANT

TPM concept has been implemented in the manufacturing plant operating globally in the lighting industry. The company is recognized as one of the leaders in its sector and manufactures ceramic components. The main application of the ceramic components is the assembly of outdoor lamps. Pilot area focused on kneading process on mixing machines.

The process of TPM concept implementation in the studied company started in 2012 and has continued to the present. The implementation consisted of three phases: preparation, implementation in the pilot area, implementation in the whole plant area. The first stage of the implementation included the appropriate preparation of the TPM concept. This stage consisted of the following steps:

- management declaration,
- information and training campaign,
- design of the TPM organisational structure,
- determination of strategic objectives and main indicators,
- preparation of the master plan.

In the preparatory phase, noteworthy is the point related to the design of the organisational TPM structure. The structure was built based on the TPM pillars recommended by JIPM, while the main emphasis was placed on pillars: autonomous maintenance, planned maintenance, focused improvement, and training and education. For each of the pillars a leader has been determined with the team and the specific responsibilities and tasks were assigned. It should be noted that the TPM structure was entered into the present structure of the company. The second phase of implementation included the appointment of the pilot area. It has been limited to one machine, where during six months the operation of basic techniques related to TPM has been tested. Within the pillar of autonomous maintenance the workshop of the machine initial cleaning was conducted, during which production employees were detecting abnormalities tagging them with red cards, developed one point lessons and created the standard of the machine cleaning. In the next steps the sources of contamination and the hard to access places were identified, also the standard of inspection was formed. Then, the lubrication standards were implemented. The standards of cleaning, inspection and lubrication were developed by the operators themselves in consultation with employees of the maintenance department and the engineering staff. They have become the part of the standard work of operators and were preceded by practical trainings. During the implementation of activities related to the autonomous maintenance, employees of other TPM pillars focused on tasks within the functioning of own areas. Responsibilities of the pillar of the planned maintenance relied on the support of the production in the removal of detected faults during the cleaning and operation of machines and on the analysis of equipment criticality. The criticality analysis became the base to define the schedules and functional areas of periodic inspections and prevention. Maintenance services have also focused on training production operators regarding activities of removing minor failures and conducting inspections and lubrication. Based on the analysis of OEE losses, the focused improvement pillar has identified major improvement projects. They concerned the reduction of breakdowns on the pilot machine and reduction of the blocked products due to the quality issues. Projects were implemented based on the PDCA methodology. All actions of the above-mentioned pillars were coordinated by the pillar of training and education. Its main tasks consisted of developing training plans, preparing training materials, determining internal trainers and supervising the training process. The last step of the TPM implementation included the step of spreading techniques and work standards developed in the pilot area on other plant areas. It was held in accordance with the pre-defined TPM master plan implementation.

TPM concept implementation in the studied enterprise was presented in the framework manner. The aim of the article is not to accurately describe the implementation process, but to examine how the TPM concept implementation affected the functioning of the company. Consequently, the following research hypothesis has been set: TPM concept reduces manufacturing process variation.

3. RESEARCH METHODOLOGY

3.1. DATA COLLECTION

In order to conduct studies data on the production waste in the final control of the analysed company has been collected. The selection of the variable in the form of the waste is purposeful, as the production waste in a very meaningful way reflects the evolution of the process variation. The waste control takes on the form of the visual inspection, where based on the certain standards quality controllers separate good and bad products. Reliability of data has been confirmed by the Kappa test, which is performed regularly twice a year according to the measurement system analysis in the company. The results of the Kappa test reached the value in the range of 90%. Therefore, data can be regarded as reliable. Data were collected for the period of 5 years and 4 months. They were registered in the form of waste pieces and in the percentage grasp for the given month. An assumption has been made that the period of first 36 months is the period before the implementation of the TPM concept, while the period of next 28 months is the period after the concept implementation. The last statement is a contractual assumption, because really the implementation of the TPM concept in the company does not end and is a continuous process. Nevertheless, the application of first changes and the related effects were observed in this period. Major achievements of TPM implementation in this period were described in chapter 2.3.

3.2. AN EXPLORATORY ANALYSIS

The first step in the study was to conduct the exploratory analysis. The main objective of this study was to check the missing data, verify outliers and to visualise data in the studied period. To this end the graphs have been made:

– data distribution histograms in the percentage terms,
– time series for the whole studied period.

3.3. STATISTICAL MODELLING

Further studies used the tools of the data statistical analysis. In the first step the process capability analysis was performed for the attribute data (based on the binomial distribution) and for continuous data (in case of measuring the waste in the percentage terms) for the period before and after the TPM implementation in the company. In the second step inferential statistics methods were performed in order to confirm the research hypothesis. For this purpose the t-Student test was used for two means obtained before and after TPM implementation (data in terms of %) and the test of two fractions (data in the attribute terms).

All analyses, both in the exploratory phase, and in the explanatory phase, were conducted using the Minitab statistical software.

4. RESEARCH RESULTS

The results of the process capability analysis before and after the TPM concept implementation in the company based on the attribute data (the share of waste in relation to the total production) are presented in figure 1.

Data presented in figure 1 show that the average waste decreased from the level of 9.38% in the period before the implementation of TPM to 5.49% in the period after the implementation. The value of the DPMO indicator decreased from 93,797 to 54,942, and the value of the parameter Z increased from 1.32 to 1.60. As a result of the conducted statistical test for the difference between fractions in two populations, the p-value was obtained close to the zero value (p-value < 0.001), with the 5% level of significance, what means the confirmation of the alternative hypothesis that the waste in the period after the TPM implementation in the company is statistically lower than the target level of 7%.

The results of the process capability based on continuous data (percentage terms) are presented in figure 2.

Data presented in figure 2 show that the histogram of waste data measure in percentage after the implementation of the TPM concept is more slender and moved towards the lower specification of the process. The process specification limits were set at the level between 0% (lower specification) and 7% (upper specification). The value of the potential capability indicator of the process Cp increased from 1.36 to 1.86 after implementing the TPM concept in the studied company. Accordingly, also the value of the real capability indicator of the process Cpk increased from -0.93 to 0.79, which means a better centring of the process.

In order to confirm that the process variability has significantly changed, the statistical t-Student test has been performed for two means. Data were presented in figure 3.

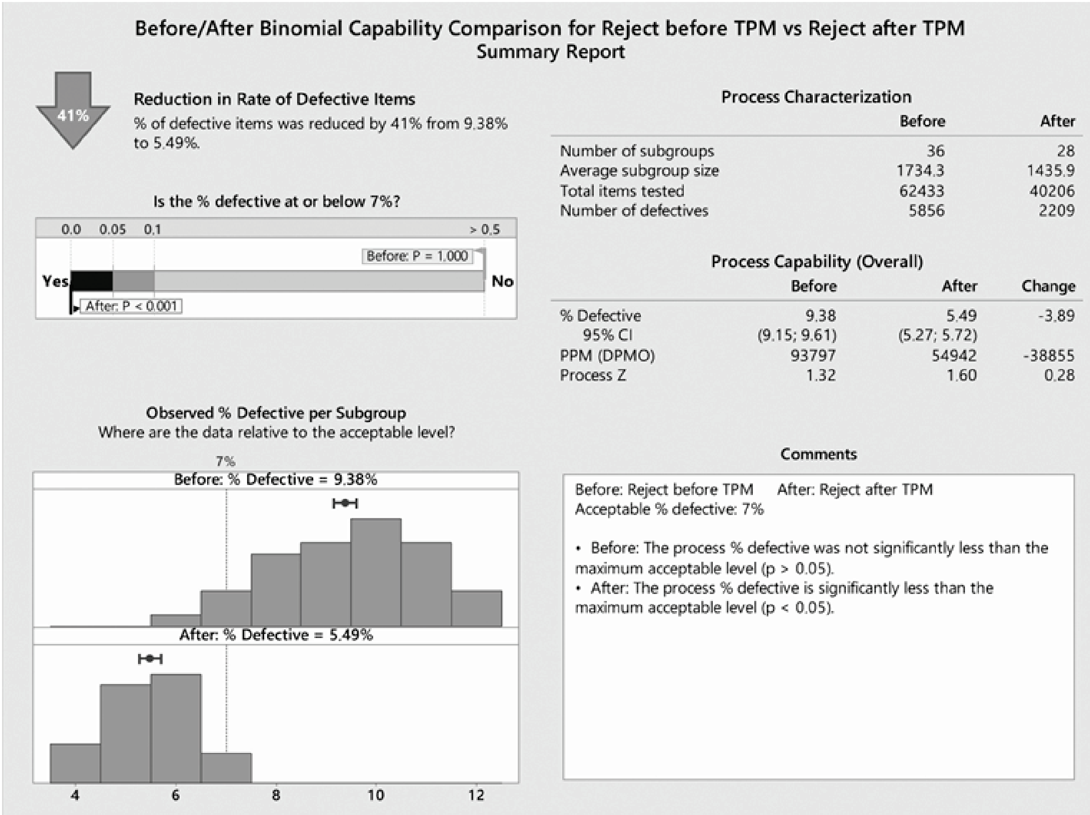

Fig. 1.The process capability (binomial distribution).
Source: own study in the Minitab program.

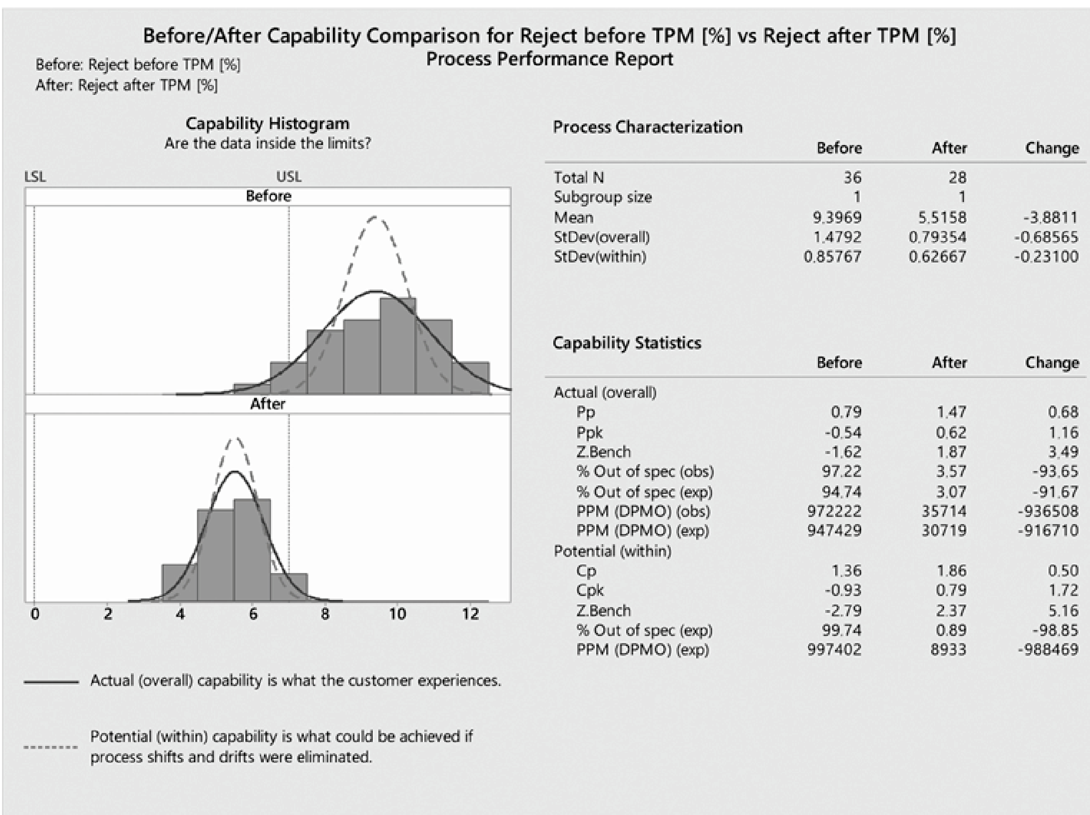

Fig. 2.The process capability (continuous data).
Source: own study in the Minitab program.

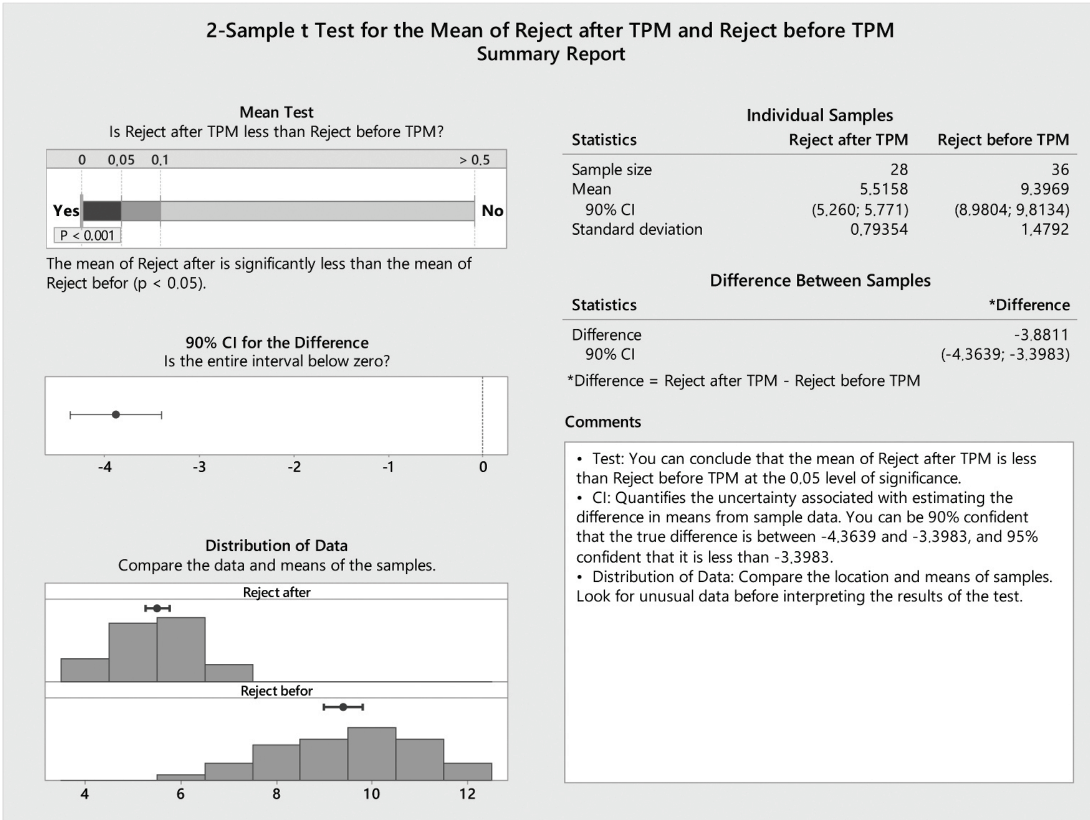

Fig. 3.T-Student test for the mean waste before and after implementing the TPM concept.
Source: own study in the Minitab program.

In the t-Student test for two means the following hypotheses were adopted:

- H0 zero hypothesis – the average waste after the TPM concept implementation is not significantly lower than the waste before the implementation of the TPM concept.
- HA alternative hypothesis – the average waste after the TPM concept implementation is significantly lower than the waste before the implementation of the TPM concept.

In the conducted test the p-value was obtained close to the zero value (p-value < 0.001), with the 5% level of significance. This means that the alternative hypothesis is true, saying that the mean waste after the TPM concept implementation is significantly lower than the average waste in the period before the concept implementation.

5. CONCLUSIONS

Test results presented in the previous chapter lead to the following conclusions. The variability of the manufacturing process measured by the production waste has been significantly reduced as a result of the implementation of activities related to the TPM concept. The waste level has decreased significantly from 93,797 ppm to 54,942 ppm, what has been confirmed by appropriate statistical tests. The process capability indicator Cp increased from 1.36 to 1.86, and the centring indicator of the process Cpk increased from -0.93 to 0.79. The presented results allow for a positive verification of the posed research hypothesis that the implementation of the TPM concept in the production company decreases the variability of the manufacturing process. It should be noted that test results cannot be generalised to a larger population of enterprises. They were carried out for the particular entity in the given market situation. Nevertheless, they are a strong prerequisite confirming the positive impact of the TPM concept on the functioning of the production plant. In the future it would be worthwhile to conduct studies on a larger sample of companies in order to confirm the assumed hypothesis.

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Adrian Wojciechowski
Poznan University of Technology
adrian.r.wojciechowski@doctorate.put.poznan.pl