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Research Article

6 Sigma and DMAIC Method: Basic Tool Teaching and Application for Beginning Practitioners in Automotive Assembly

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Abstract

The 6 Sigma methodology is widely used in different types of industries, from manufacturing type industries to service industries. The objective of the methodology is based on reducing variability in the production system, that is, achieving that the standard deviation is as many times as possible within the mean of the process being measured. The Six Sigma methodology is based on the DMAIC process which is to define, measure, analyze, implement, and control, with these stages, it is possible to identify quality critics and understand their root cause, therefore, if it is known Why a problem occurs, it can be fixed. With DMAIC methodology, the reduction of the variation that arises from the types of problems that were mentioned within the 6 Sigma methodology is sought. In the other hand, 6 sigma and DMAIC process possess more that 40 quality tools to improve the critical of quality and in these manners increase the company efficiency. In such a way, the objective of this research is the presentation of the most effective tools and simply to apply in companies of the methodology, also how this quality tools can be applied in any type of problem to increase efficiency and productivity, this with the necessity of companies' quality improvement and beginners' practitioners can used as a simple way of the methodology implementation.

Keywords: Quality; 6 Sigma; DMAIC; FMEA; SIPOC; VOC; Variation.

1. Introduction

Six sigma arises from statistics, which is defined as the standard deviation of the data concerning the mean values and the less variability (Navarro Albert et al., 2017). When working at a six sigma level, the degree of efficiency taken in parts per million is 99.99997% efficiency, that is, only 3.4 or 4 parts of defects can or are expected to be produced for every million parts produced (Herrera Acosta & Fontalvo Herrera, 2006). However, it is known, through the analysis of different processes, that every process, even if it works at a level of six sigma, will have an inherent variation of 1.5 sigma over time, this is due to the types of noise existing in every system. production, that is, internal noise, noise between parts and external noise (Safdar & Ahmed, 2014). In this way, the six standard deviations of the methodology can be treated as a reference that cannot be reached, but it can be had as a type of philosophy of improvement (Giménez, 2005). Therefore six sigma methodology is based on project methodology in a set of phases called the DMAIC process, that is, define, measure, analyze, implement and control (Ocampo & Pavón, 2012). With the use of these phases i.e.,, DMAIC process, the implementation of six sigma projects is possible since they allow the analysis of the critics that are divided into quality critics (Nonthaleerak & Hendry, 2006). This variables critics are: Transport critics and cost critics, within these it is possible to measure the variables that present some problems and identify why this failure is happening, all to improve the process, as mentioned, of goods and services (Curristine et al., 2007). Within each phase used in the implementation of six sigma projects by using the DMAIC process, there are more of 40 quality tools that can be used to determine which variable or variables it is desired to control first and after a set of analyzes. By using this DMAIC process the root cause of these variables that fail can be determined and it is possible to implement an improvement in the behavior of the variable or a reduction as much as possible of the defects that the variable that is being analyzed entails (Salkind, 2013). The over 40 tools can be divided by each stage of the DMAIC process for a better understanding and its proper implementation, for example, the voice of the customer, process mapping diagrams, design of experiments, root cause diagrams, among others (Uluskan, 2019). This manuscript presents the phases of the Six sigma DMAIC process and its proper implementation for the reduction of critical variables, using quality tools that are defined in each part of the six-sigma process. So that the implementation and types of tools that can be used in the application of the 6 sigma methodology are presented in a simple and easy-to-understand way so that the use of this method can be efficient in increasing productivity, reducing variability, critical variables, and adequate decision making (David Meza & Ki-Young Jeong, 2013).

2. DMAIC Process Concept and Used Tools

The process that uses the 6 sigma methodology for the reduction of waste or the elimination of problems in critical variables is the DMAIC process, which is to define, measure, analyze, implement and control

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(Rodriguez et al., 2022). This process consists of the identification of the variable(s) that are of a critical type about quality and make the product, process, or service did not meet the requirements of the clients. Within each phase of this process, different quality tools are used that are even cataloged for each phase to guarantee compliance with the established objectives, that is, to reduce the selected critical variable as much as possible (see Figure 1) (Garza et al., 2016).

Fig .1. DMAIC Process Tools

Next section presents the phases of the 6 sigma and DMAIC process and the most used tools to this process improvement.

3. Phase Define in 6 Sigma Project and DMAIC Implementation

In the defining stage, the objective is to find out about all the possible problems or variables that are affecting the product or process and catalog them, for this, tools such as the SIPOC diagram, the voice of the customer, process mapping, and chain mapping are used. of supply, among others (Morales, 2007).

In addition, at this stage, it is defined once the selected variables are in place, which would be the goals to be achieved by applying the six-sigma methodology and the DMAIC process (Simion, 2021). Because once it is known which is the quality critic or what is affecting the quality, it is possible to determine in more consistent figures what is going to be achieved after the implementation of the project. These objectives, in addition to the reduction of the variables, are almost always done based on the savings that are expected to be obtained by reducing the significant problems that they have (Mantilla Celis & Sánchez García, 2012). The tools used in the define stage are.

3.1 Process mapping

Process mapping is a graphic illustration of the stages of a process, which do not identify the dynamics of a process since they are static (Monika & Jan 2013). In addition, process mapping is qualitative and there are different uses for this tool. Process mapping provides an overview of all processes so that the basic operation of a company can be observed in these, without having to go into such deep technical details, which allows a generalization of the development of the product or provision of the service. The process map focuses on representing classifications, relationships, and dependencies between singular processes (Poels et al., 2020). These aspects are usually shown as a visual representation that serves as a means of basic communication and for a greater understanding of current business processes (Price Waterhouse Coopers., 2017).

3.2 Deployment of the quality function

The productivity of a company is affected by quality, processing time, value chain time, and cost, among others (Olaya-Escobar et al., 2005). As time progresses, customers perceive quality as something innate to the product and therefore this must be fulfilled according to its needs (Duque, 2005). That is, the needs of a client must be transformed into product specifications, and these, in turn, from the process to satisfy the same client, which results in something that could be seen as complex, however, a tool that allows this cyclical process to be carried out. and in turn, prioritizing these needs or specifications is the deployment of the quality function (QFD)) (Basri, 2015) .

3.3 Kano model

The Kano method is a quality management tool that helps in the development and analysis of products and services (Nurjannah et al., 2020). This method classifies customer requirements, mandatory, one-dimensional, and attractive. A requirement is considered mandatory if its absence causes customer dissatisfaction, one-dimensional if with this feature the customer's compliance increases linearly with the functionality of the product or service, and attractive if customers value this attribute. if it is present but does not denote a difference in its absence(Horton & Goers, 2019).

3.4 SIPOC diagram tool

The meaning of the acronym SIPOC is Supplier, inputs, process, puts, and customers. This table is a graphic representation of a process in which the internal and external suppliers are integrated, the inputs of each supplier, the process flow diagram, the outputs of that process, and finally the clients of those outputs. internal and external in the same way (Marques & Requeijo, 2009). The objective of this method is the improvement of processes based on the schematic representation of the key elements of the process. The SIPOC method is used to broadly analyze the process, analyzing in turn the clients and what they expect because of said process.

4. Measure Stage in 6 Sigma DMAIC Project

The measure phase uses the quality critics identified in the define stage, that is, the variables that are considered significant in the generation of problems within the process (Rahman et al., 2017). As is well known, there is variation in every process, and from this stage, the objective is to identify this variation. For this stage, it is extremely important to know what you want to measure and how it can be measured (Hambleton, 2007). For the selection and measurement of the critical variables, different types of tools are used that will help to know the variation and the level of significance of the variables selected in the previous phase.

4.1 Process Capacity Index

The process capability index (PCI) is formulated in such a way that it measures the times that the standard deviation of the process is within the customer's specification limits. On the other hand, when a process is normal and it is under statistical control, then the quality characteristic of the manufactured elements to be measured is expected to be between $\mu - 3\sigma \; and \; \mu + 3\sigma$ (99.73%). Therefore, if 6σ is less (or greater) than the interval of the tolerances to be met, we have:

$$C_p = \frac{USL-LSL}{6\sigma} \quad (1)$$

4.2 Pareto diagram

The Pareto diagram is a graphic representation where the possible variables that represent a problem for the company are established. This diagram is also known as the ABC diagram because it gives priority to the most critical variables. This diagram uses the 80%/20% rule, that is, eighty percent of the problems in a process are due to twenty percent of the critical variables. With the use of the Pareto diagram, it is possible to determine which variables should be paid attention to and determine their causes and implement improvements in the following stages of the DMAIC process (Westcott, 2009).

4.3 Failure mode effect analysis (FMEA)

The FMEA is a very powerful tool that allows us to identify errors in products and processes and objectively evaluate their effects, causes, and detection elements, to avoid their occurrence and have a documented method of prevention. In addition, the FMEA is a living document in which a large amount of data about our processes and products can be stored, making it an invaluable source of information (Domagala, 2022).

• Product: serves to detect possible errors in product design and anticipate the effect they may have on the user or manufacturing process.

• Process: this is an analysis of the errors that can occur at each stage of the process and is used to prevent those failures from having negative effects on the user of the product or service or subsequent stages of the process.

• Systems: used in software design, to anticipate errors in its operation.

• Miscellaneous: FMEA exists for many other types of errors that generate negative effects and whose causes must be documented to anticipate problems (Qiu & Zhang, 2022).

5. Analyze the Stage of the DMAIC Cycle

The analysis stage within the DMAIC process aims to identify the source of the problem that is caused by the critical variables selected from the measurement stage (Mansur dos Reis et al., 2022). The tools that are used in this stage can vary according to the type of project that is being carried out, however, all of them must be based on the scientific method, that is, the collection of data and its analysis in a precise manner. and following a methodology that allows the correct interpretation and identification of the root cause.

5.1 Value stream map (VSM)

The value stream map (VSM) for its acronym in English, is a graphic representation of the supply chain where it is included from suppliers to customers. This tool is an efficient way to globally analyze what happens throughout the value chain and determine which operations do not add value or have a very long waiting time. After identification using the value stream map, the critical variables of this diagram can be ranked to reduce or eliminate them (Paredes Rodríguez, 2017).

3.10 Tool 5 why?

The Five Whys is a systematic tool that allows the identification of the root cause of a problem by analyzing why it is occurring, in addition, according to the answer obtained, the same question continues to be applied until reaching a cause. the root of the critical variable. It should be noted that, although the tool is called five whys, it does not necessarily have to be applied only five times, the objective is to find the root cause of a problem, therefore, the number of whys that will be applied will depend on whether it is reached. a cause of the analyzed. The ultimate goal of the 5 Whys is to determine the root cause of a defect or problem to fix it effectively (Khan et al., 2019).

3.11 Ishikawa (or cause-effect) diagram

The cause-effect or Ishikawa diagram is a graphic method that relates a problem or effect with the factors or causes that possibly generate it (Carmen Nadia Gheorghe, 2010). The importance of this diagram lies in the fact that it forces us to look for the different causes that affect the problem under analysis and, in this way, the mistake of directly looking for solutions is avoided without questioning what the true causes are. The use of the Ishikawa diagram (DI) will help not to take the causes for granted, but to try to see the problem from different perspectives. There are three basic types of Ishikawa diagrams, which depend on how the causes are sought and organized in the graph (Liliana, 2016).

6. Implement Stage of the DMAIC Cycle

In the implementation stage, the root causes of the problem have already been identified, so the solution must be easy to implement and the improvement must last for a long time in the company (Smętkowska & Mrugalska, 2018). If continuous variables are used or factors were detected in this stage, an experimental design can be carried out to determine the best arrangement of the variables to reduce the problems that were obtained in the defined stage (Akmal et al., 2021).

6.1 Brainstorming

Brainstorming or brainstorming sessions are a form of creative thinking aimed at allowing all members of a group to participate freely and contribute ideas on a certain topic or problem (Bhargava & Gaur, 2021). This technique is very useful for teamwork since it allows reflection and dialogue regarding a problem and in terms of equality (Miluska Aylin, 2016).

6.2 Design of experiments (DOE)

It is a test in which changes are made in the independent variables so that changes in the independent variables can be observed, to obtain the best-desired result, that is, the greater is the better, the lesser is the best. or nominal is best (Fhionnlaoich et al., 2019). A design of experiments can be implemented to overcome limitations. In essence, the design of experiments is the strategic planning of experiments and the application of statistics. It provides a robust framework designed to maximize the amount of information obtained for a given number of experiments (Arnold, 2006).

7. Control Stage of the DMAIC Cycle

The control stage consists of maintaining the improvements implemented, for which it is possible to use some tools that allow visualization and thus maintain control of what has been improved. On the other hand, at this stage, the variables that were determined to be criticized are measured again to verify that the improvements implemented reduced the problem that was defined in previous stages (Singh & Khanduja, 2014).

7.1 Statistical process control

Statistical Process Control (SPC) is used to analyze and control the process. performance, proactive control of processes, distinguishing between natural and assignable variation, identifying and preventing the process of special causes, and involves the use of control charts to determine if a process is operating under control (Estanislau et al., 2022). The best tool for investigating variation in a process is a control chart. A control chart is often called a time series diagram that is used to monitor a process over time (Liu & Zhang, 2014). It is a graph of a process characteristic, usually over time with statistically determined limits. When used for process monitoring, it helps the user to determine the appropriate type of action to carry out the process, depending on the degree of variation in the process (Prasetyo et al., 2022).

8. Automotive Harnesses Assembly Application

8.1 Definition stage in 6 sigma DMAIC application

The objective of this research is to increase the efficiency of the ForkLift 011 production line, which works under a wide range of models, which are classified into five patterns A, B, C, D, and E. In the production line, there are currently a total of 8 tables dedicated to the Sub-Assembly, where seven people work. To carry out an analysis of the current situation and the quality critics, the QCD (Quality, Cost & Delivery) tool was used.

The defects are measured by DPH (Defects per 100 harnesses produced), and the global goal is 1.17 DPH for the production line, figure 3 shows the number of defects in percentage obtained through the QCD.

89% of ForkLift production line 011 defects are detected in the Electrical Test process, that 89% implies a total of 134 defects per production turn.

8.2 Measurement Stage in 6 sigma DMAIC application

In this stage, the number of defects in the production line is measured through process capacity indices, because the process capacity indices show the amount that the standard deviation is within the customer's specification limits, which implies an easy interpretation of the number of defects and its easy contrast in the control phase (Kaya & Kahraman, 2011).

8.3 Process capability index

The process capability index is formulated in such a way that it measures the times that the standard deviation of the process is within the customer's specification limits. When it is true that a process is normal and it is under statistical control, then the quality characteristic of the manufactured elements to be measured is expected to be between (99.73%). On the other hand, the index, known as the real process capacity index, is considered a corrected version of the one that does consider the centering of the process. The results obtained in the application of the process capacity indices (see Eq.1) in the production line were obtained:

CpK: 0.1966
PPM: 274,900

8.4 Analysis stage of DMAIC cycle

Therefore, it is concluded that the production line is not capable of meeting the customer's requirements, on the other hand, a level of leads to defects, which generates losses of material, product, and the repair of defective harnesses, it is said a loss of quality.

8.5 Ishikawa diagram application

Once the sigma level of the production line is obtained, an Ishikawa diagram is carried out to identify the root cause. The results obtained in the pilot test are considered to solve the problem (see Figure 2).

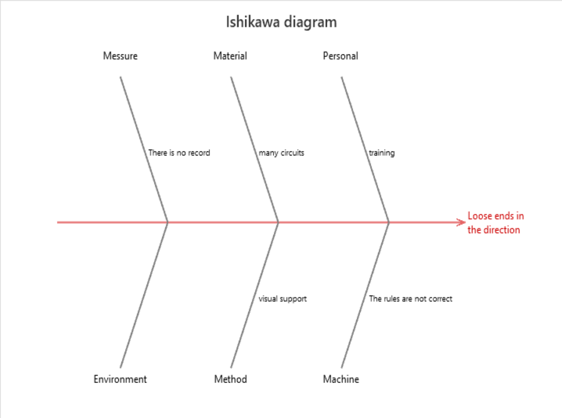

Fig. 2. Application of Ishikawa Diagram

It was found that the method was not correct, since the sequence on the ruler causes the cables to twist; Regarding labor due to lack of training, optimal results are not obtained, since the method is new, and for the Sub-Assembly line it is unknown, this entails a different time from the standard and errors on the part of the workers.

8.6 5 whys method

1. Why?
Generates dead time due to lack of cable
3. Why?
Malfunction of the KANBAN methodology
4. Why?
There is no follow-up/application of the methodology
5. Why?
KANBANs are not activated/removed from the

Fig. 3. 5 Whys diagram

With the implementation of this tool, it was possible to observe what the main problem was, and each root cause that caused it was detected on time. Offering each problem, a timely solution to improve the efficiency of the ForkLift 011 line. This tool facilitated how problems were detected from the root cause in the production line. Once the functionality and benefits that the implementation of the improvement in the production line would bring were verified, the team undertook the task of designing a slider that would meet the needs of the harness, always taking care that the components were not damaged and easy for operators to handle.

8.7 Improvement stage of DMAIC cycle

The improvement of the new ruler in the sub-assembly process was put into operation to reduce the loose ends that reached the addressing area, thereby reducing labor that does not add value to the product and reducing the time to route the entire harness.

All the personnel involved in this production line met to let them know how the new operation of the improvement would be in the areas of its assembly and direction. So that all staff is aware of what is intended to be achieved with this project.

It is through pilot tests that the personnel directly involved with the product, in this case, the line operators, were trained, and this gradually adapted them to work with the new method that facilitated work in said areas.

With the introduction of the improvement to the production line, the number of operators required for the Addressing area was automatically reduced.

8.8 Control stage of DMAIC cycle

In this last stage, a record of a sample of times that was carried out in the Addressing area was made, to observe the behavior of the implementation of the improvement in the production line. Below is a graph that was obtained with a sample of 14 times taken in the Directing process where it is seen that the improvement presents shorter times than those obtained if the process continued to be carried out in the manner traditional (see Table 1).

Table 1.
Pilot Run

Model	Cycle Time
229	700.00
2238	606.00
3560	555.00
1297	663.00
229	775.00
223	726.00
3560	603.00
229	775.00
3560	560.00
3560	524.00
229	654.00
229	817.00

Below is a figure which was obtained with a sample of 40 times taken in the Directing process where it is seen that the improvement presents shorter times than those obtained if the process continued to be carried out in the manner traditional. With the implementation of the improvement, it was possible to reduce the total time in the addressing process by 37%, which resulted in the process being faster than in the traditional way.

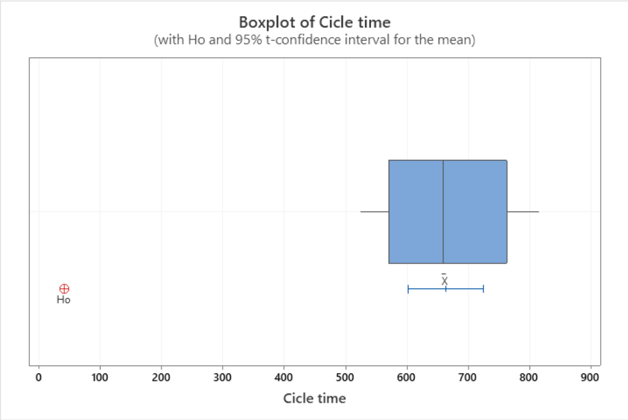

Fig. 4. Box Plod Difference between means

9. Conclusion

DMAIC methodology is used, which means define, measure, analyze, implement, and control. At each stage of the DMAIC process, there are quality tools that allow the achievement of the stage in which the project is. In the same way, each stage of the methodology was described, seeking that in the simplest way it can be used by practitioners of the Six Sigma method, in the implementation of projects and reduction of quality critics, from different types of companies, from conventional production companies to service companies or even government. On the other hand, can conclude by stating that the objective of this project, which was to increase the efficiency of the ForkLift line 011 as well as reduce the man hours required to produce, has been met. Having a very favorable impact on the company where he did his professional residency. It is very important to point out that the causes found that directly affected the efficiency of the production line, as well as the large investment in man-hours to produce, was the large number of personnel assigned to one of the areas that did not add value to the product., this area was Directed, once the root cause was identified, the reduction in the number of necessary operators was successfully achieved.

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