

Sigma Level Verification of a Thermoplastic Industry with the Support of DMAIC Method

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Abstract. This study aims to determine the sigma level of the production process of a thermoplastics industry with the implementation of DMAIC approach. To achieve this purpose it was conducted interviews to know the production system, analysing the non-conformities in the produced forks. It was found that the industry has a sigma level that is the reality of industries in general, however, this level still does not equal to what is presented by large industries. The paper contributed to the improvement of industrial quality control, and the proposed method it is being evaluated so that other improvements can be implemented.

1 Introduction

The competitive intensification arising from the globalization caused the thermoplastic industries begin to adopt strategies that enable cost reduction, customer loyalty and expansion of its consumer market. In this context, the introduction of quality techniques for industrial processes has become indispensable for survival in the market.

In light of this, the Six Sigma philosophy is currently one of the most modern quality management concepts [1], causing industries to improve the quality control of this processes. With the advent of Six Sigma since the 1980s, it has been widely recognised as the most effective methodology for obtaining a breakthrough improvement [2], i. e., is a process focussed program and aims to improve the process through systematic methodology [3]. In this way, the goal is to stop the defects before they appear and reduce quality costs by adopting a predictive rather a reactive approach toward rejection and rework [4].

The utilization of this philosophy can be implemented through the DMAIC method (Define, Measure, Analyze, Improve, and Control) [5] that consists of refers to five interconnected stages that systematically help organisations to solve problems and improve their processes [6]. That's stages as evidenced in Table 1.

Table 1. Brief description of DMAIC phases [7].

DMAIC phases	Description
Define	Determines the process output characteristics that are critical to customer satisfaction, that is, what should be investigated
Measure	Qualifies and/or quantifies the existing non-conformities for the particular process and can assign critical inspection points to be analyzed
Analyze	Establishes the procedure for data collection and after the data being measured should start analyzing the process for find the sigma index
Improve	Is the improvement of processes, modifying them according to the results obtained and the targets set in Analyze step
Control	It has an emphasis on improving the quality of products and/or services, as the process control aims to continuously improve the industry

Moreover, it is essential to check the sigma level that an industry to set a plan of improvement and quality control, as well as assist in the implementation of the DMAIC method. In this sense, the achievement of Defects Per Million Opportunities (DPMO) is used in which displays the amount of errors that arise if an activity was repeated a million times [8] using three criteria namely [9]:

- Unit: The item produced or receiving assistance;
- Defect or non-conformity: shall mean any component or event that does not fit within the customer's specification limits;
- Opportunity: A probability of non-conformity happen.

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Therefore, the equation of DPMO can be expressed by Equation 1.

$$DPMO = \frac{1000 * \text{number of defects}}{\text{number of units} * \text{number of opportunities per unit}} \quad (1)$$

Furthermore, as from DPMO can measure the sigma index of process. Thus, Table 2 below is a list of some sigma indices with their respective values in DPMO, using the fluctuation of 1.5 standard deviation.

Table 2. Sigma process and DPMO.

Process	DPMO
1 σ	317.300
2 σ	45.500
3 σ	2.700
4 σ	63
5 σ	0,57
6 σ	0,002

In light of the foregoing, the aim of the paper is to check the sigma level of a product of thermoplastics industry, through implementation of the DMAIC method proposed in order to improve the quality control of their processes.

2 Methodological procedures

In order to achieve the proposed objective, the article was focused on the production of forks, analyzing only the two models with the greatest turnover, since among the manufactured product families, presenting a greater rework index. For purposes of verify de sigma level, were collected the data of the machines 20 to 25, since they operate periodically. Finally, data collection techniques are noted in Table 3.

Table 3. Data collection instruments and their applications in thermoplastic industry.

Data collection instruments	Applicability in industry
Non-structured interview	There was interviews with industry managers, supervisors and employees involved in production during the development of the article
Check sheet	Data for forks were collected each hour, checked the total number of produced forks, as well as the number of conforming and non-conformity (defective). These data were entered into a systematic check sheet as has defined fields for inserting fork model being produced; date and time of collection; units produced, compliant and non-compliant; responsible for completing and additional observations
Non-participant observation	In preparing the study, this type of observation was adopted in order to meet the existing production process, enabling greater agility to design the DMAIC project being suggested for managers

3 Results and discussion

The thermoplastics industry is located in the city of Campina Grande for more than ten years in the market, with the target audience throughout northeastern Brazil region. Its production is diverse, composed of: forks, display hangers, shoe soles, cable strainers, supports for rails and keychains. The production occurs in three shifts, counting 200 multipurpose employees who are trained periodically. The industry does not have an explicit policy of quality control, which is causing a lot of feedback from non-conformity products. Therefore, a partnership between managers and professors of the industrial engineering department of a local university was carried out, which allowed the development of this paper.

The process begins with receipt of raw material which arises from the supplier itself, in which material consists of Polyvinyl Chloride (PVC) pigmented with the desired color for the manufacture of forks. In this process, the production supervisors perform a count of the amount of material received, with the purpose of comparing with the number in the order of manufacturing issued by the supplier.

If a problem occurs, this it is passed immediately to the supplier, in order to correct the mistake. At this stage it is evident the first Research Points (RP) of the production process. It should be noted that at no time of this research there was a problem with the receipt of raw material.

Then the pigmented PVC is stored in the warehouse until your application is requested. Occurring the request, the PVC is sent to the sector of preparation of raw materials, where they are mixing it with the raw material of the same color coming from the rework, and this goes through a grinding process. It also occurs in the mixing process to maximum 20% of pigmented PVC value should be used for the raw material coming rework.

Subsequently, the raw material it is sent for injection molding so that the fork can be designed. During the injection process are removed four forks units, i.e. two pairs and one stalk (which is the leftover injection). The units are inspected visually and by touch the injection operator, in order to ascertain whether any non-compliance features described in Table 4.

If the forks are well manufactured the process continues to next stage. However, if there is any type of non-compliance they are arranged in a scrap box, together with the stalks of the process. Therefore, this stage is the existence of the second PI. If there is any problem with the injection, the operator should contact the supervisor of production to enable it to streamline the problem and possible solutions.

Performed the injection process, the operator hopes to collect 100 pairs of forks on your desk, so that was can put them in the products produced box. These boxes have a predefined number of forks to be produced, according to the order manufacturing company. When the box is full, another operator holds its drive to the warehouse. Finally, they are sent for shipping according to the needs of customer-supplier.

3.1. Defining problems (D)

During conversation with the managers and investigation of the production process, it was found that the main problem is the generation of rework by the forks production process, causing it to become focus of the study. Non-conformities can be divided into four types as shown in Table 4.

Table 4. Non-conformity presented in the injection process and its respective description.

Non-conformity	Description
Contaminated material	Are the remnants of dirt or stains on the forks
Burned Material	That's when the fork exceeds the maximum time in the injection mold, resulting in a burning fork
Incomplete injection	It occurs when the raw material does not meet all the mold, resulting in forks with the unfinished body
Operator failure	Are failures from operator error in the removal of forks

3.2 Measuring the quality of forks (M)

In order to proposed objective, we sought to identify the RP process, in which proved to be:

- RP 1: The arrival of the raw material, where it makes a quantitative inspection through the comparison of the amount of raw material supplier sent and the amount that arrive on the industry;
- RP 2: The verification carried out by injection operator in which is whether the fork is conforming or nonconforming, with a qualitative survey based on touch and visualization of the operator.

After the definition of the RP, it was found that has inspection characteristics for attributes, as the fork is regarded as conforming or non-conforming.

3.3 Analysis of failures in the process (A)

Defined the types of inspections and their characteristics, began the process of quantification of defects in each RP, thus reporting in which sigma level the industry is developing its activities. However, it was first necessary to establish the procedure for data collection. Therefore, Table 5 shows the adopted data collection procedures.

Table 5. Data Collection Procedures for RP.

RP	Collection time	Samples taken daily	Measurement location
Arrival of the raw material	13 days	1	Receiving dock of raw materials
Verification of forks	13 days	4	Number of machines 20 to 25

Regarding the RP 1, during the data collect there was no non-conformity. Thus, only the RP 2 was addressed in later analysis. From the perspective of RP 2 that perform the fork checks, if found the data shown in Table 6, below.

Table 6. Measured data in the industry.

Machine number	Total of opportunities	Total of non-conformity
20	16.070	295
21	17.520	346
22	16.826	313
23	17.240	399
24	16.132	68
25	18.856	442

It is verified the Total of opportunities is the number of forks is produced during collection, including compliance and defects. Knowing the DPMO can be calculated by Equation 1, one can calculate the DPMO for each machine, as described in Table 7 below.

Table 7. DPMO calculation for the forks injection process.

Machine number	Total of opportunities	Total of non-conformity	DPMO
20	16.070	295	18357,2
21	17.520	346	19748,9
22	16.826	313	18602,2
23	17.240	399	23143,9
24	16.132	68	4215,2
25	18.856	442	23440,8

With the data obtained above, it becomes possible to conversion of the DPMO for the sigma level process, considering the deviation sigma of 1.5. Thus, Table 8 shows such a conversion.

Table 8. Sigma level calculation for fork injection process used for each injection [7].

Machine number	DPMO	Range of DPMO	Sigma level of process
20	18357,2	17.864 < X < 22.749	2,1
21	19748,9	17.864 < X < 22.749	2,1
22	18602,2	17.864 < X < 22.749	2,1
23	23143,9	22.750 < X < 28.715	2
24	4215,2	3.466 < X < 4.661	2,7
25	23440,8	22.750 < X < 28.715	2

It is observed that the injectors are inserted into the average of other industries, with its sigma ranging from 2 to 2.7, as evidenced by the Table 9. In this context it is essential to look for causes of defects, thereby improving the sigma level.

Table 9. Process sigma level and the classification of industries [10].

Sigma level	Classification of industries
$4,5 < X < 6$	Uncompetitive industry
$1,5 < X < 4,49$	Average industries
$0,5 < X < 1,49$	Uncompetitive industry

3.4 Design to improve the process (I)

From the acquired knowledge in the company, it is recommended an improvement plan which consists in:

- Develop a team of employees to review each checkpoint periodically, as well as the entire production process;
- Train a staff about the importance of inspection, showing rework generated by the industry;
- Conduct qualitative inspection upon receipt of raw materials by sampling to assess the quality of the material is in accordance with the needs of industry;
- Develop a multifunctional matrix in relation to employees and production sectors in order to check which one has a greater ability to work in Forks sector;
- Integrated application of the seven quality tools, which were the Ishikawa diagram, Pareto chart, histograms, check sheets, scatter charts, flow charts and control charts. The integration of these tools allows identifying the possible causes of the problems.

3.5 Design for controlling the process (C)

After all these improvements mentioned above, it is necessary to use industry methods to maintain satisfactory level of quality, and to continuously improve its processes. Thus, the inclusion of the PDCA cycle is an extremely important key factor as it emerges as a strategic planning based on quality. With the deployment cycle, it is suggested the training of employees in relation to Team Six sigma, forming the Green Belts, Black Belts and Master Black Belts on the shop floor.

However, some recommendations are conducive to industry at the time of implementing the control phase of the DMAIC method, as follows:

- Hiring qualified professionals to give lectures to six sigma team on the subject of control of the production process;
- Adoption specific software to six sigma control;
- Develop a team of critical evaluation of the method, from the use of data collected and situations experienced in the industrial scope.

Still on the possibility of implementing the PDCA cycle in the Control phase of the DMAIC method, has the following suggestions:

- Plan: This step may begin with the planning team six sigma, set employees who can act on it;
- Do: it must be set in motion all the planning performed in the previous step, making six sigma team starts its work;
- Check: the Six Sigma team must check the index sigma process, as well as another team of developers can analyze the results obtained by the seven quality tools;

- Act: Due to the results obtained in the selection stage, the Six Sigma team should seek ways to act on the difficulties according to the established in the Planning phase.

4 Conclusions

The Philosophy Six Sigma proves to be an effective and efficient strategy to ensure quality. On the other hand, its implementation involves a master plan by senior management and periodic training of all employees. Thus, the DMAIC method emerges due to its great versatility [11], which allows greater flexibility for Team Six sigma achieve your goals and objectives.

This paper sought to know the product that is bigger rework index, analyzing the existing critical points, aiming to get the sigma level that the industry stayed in their production processes. It was found that the industry has a sigma level comprising the average of industries in general, but this index is still far compared to level six sigma presented by large industries. In parallel, it was also proposed the incorporation of the DMAIC method in the industry that can offer competitive gains besides causing products with higher quality standards.

Therefore, the development of this study contributed to a reassessment of existing quality management in the industry, knowledge is harnessing widespread during the period of their realization. In addition, it is noteworthy that the proposed plan in this paper is feasible and has high probability of being implemented, given that its principles can be adapted to the industrial reality. Currently, the model is being implemented in the company and will be evaluated in its entirety in future researches

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