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USE OF THE DMAIC TOOL: HIGH FAILURE RATE IN THE HEAT SINK BOLTING PROCESS

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ABSTRACT

The DMAIC methodology has the potential to detect flaws in production processes and point out improvements for the results. In this sense, the general objective of this research seeks to point out through a case study how the use of DMAIC within a company in the manufacturing sector of other assorted electrical equipment and components, evaluating the high failure rate in the heat sink screwing process, can be an effective tool to leverage and improve the company's production processes, thus resulting in greater profitability. Thus, the specific objectives seek to present and conceptualize what is quality management, conceptualize what is production management and how the application of its primary principles result in advantages for an effective production management, elucidate what and how a process mapping occurs in accordance with the process engineering, To present and conceptualize what the continuous improvement of processes is and what its main tools are, to conceptualize what the DMAIC methodology is, and finally, to conduct a case study in a company that produces and supplies automotive parts, pointing out how the use of DMAIC can be a great differential, in order to reduce failures in production processes and leverage profitability. In order to reach the objectives, bibliographical research was carried out to survey the theoretical basis and, subsequently, a case study was applied in Company X. Finally, it is suggested that a new case study be conducted, where the DMAIC methodology can be applied again, in order to demonstrate its effectiveness in manufacturing companies.

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INTRODUCTION

To be successful, to position itself advantageously over the competition and to increase consumer interest in the products and services it offers, the company must make sure to control and guarantee quality. What it sells must be constantly improved to meet market demands and customer expectations. It therefore implements a quality approach that brings together and organises all aspects of the company's operation in order to achieve quality objectives. Quality management is critical to the growth and performance of any company. It is also a valuable resource in the struggle for customer connections as it strives to provide a better customer service experience. Quality must be maintained at all levels for your business to thrive (MORAIS; GODOY, 2006). The importance of quality management lies in its potential to help companies improve the reliability, durability and performance of their products.

These elements help a company to stand out from the competition (CERQUEIRA and NETO, 1991). The implementation of a quality approach within a company aims to control, guarantee and plan the management in a quality system in an industry. It consists of improving the quality level of products and services. This is intrinsically linked to production processes and procedures. In fact, quality procedures are part of the continuous improvement process. It aims to optimise management systems, professional practices and customer satisfaction. Thanks to the implementation of a quality management system, any industry ensures the monitoring of quality indicators. This also makes it possible to define the overall quality approach (the performance of internal audits) to detect areas for quality improvement. The quality manager is usually the first person responsible for quality management within the company. He monitors quality and safety within the organisation, defines the quality policy and ensures continuous quality improvement.

In terms of quality, the main objectives are to increase customer satisfaction and, more generally, to enable the company to gain in efficiency and performance. However, the customer is not the only party to be satisfied when developing and applying a quality approach; suppliers, shareholders, but also the company's staff should also be taken into consideration (WEBB, 2019). A quality approach and its guidelines should be clear and accessible to everyone internally. It will be difficult for anyone in the business to comply if they do not understand them. The success of the quality approach also depends on the degree of involvement of the staff as a whole. Managers ensure that the guidelines are applied and listen to the employees, while they carry out their duties scrupulously respecting the procedures, having the opportunity to share their suggestions (MESQUITA and ALLIPRANDINI, 2003). Moreover, the effectiveness of the quality approach is only guaranteed if it integrates observations and suggestions at the service of improvement. This information comes both from within the company (defect observed by an employee in terms of equipment, idea to improve his performance, for example) and from outside (consumer opinions). Listening and analysis are also part of the conditions for a successful quality approach in the company. Within this question, the present work will seek to answer, through a case study, how the use of DMAIC in a manufacturing company of other assorted electrical equipment and components, evaluating the high failure rate in the *heat sink* screwing process, can be an effective tool to leverage and improve the company's productive processes, thus resulting in greater profitability?. In order to achieve an effective contribution and for the academic environment, this research is justified from its comprehensive content as to the theme, adding or strengthening the knowledge already present in the literature on the use of DMAIC methodology to elucidate possible problems and failures that are found in the production processes in organizations. The research is also justified from its rich and accessible presentation assimilation and understanding, adds to its social context, where people in possession of technical knowledge or not will be able to understand and know the context presented, thus, this group may receive information regarding the use of tools that have the potential to provide improvements in the productive results on the factory floor.

THEORETICAL FRAMEWORK

Quality Management: Quality Strategies: Modern industries are on the track of a highly competitive market, seeking to win customers. For a company or industry to have competitive advantage, one of the main criteria is to ensure the good quality of its products and services. The development of an appropriate quality strategy requires taking into account several factors (SOUZA et al., 2019):

- External environment: political, cultural, technological progress, changing consumer needs, market volatility, increased competitiveness, integration, globalisation, lack of energy resources;
- Internal environment: which is associated with production capabilities, closely linked to skills and competencies in management, marketing, design, research and technology.

The implementation of the quality strategy requires a defined product strategy. the most important factors that determine the success of the product strategy are (TÓFOLI, 2011):

- The level of income and price elasticity of demand for manufactured goods;
- Knowledge about customer needs and preferences;
- Information on market size and scope;
- The ability to understand product design and remove its weaknesses and threats;
- The increase in consumer actions of evaluation and purchase, regardless of the channel used, has caused a revolution in the processes and manufacturing sector. Consumers today have at their disposal online and offline channels where they can find products that they are looking for and that deliver answers to their problem, meeting their needs.

To achieve such a goal to serve the customer, there are strategies that can be applied (SOUZA et al., 2019):

- Customer Ombudsman, it is important that the manufacturer attends and listens to its customer, since the evaluation of the use of the product will come from him;
- Reduce order cycle time and rework by automating pricing, quotations and customer approvals with a single integrated system, which will minimise potential errors in production;
- Tracking product quality levels in real time and setting individual and team targets to improve them works when every employee sees how important what they are doing is;
- New product designs must have rigorous quality and engineering readiness reviews before being released for production;
- Use real-time quality data to bring urgency to the need for improvement;
- Use of Quality audits to find possible faults in the production line and obtain improvements;
- Using real-time data to measure and reduce the total cost of quality and improve customer satisfaction, achieved faster decision-making;
- Work flows under supervision so that possible faults can be remedied quickly.

Production Management: Production is a scientific process that involves the transformation of raw material (input) into the desired product or service (output) through the addition of economic value (TODOROV, 2021). Production can be broadly categorized into the following based on technique:

- Production by separation: Involves the desired output is achieved through the separation or extraction of raw materials. A classic example of separation or extraction is oil into various fuel products (RITZMAN et al., 2004);
- Production by modification or improvement: involves changing the chemical and mechanical parameters of the raw material without changing the physical attributes of the raw material. The annealing process (heating at high temperatures and then cooling), is an example of production by modification or improvement (TODOROV, 2021);
- Assembly manufacturing: the production of cars and computers are examples of assembly manufacturing (RITZMAN et al., 2004).

Production management involves planning, organising, directing and executing production activities. The ultimate goal of any production management solution is to convert a collection of raw materials into a finished product. Some people refer to production management as the meeting of the 6 "Ms" (ANDRADE et al., 2010):

- *Mens* (men);
- *Money*;
- *Machines*;
- *Materials*;
- *Methods*;
- *Marketing* (markets).

These constituents come together to provide consumers and businesses with the products they need or want. Production management principles are often referred to as operation management principles and are designed to facilitate the production of goods of the required quality and quantity. In an economic environment that has become so competitive, financial issues are crucial. The selling price of products depends more and more on market demand and is still strongly influenced by competition. To remain competitive and, above all, to ensure an adequate profit margin in the sale of their products, the main resource of industrial companies is the reduction of production costs (ANDRADE et al., 2010).

An efficient production management solution will also deliver products at the time they are demanded by the market at the lowest possible cost. Any successful production management solution requires optimal use of production capacity to keep costs to a minimum (PEINADO et al., 2007).

Process Mapping: Process mapping is a management tool used to visually represent the workflow and the steps and people involved in a business process. These maps are also commonly called flowcharts or workflow diagrams. Organizations use this tool to gain a better understanding of a process and improve its efficiency (PACHECO et al., 2021). By creating easy-to-follow diagrams, stakeholders can identify aspects of a process that can be improved. This includes identifying bottlenecks in workflows and other inefficiencies, such as repetitive tasks, ideal for automata (MOREIRA, 2011).

Process mapping offers many benefits. Several benefits are mentioned on an abstract level - better understanding a process and increasing efficiency. More specific benefits of creating a process map include:

- Increase in job satisfaction. Employees know what to expect, what their responsibilities are and appreciate the transparency that a process map offers (PASCOAL, 2008);
- Improved employee performance. Employees who understand their roles and where to find help when they need it are more productive (MOREIRA, 2011);
- User-friendly. Business process maps are simple to follow and are ideal for tasks such as employee training and brainstorming sessions. BPM software makes it easy to design and test processes, as well as share them with the team (PACHECO et al., 2021);

Process maps use visual representations, such as basic symbols to describe each element of the process. Some of the most common symbols are arrows, circles, diamonds, boxes, ovals and rectangles. These symbols can come from *Business Process Model and Notation* (BPMN) or *Unified Modeling Language* (UML), which are graphical notation methods for process maps. Most organizations will need to use only a few of the most common symbols to complete a process map. Some of these symbols include (PACHECO et al., 2021):

Since process maps leverage visual clues and symbols, they make it easier to communicate a process to a broad audience. This can lead to greater engagement, as long-form documentation can be more tedious for owners to create and end users to consume (HAMANAKA et al., 2019). By leveraging pre-made templates within process mapping software, teams can easily collaborate and discuss ways to streamline work processes, enabling business process improvement. By doing so, companies can also better address specific challenges, such as employee onboarding and retention or declining sales (MOREIRA, 2011).

Continuous Process Improvement: Nowadays, improving quality is a recurring problem for companies. The optimization of this process is often the responsibility of the continuous improvement manager. Continuous improvement is an essential approach to guarantee the sustainability of management systems and performance improvement (MESQUITA and ALLIPRANDINI, 2003). In a constantly changing context, increasingly demanding and with increasing competition, it is essential that each company implements actions that enable it to continuously improve. These actions respond to opportunities for improvement and should bring quantifiable results for the entire organisation. The enterprise is a living system and the continuous improvement approach helps to structure this dynamic, defining a framework for the implementation of these actions (JUNIOR, DE LIMA and STOCO, 2020). The continuous improvement approach consists of carrying out permanent and sustainable actions to improve all the company's processes, eliminating failures and strengthening the assets that generate value. This allows for regular re-evaluation of integrated practices, questioning processes and developing the company in a sustainable way (GONZALEZ and MARTINS, 2007). Integrating a continuous improvement process into your company culture will enable you to gradually increase growth and performance at all levels of the organisation, reduce costs and improve your company's efficiency, productivity and profitability. Continuous improvement is also one of the main principles of the ISO 9001 Quality Management System standard (LOUSAS, 2018). As the 5th pillar of quality management, according to the international standard ISO 9001, continuous improvement is an operational approach aimed at gradually reducing dysfunctions in a company's processes, customer dissatisfaction or even risks. Gradual, focused on value creation and waste reduction, it logically does not require significant investments or organisational upheavals that could disrupt the teams. On the other hand, its effects are only felt in the medium and long term (JUNIOR, DE LIMA and STOCO, 2020). Continuous improvement is thus opposed to the principle of process reengineering or radical innovation, which implies a sudden change, sometimes in total rupture with the processes, practices and technologies used until now in the company (MESQUITA and ALLIPRANDINI, 2003). Continuous improvement is a comprehensive approach, involving the use of a number of tools, adapted to the context or the objective pursued. Thus, continuous improvement is a management method that favours the adoption of gradual improvements that are part of a daily search for efficiency and progress, appealing to the creativity of all actors in the organisation (LOUSAS, 2018). It follows as a principle the theory of small steps, aiming at constant and regular progress, which does not exclude, however, the spectacular progress (breakthroughs). It also implies a change of culture based on the development of problem-solving skills, which assumes a mass effect (GONZALEZ and MARTINS, 2007). To establish an environment conducive to change, the leader must engage personally in the process, i.e., set an example to his collaborators and demonstrate to them the importance of continuous improvement to the organization. Moreover, to ensure the adherence of his employees to the planned improvements, he must provide them with the appropriate means (time, money and support) and demonstrate his openness to the ideas and initiatives of his team members (JUNIOR, DE LIMA e STOCO, 2020).

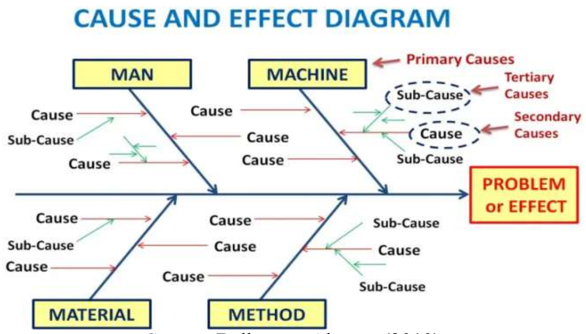
In an organization that aims to improve, the employees, seen as experts in their work, are in the best position to present improvement ideas. Therefore, it should have a program that allows them to easily define and propose their improvement ideas (MESQUITA and ALLIPRANDINI, 2003). Here is a continuous improvement model that allows a company to structure itself and create an environment that encourages employee development. This model is composed of six elements (LOUSAS, 2018):

- The vision (strategic objectives), which ensures that each action is justified and contributes to achieving the expected result;
- The organisation, which considers employees at their fair value and allows them to develop;
- The improvement programme, which determines and prioritises the actions (innovation, kaizen workshop, 5S method, SMED method or others, small improvement suggestions, etc.);
- Training, which enables the actions to be carried out;
- Monitoring progress through performance indicators (customers, results and processes);
- Recognition of the work done by employees.

Main tools

Cause and Effect Diagram: Also called fishbone or Ishikawa Diagram, the Cause and Effect diagram represents the visualisation of a problem-solving process in which the causes of a problem are sought analytically, breaking down the root causes until the root of the problem is reached. The cause and effect diagram can make a valuable contribution during the analysis as it stands. It can systematic and detailed determination of the causes of problems, as well as for the analysis of processes (BALLESTERO-ALVAREZ, 2010). The Ishikawa diagram (Figure 1) was developed by the Japanese scientist Kaoru Ishikawa in the early 1940s and later named in his honour.

This technique was originally used in quality management to analyse quality problems (origin: fishbone approach) and their causes. Today it can also be transferred to other problem areas and has spread around the world. Regarding the factors addressed, there are the following triggers for each type:



Source: Ballestero-Alvarez (2010).

Figure 1. Cause and effect diagram

According to Carpinetti (2012) when used for process analysis, the main arrow has the process outcome at the top instead of the problem, while the individual "fish bones" or "branches" represent the activities in hierarchical order. The method can be carried out alone or as group work, here too the advantages of group dynamics processes should be used. Use in the context of organisational studies generally occurs as group work in workshops. By bringing in third parties, a multifaceted view is made possible.

Kaizen: The original meaning of the Japanese word kaizen can be literally translated as "improve bad points". The most popular translation is "change for the better", or simply "improve". However, in its primary sense, kaizen does not explicitly imply continuous improvement. Nor has it been used in the sense of a philosophy or culture (NATALI, 2004). In fact, the modern meaning of the word originated in the Toyota factories. After the Second World War, many Japanese companies were influenced by the methods brought in by the American advisors sent out under the Marshall plan. Although this method has been implemented elsewhere, Toyota is the best example of a company that practiced continuous improvement very well, creating effective management systems to generate, capture and review improvements in endless cycles. Toyota's system of production management techniques is called the Toyota Production System. It is based on a number of fundamental principles, one of which is called kaizen. As used by Toyota (or more generally, in manufacturing), this term means continuous improvement. Kaizen became one of the fundamental practices first mentioned by lean manufacturing in the United States and then by lean management (NATALI, 2004).

To apply the Kaizen philosophy of continuous improvement in the company it is necessary that the managers gradually involve all employees in this process, triggering a chain reaction. As it often happens, if the improvement starts from the top down, according to the top-down scheme, the managers who want to achieve the improvement in small steps of the production and organization systems must incorporate the various divisions, departments and areas in a kaizen perspective, the sectors, even the offices and departments, where all the human resources within the organization chart of the company, will have to commit themselves, from the kaizen point of view, to implement all the work processes NATALI, 2004). Today, kaizen is "a Japanese business philosophy of continuous improvement in work practices, personal effectiveness, etc. In today's dynamic and risky business environment, more and more companies are becoming more efficient through the application of lean thinking. Of which kaizen culture is a very important part. The Toyota production system is known as kaizen, where all line personnel are expected to stop production if an anomaly occurs and suggest, together with their supervisor, an improvement to solve the anomaly. This approach usually results in small improvements, while promoting small, aligned and continuous improvements and standardisation leads to a big improvement in productivity. According to ROTHER & SHOOK (1999) the elaborate method of kaizen includes making changes, following up results and making adjustments. Large-scale planning and large projects are replaced by smaller experiments, which can be adjusted quickly when new improvements are suggested. Dealing with change, however, even if it is for the better, is never an easy task, as people tend to cling to a comfort zone and show a lot of resistance to any alteration to their *modus operandi*. For this reason, changes must be gradual and fully communicated within the organisation so as not to compromise the balance of the structure.

The *Kaizen* method follows ten specific principles, which are outlined below:

- Improve everything continuously;
- Abrogate old and traditional concepts;
- Not accepting excuses and making things happen;
- Say no to status when implementing new methods and assume they work;
- If something is wrong, correct it;
- Empower everyone to participate in problem solving;
- Get information and opinions from various people;
- Before making decisions, ask "why" five times to get to the root cause (5 Whys);
- Be economical. Save money with small improvements and spend the money saved on other improvements;
- Remember that improvement has no limits and never stop trying to improve.

For *kaizen*, one works and lives in the most balanced and satisfactory way possible if at least three requirements are met: financial and emotional stability for the employee, a pleasant organisational climate and a simple and functional environment.

Lean Manufacturing: Lean Manufacturing originally referred to the systematised production organisation found by Womack / Jones / Roos in their MIT study (1985 to 1991) among Japanese car manufacturers, which is used in the USA and Europe opposed to the buffered production that prevailed at the time and was called by them (buffered production) (MESQUITA and ALLIPRANDINI, 2003). Regardless of this definition based on the situation of the moment, lean production is understood as an integrated socio-technical system whose central objective is the elimination of waste while reducing or minimising fluctuations on the supplier, lateral and internal customer side. The function of lean manufacturing abolishes the principle of "armouring manufacturing systems against market contingencies". i.e. the possibility of faster reactions to market changes, with the task of adapting and rationalising production using standardised methods being decentralised and shifted further down the hierarchy JUNIOR, DE LIMA and STOCO, 2020). In short, lean manufacturing is the continuous effort to reduce waste in the manufacturing process. Waste is anything that consumes resources without adding value to the customer. The seven wastes defined in the original Toyota Production System are (GONZALEZ and MARTINS, 2007):

- Unnecessary transport
- Excess Inventory
- Unnecessary movement of people, equipment or machinery
- On standby, idle staff or unused plant and equipment
- Overproduction of products
- "Rework" - Using more resources than necessary to achieve the client's desired result
- Defects that require resources to correct

When applying the lean methodology, practitioners wish to reduce these seven sources of waste or even remove them entirely from the production cycle. Continuous improvement is fundamental to the methodology (LOUSAS, 2018). The reduction of waste, scrap and rejects is not an isolated or one-off process, but is embedded in the application of lean principles as a comprehensive methodology. This allows increasingly precise optimisations. Lean manufacturing is based on five fundamental principles designed to address all aspects of the production cycle (GONZALEZ and MARTINS, 2007):

- Defining value from the customer's perspective: setting a top-down price that the customer is willing to pay. The aim is to optimise production in such a way that a profit can be achieved at that price.
- Identifying the value stream: Gaining a full understanding of the product life cycle to eliminate inefficiencies.
- Application of the flow principle: ensuring a continuous flow of operations, each interruption inevitably leads to waste.
- Applying the pull principle: Similar to just-in-time production, nothing is manufactured until it is ordered by the customer.
- Pursuit of Perfection: Continuous improvement to relentlessly pursue the perfect process.

Pareto diagram: The Pareto Diagram, like the Ishikawa diagram and other *Lean Production* tools, is a graph that represents the importance of the differences caused by a certain phenomenon and is useful to visualise the relevant elements of a system (SILVA, 2019). The Pareto diagram, composed of a series of bars whose height contains the frequency or impact of the problems where in the abscissa line is against the causes and in the ordinate line its incidence in percentage. The graph is useful to analyze the dynamics of a type of activity and group it according to the effects observed (RODRIGUES, 2015). Through the diagram it is possible to associate causes and effects, allowing the identification of intervention priorities on objective bases, and not on sensations due to the urgency of the moment. The chart highlights, among a series of causes, those that have the greatest impact on the phenomenon considered. It can be a useful tool and support for problem solving (NEUMANN et al., 2013). This tool highlights the most relevant aspects of what is being analyzed allowing visualization at a glance along with the pivot tables and the vertical search function, represents a visual and immediate method of data analysis and visualization (SILVA, 2019).

DMAIC Methodology: The DMAIC methodology is the result of the junction of two methodologies: *Lean*, originated in Japan in the 1950s and improved by Toyota and *Six Sigma*, originated in the 1980s with Motorola and improved by *General Electric* (GE). The first one focused on the increase of the process speed and the second on its precision and accuracy (ARAUJO et al., 2006). The main benefits of using *Six Sigma* is to reduce organizational costs, increase the quality of products / services / processes, retain and retain customers, eliminate activities that do not add value, provide greater involvement of teams and, especially, make a cultural change (PEINADO et al., 2007). *Lean Six Sigma* (LSS) is, therefore, a disciplined methodology of improvement, where the focus is on the elimination, or at least the reduction to minimum levels, of defects and waste, and on increasing the speed of processes. In short, doing more with less and better.

PDCA Cycle: The PDCA cycle is a simple iterative management method aimed at testing process changes and problem solutions for continuous improvement. Like many process and quality control techniques used in various industries today, PDCA has its roots in 20th century manufacturing practices. Because of its simplicity and high reproducibility, it is widely used in industries other than manufacturing, and is widely used at the individual level, team level, and company-wide level. The prototype of the PDCA cycle is called the "Shoo Heart Cycle" proposed by W. Edwards Deming, an American engineer and university professor. It was named after Walter Shewhart, an American statistician and "father of modern quality control". Mr Deming is known for his achievements in Japan, and his ideas influenced post-war Japanese industry and reconstruction. The name PDCA was also conceived by the audience who attended Mr Deming's lecture in Japan, and it stands for "Plan, Do, Check, Act", which summarises Shewhart's cycle. The idea and logic of repeating and repeating the same cycle several times is a common feature of other quality control methods of the time, such as lean manufacturing, kaizen and Six Sigma, which originated in the manufacturing industry.

The PDCA cycle consists of four stages: planning, execution, evaluation and improvement. This process is continuous and, after a cycle, it proceeds to the first stage of the next cycle (NATALI, 2004):

- ***Planning:*** This step reveals the current and desirable situation. Simply put, it defines a goal, how to achieve it and how to measure progress against it. What specifically you do in this step depends on what you are trying to do throughout the PDCA cycle, and different teams approach this differently. In some cases, it can be broken down into several intermediate steps, such as DMAIC, a process improvement technique (TBM, 2000);
- ***Action:*** Once you have an action plan or an interim solution to your problem, try it out. The execution stage is a place to test the first proposed change. However, keep in mind that what you are doing here is only an experiment. This is not a place to implement solutions to problems or process changes in earnest. Make small changes within your reach. You also need to be careful not to be influenced by external factors or interfere with other processes or operations of your team or organisation. The purpose of this step is only to collect data and information about the impact of the test. The data and information obtained here will be used in the next step (GOMES, 2004);
- ***Grading:*** After the pilot test has been completed, it is necessary to check whether the changes to the process and the solutions to the problems have produced the expected results. This evaluation stage analyses the data obtained in the execution stage and compares it to the original goals and objectives. In addition, validate the test method used to see if it deviates from the method determined in the planning stage and if it affects the process. The overall goal of this step is to determine how successful the work has been so far and what to take into the next step. As a result of this step, you can decide to carry out another test. It is possible to repeat the execution and evaluation until a satisfactory solution is found to move on to the next improvement step (IMAI, 1994);
- ***Improvement:*** Arriving at this last stage, the changes to be implemented are identified. However, as the PDCA cycle means, the implementation of any changes in this improvement step does not end the process. A new baseline should be defined based on the newly improved products and processes and the solved problems, as a reference value for the next PDCA cycle;

Even if the PDCA cycle is successful, it will be necessary to improve the plans and actions to achieve the goals and achieve higher results. Besides improving behaviour, it is also considered to further develop good behaviour. On the other hand, if there is no prospect of improvement, it is necessary to decide for the cancellation of the plan itself (ARAUJO, et al. 2006). At the heart of PDCA is a standardised approach and orientation to solving problems and continuously improving things. However, this is also common to many management and quality control methods, with different levels of complexity and different numbers of success stories (GOMES, 2004). The biggest feature of PDCA is that the process of planning, execution, evaluation and improvement is simple, clear and intuitive, and many people will understand its meaning and apply it in their work. This is the reason why it not only continues to be used in the business world, but also spreads across industries and permeates many people. To work in a team, it first requires the consent of a certain number of members, but because it is simple, it is relatively easy to incorporate it into the organizational culture and the overall business process (ARAUJO, et al. 2006). The PDCA cycle, which repeats the process over and over again, is also characterised by eliminating errors and preventing recurrences. This cycle is designed to identify errors and their root causes as the process is repeatedly optimised. You can accumulate data and experience to understand the process as you continuously test and implement various solutions. Therefore, the PDCA cycle can not only solve problems, but also accumulate valuable information related to various processes of teams and organizations.

MATERIALS AND METHODS

To develop this research, we used the DMAIC tool, described in the previous section, taking into account a case study: the production of a vehicle panel module of a company, whose board receives a *heat sink* via screwing. In this procedure, failures were detected that generated losses, either by production stoppage or by rejection of the final product.

Company profile: The company where the study was applied is a multinational and has one of the headquarters in the city of Manaus. To give an idea of its size, the annual global turnover of this company, in the year 2021, was around 3 billion dollars. Although it was founded in Brazil on July 29, 1998, this Manaus unit was only established in 2009. The company operates in the sector of Manufacturing of other assorted electrical equipment and components. Its activities include the production and supply of automotive parts. The company name will not be disclosed due to lack of authorization to do so, so it will be referred to only as "company" in this study.

Materials used: In this study, the materials used had the objective of measuring parts and verifying indexes of the project, which consisted of a part of an automotive panel manufactured by the company. Among the tools used are: pachymeter, torque meter and screwing angle, screwing speed meter and the use of software, licensed by the company to obtain comparative graphs.

Application of the DMAIC tool: For this study, we used the DMAIC tool as a method. As already mentioned, DMAIC is a disciplined improvement methodology, where the focus is on eliminating, or at least reducing to minimum levels, defects and waste, and on increasing the speed of processes. In short, to do more with less and better (VERGUEIRO, 2002). For the present case, it is understood that this methodology is the most adequate, besides also being of easy domain of the researcher. Thus, once the methodology is defined, the unfolding of its application is presented below.

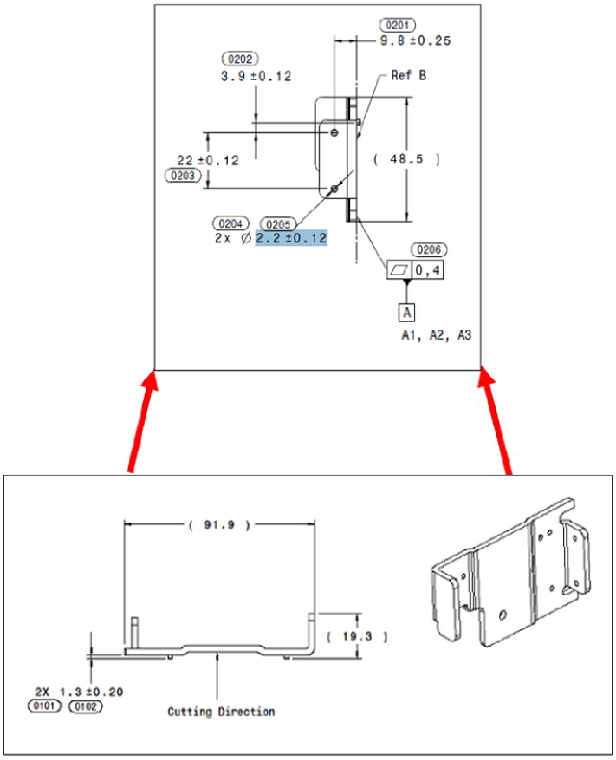
Define: The first part of applying the DMAIC tool is precisely to define the problem. Thus, a high *rate* of rejects was identified in the process related to the *Heat Sink* screwing, affecting the *rate hour* and the *scrap* (Figure 2).

Source Authors (2022).

Figure 2. Step 1 (*Problem Statement*)

Figure 2 above shows the cabinet where the company screws the board. Briefly, we explain the procedure: the automotive part, which makes up the panel of the vehicles that the company manufactures, is basically made of electronic components such as microprocessor, display, logic elements, resistive components, capacitive, transistors and so on. After all the proper procedure of manufacturing these circuits, the piece is removed from the line and taken to the cabinet shown in Figure 2, where some screwing will be performed, including the heat sink in question. It was at this point in the production, already well advanced, that those responsible identified flaws in the dimensioning of the holes, as the pieces began to break due to the mechanical process of screwing.

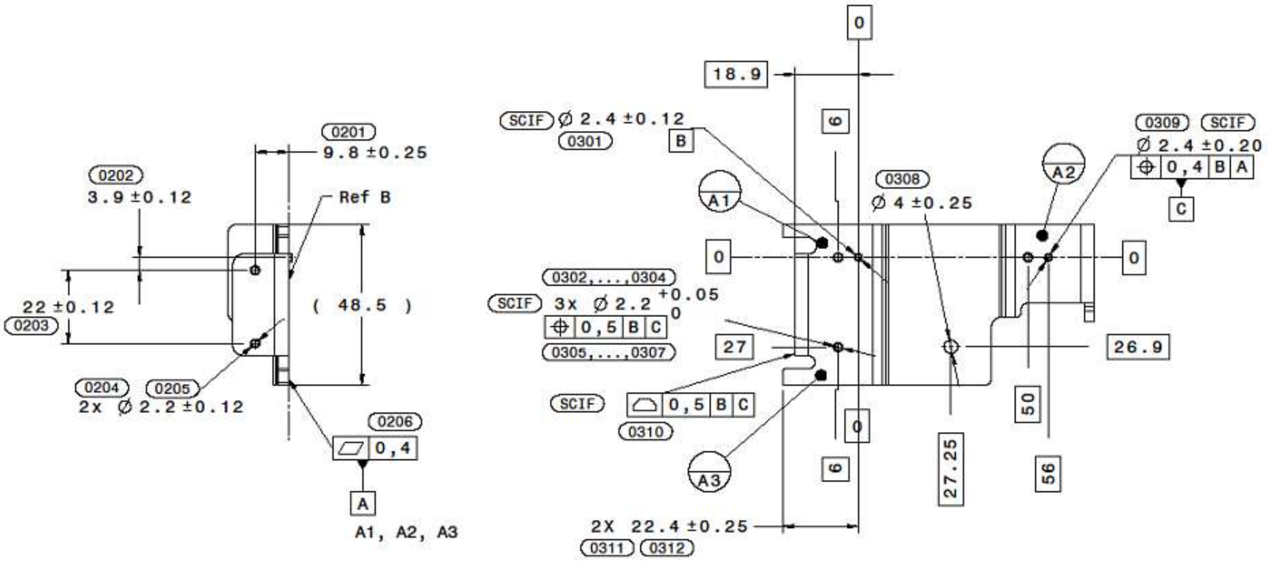
Measuring: In the measuring process, it was raised the hypothesis that the *heat sink* could have been manufactured out of the specifications determined in project. The figures 3 and 4, below, show us that the diameter of the hole where the screw should be inserted is 2,2 millimeters, with a margin of more or less 0,12 millimeters of error (label 0205 in the figure). Thus, in possession of the project, which represents the ideal dimensions of the piece, we can compare the project with the physical piece.



Source Authors (2022).

Figure 3 - Dimensionals on *Heat Sink* Parts

Analyze: Following the DMAIC tool, the data analysis (*Analyze*) stage was performed, where we analysed the factors that can cause the screw to become unscrewed. To better represent these factors, we used a cause and effect diagram (figure 5). In this analysis, we identified that a material related cause could be the *heat sink* supplying out of specifications. It is worth highlighting that the company does not manufacture this metallic sink, but receives it from a third-party supplier, which must follow the project properly. That said, one possible cause of the method can be related to the failure to review the parts. If the part comes from an external supplier, there should be a review procedure in place to verify that the product has been delivered as specified. Furthermore, we relate as a possible machine cause some possible defect that the cabinet shown in figure 2 may possess, resulting in a bad screwing operation. Finally, related to labour, we relate as a possible cause the lack of guidance in the decision-making process, given that there may not be clear parameters on how to proceed when a defect of this type appears on the plate.



Source Authors (2022).

Figure 4. Dimensionals on *Heat Sink* Parts

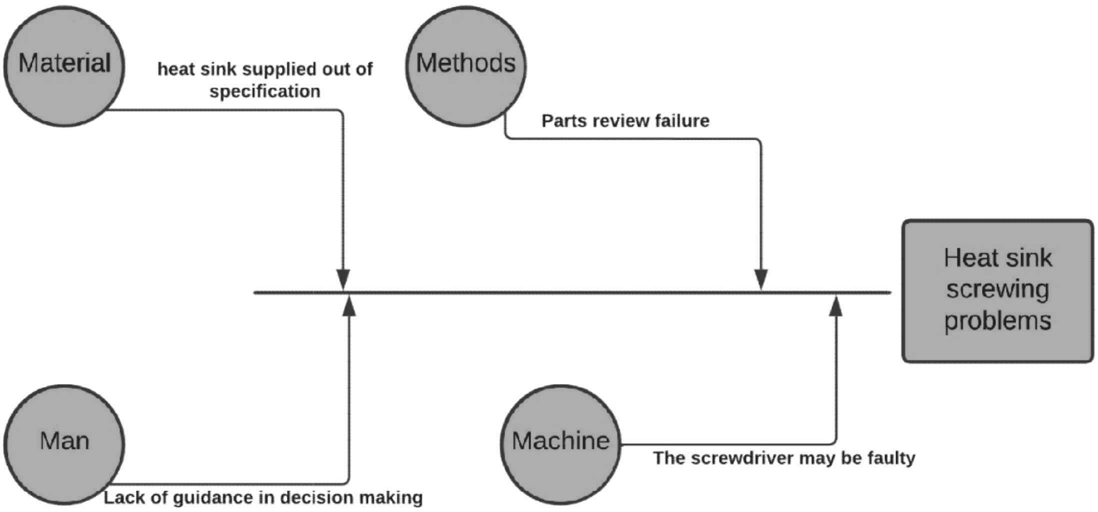


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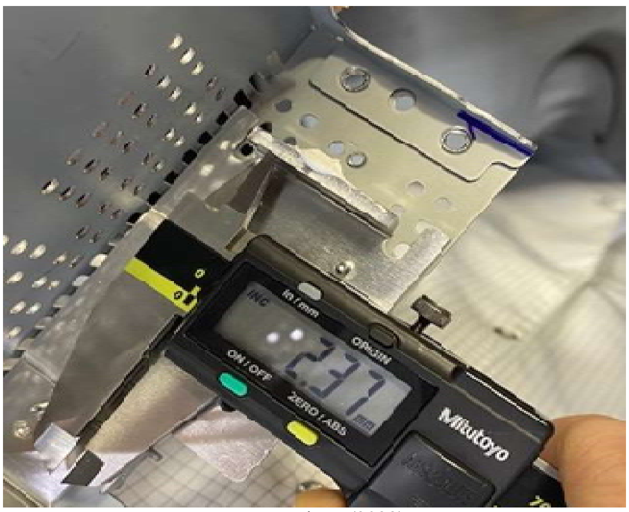
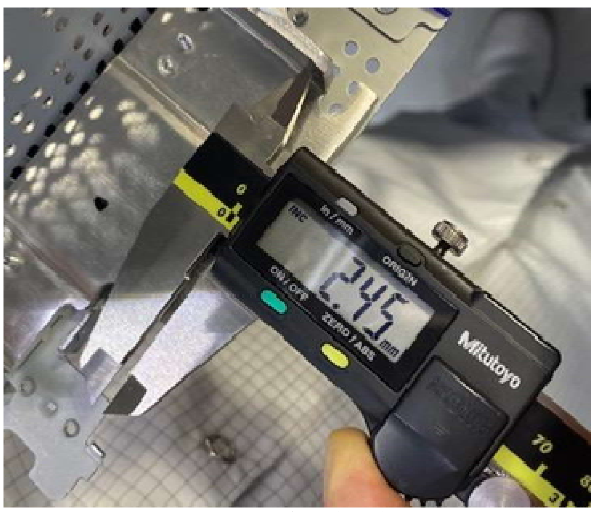
Figure 5. Step 3 (*Analyze* or data analysis)



Source Authors (2022).

Figure 6. External side hole (right in this view)



Source Authors (2022).

Figure 7. External side hole (right in this view).

Improve: At this stage of our methodology, we received confirmation from the company that the root cause of the problem was in the material, specifically heat sink produced out of specification. Besides that, we associated in this research a failure in the parts revision as one of the causes of the problem. Thus, the following action plan was created, according to Table 1:

The continuity of the application of DMAIC in this case study will be presented, due to the data that was obtained, in the Results and Discussions section below.

RESULTS AND DISCUSSION

As already explained in the previous section, this case study uses the DMAIC tool. In the previous phases, it was possible to observe that:

- ***Define:*** High rate of rejects in the process related to the *heat hink* bolting
- Measure: the *heat sink* may have been manufactured out of specification
- ***Analyse:*** among the potential causes, we have identified two - the faulty part was manufactured out of specification by an external supplier and there is a failure to review this item.
- ***Implement:*** An action plan has been put in place to address the issue

Having been exposed, in a summarised way, the use of the DMAIC tool so far, we will treat as results and discussion the data obtained from the execution of the action plan, still in the Implementation phase within DMAIC, as well as what was obtained in the Control phase. Firstly, the company made contact with the manufacturer of the heat sink requesting the necessary adjustments to the part. Next, we present (in figures 6 and 7) the measures that were found in the defective parts, using the pachymeter. Comparing what is shown in figures 6 and 7 with the specifications shown in figure 3, we observe that the hole, through which the bolting of the part is done, was manufactured outside the upper tolerance margins (2.2 + 0.12 mm). Thus it was proven that the defect in the piece is one of the root causes of the problem.

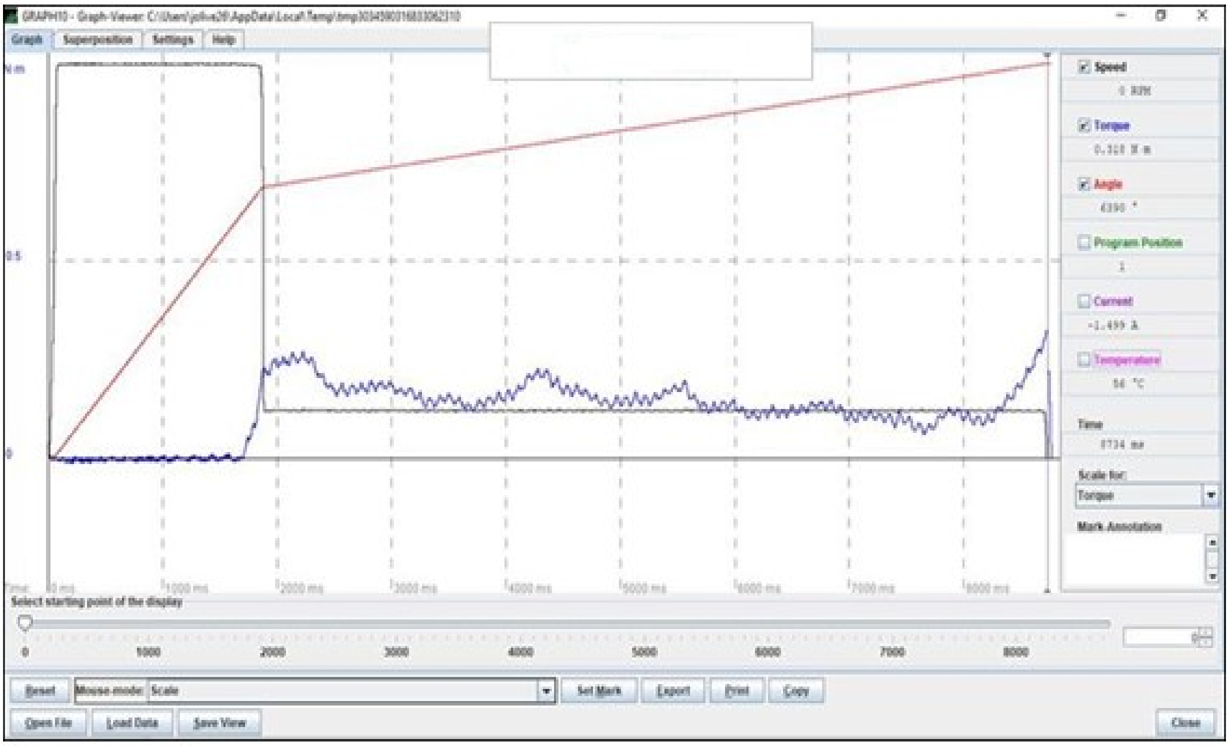
Control: In the control phase, it is necessary to follow up the action plan and establish criteria for control. Thus, with the action plan proposed in table 1, the following control actions were carried out:

Graphical analysis of torque and angle: One of the ways to check if the screwing is being done properly is by observing if there is torque in this process, once, with a hole above the specified one, the friction between the screw and the *heat sink* will be minimum. This was proved through the following figure 8, with a defective part. Figure 8 reveals that the torque of the screwdriver is low (blue line), proving that the defective part cannot be fixed on the plate. Moreover, the angle (red line), does not develop a single straight line (i.e., the same angular coefficient), which indicates that the screw "snapped", damaging the plate.

Table 1. Action plan

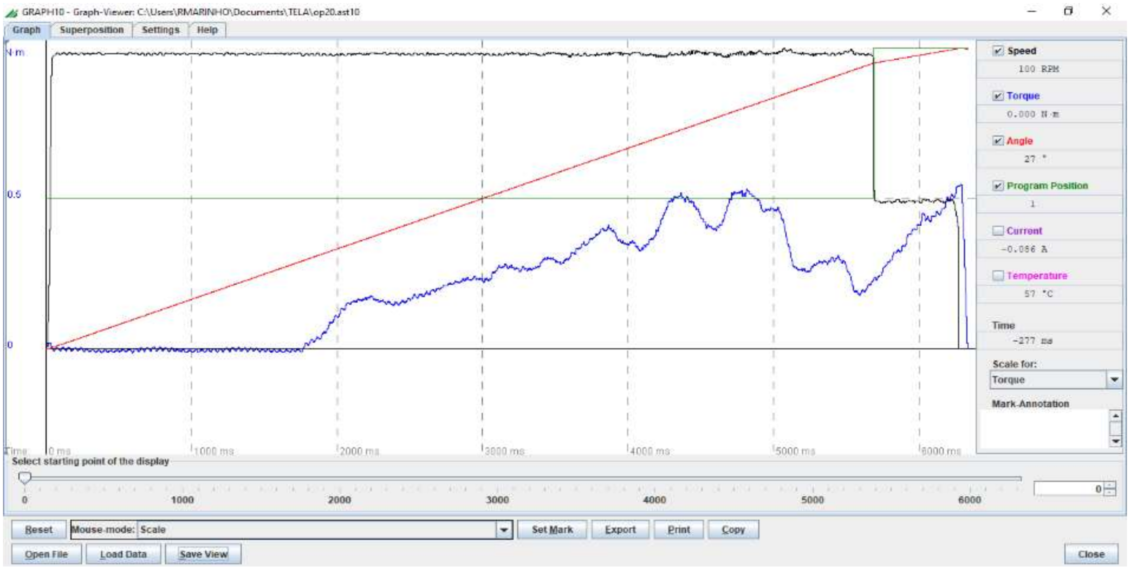
What?	Why?	How?	Where?	Who?	When?	How much?
Heat sink production in compliance with standards	The fault caused production stoppage	Forwarding the specifications and dimensional design of the part	External manufacturer	The external manufacturer must arrange for the manufacture of new parts	Immediate	Value already contracted, no need for additional
Internal revision of parts	Lack of revision caused use of inappropriate part	Use appropriate measuring instruments (caliper, etc.)	On receipt of parts within the company	Engineering and Quality Team	Immediate, on receipt of parts	No additional costs.

Source Authors (2022).



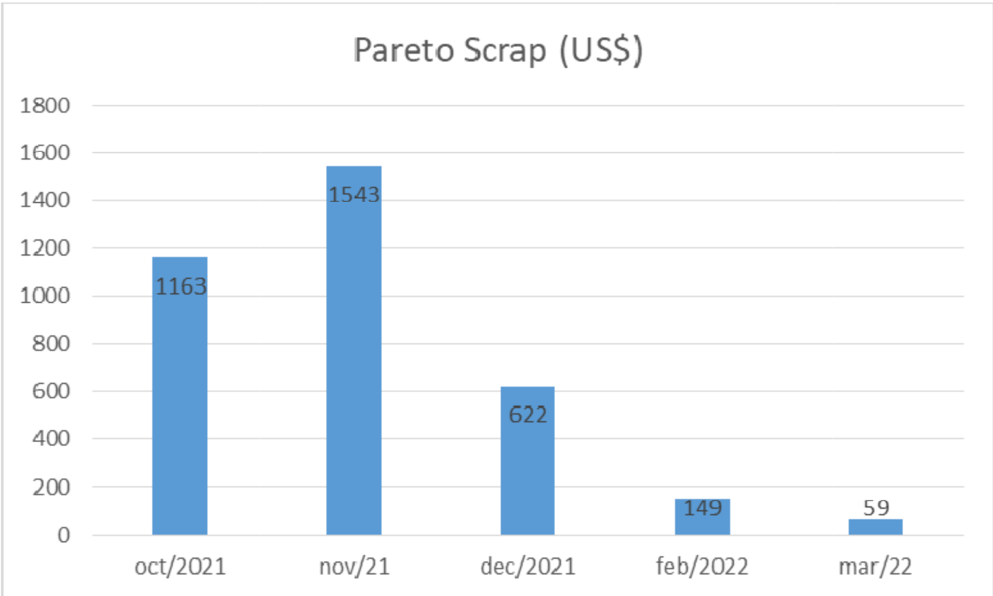
Source Authors (2022).

Figure 8. Study on the single curve of torque x bolting angle



Source Authors (2022).

Figure 9. New torque x angle curve controlling torque for *Heat Sink tapping* and angle control



Source Authors (2022).

Figure 10. Pareto total failures related to months

After a selection of parts within specification, a new chart was made, with appropriate *heat sink*, and which is shown in figure 9 below:

Table 2. Financial losses from the *heat sink* defect

MONTH	VALUE LOST
October/2021	US$ 12.058,50
November/2021	US$ 16.016,34
December/2021	US$ 6.456,36
February/2022	US$ 1.804,69
March/2022	US$ 639,58

Source: Company (2021)

It is observed that the torque increased, indicating that the screwing happened properly. Furthermore, the angle curve formed a straight line with a defined angular coefficient, proving that the screwdriver performed its procedure as expected.

Monitoring the new heat sink manufactured: Following the proposed action plan, the company began to inspect, in a sampling manner, the quality of the new heat sinks. This way, for every thousand units, it was decided that 10 would be inspected. Besides this, the external supplier gave guarantees of compliance with the project.

Monitoring the failure rate: The company provided figure 10 below, which shows the result of the interventions to solve the problem. In Figure 10 it is possible to observe that when the control actions were implemented, the scrap (number of damaged plates) gradually dropped. In addition, the company also provided the financial results of the intervention, as shown in Table 2. As presented in table 2, and according to figure 10, with the beginning of the control and troubleshooting actions in December, the company can also perceive a reduction of financial losses arising from the defect with the dissipator.

CONCLUSION

As a conclusion of this study, it was possible to observe that DMAIC is a valid tool for problem solving. In the definition phase, we observed that the high rate of scrap drew the attention of the company, but the cause of the problem was not known.

Following the DMAIC methodology correctly, we passed to the measuring phase, where the possible causes of the problem are raised, through a fishbone. Thus, it was possible to elucidate that the root cause of the problem was the heat sink, produced outside the design specifications. Next, in the implementation phase, an action plan was created, similar to a 5W2H, where it was also added as a cause the failure to review the defective part, something that could have avoided the losses. Thus, with the action plan in practice, the company started to monitor its application, controlling the execution through a graphic analysis, through sample control of the dissipator parts and verifying the effectiveness of the actions. As a result, we obtained a gradual reduction of scrap and also a significant drop in the financial values that were lost with the defective parts.

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