TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special III, Jully, 2024

UNLOCKING EXCELLENCE: A COMPREHENSIVE SIX SIGMA STUDY ON PROCESS OPTIMIZATION AND PERFORMANCE IMPROVEMENT

Carina Oana OLENICI, Adrian PUGNA

Abstract: *Six Sigma, a powerful data-driven quality management methodology, has gained significant recognition across industries, including the automotive sector. In the face of quality, cost and compliance challenges, the automotive industry strives to mitigate breakdowns, which lead to costly delays, customer dissatisfaction and reputation damage. This study delves into the transformative application of Six Sigma methodology within a German automotive company located in western Romania. Multiple hypotheses were carefully considered and analyzed using a set of statistical tools, including interval plots, box plots, trend analysis, and time series plots. Additionally, quality tools like the Ishikawa diagram and Pareto analysis were employed within the DMAIC (Define-Measure-Analyze-Improve-Control) model. The findings were highly significant, as the implemented improvement actions demonstrated a pronounced impact by substantially reducing breakdown minutes by 93%. These results underscore the efficacy of the applied corrective measures in mitigating breakdowns and emphasize the potential of Six Sigma methodology in enhancing the reliability and operational performance of automotive processes.*

Key words: *Six Sigma, DMAIC, manufacturing process, break-down time, west gate actuators.*

1. INTRODUCTION

Originating from Motorola in the 1980's, Six Sigma has evolved beyond its initial use in manufacturing and expanded into diverse domains, including healthcare, finance, telecommunications, and service industries [1]. Its core principles and tools have proven to be adaptable and successful in addressing quality improvement challenges across different organizational contexts. Six Sigma aims to reduce process variation and defects by employing a rigorous, data-centric approach, statistical analysis, and problem-solving methodologies [2]. The methodology emphasizes measuring and analysing process performance, identifying root causes of inefficiencies, and implementing targeted improvements to enhance overall outcomes.

In manufacturing industries, Six Sigma has demonstrated remarkable effectiveness in optimizing production processes, reducing defects, and improving product quality [3]. A study in the automotive sector found that the implementation of Six Sigma led to significant reductions in defects, improved customer satisfaction, and cost savings [4]. Within service industries, Six Sigma was proven to be valuable in enhancing customer experiences and service delivery. In the healthcare sector applying Six Sigma methodologies resulted in reduced patient waiting times, increased staff productivity, and improved overall patient satisfaction [5]. Moreover, it facilitates the alignment of business processes with strategic goals, leading to improved operational efficiency and cost reduction [6]. By eliminating waste, reducing process variability, and enhancing process control, the methodology drives sustainable performance improvement and organizational success [7].

A critical aspect of Six Sigma is its focus on fostering a culture of continuous improvement within organizations. By providing training, engaging employees at all levels, and promoting collaboration, Six Sigma cultivates a mindset of ongoing learning and innovation [8]. This organizational culture facilitates adaptation to market dynamics, promotes competitiveness, and ensures the consistent delivery of high-quality products and services [9].

Breakdowns in industrial processes have detrimental effects on organizations, causing disruptions, delays, increased costs, and customer dissatisfaction. Studies have shown that breakdowns lead to decreased production rates, increased lead times, and financial burdens due to repair expenses and potential penalties for missed deadlines [10-13]. The impact extends beyond operational aspects, with breakdowns posing safety risks to employees and the environment. Furthermore, breakdowns erode competitive advantage as unreliable processes result in poor product quality and customer dissatisfaction. To mitigate these issues, organizations need to implement effective maintenance strategies and proactive measures to minimize breakdown occurrences. The findings highlight the importance of addressing breakdowns to ensure operational efficiency, cost-effectiveness, customer satisfaction, and long-term organizational success.

The primary objective of this study is to mitigate the breakdown time and associated costs incurred by line stoppages for west gate actuators in an automotive company situated in the Western region of Romania. The Six Sigma project was undertaken with the principal aim of comprehensively defining and understanding the underlying factors contributing to equipment error messages, as delineated in the define phase of the DMAIC (Define, Measure, Analyze, Improve, Control) approach. Subsequently, the measurement system was meticulously evaluated during the second phase. In the analyze phase, the data collected in the preceding step was scrutinized to ascertain all conceivable causal factors, utilizing both statistical and non-statistical methodologies. The improve phase was predicated upon four pivotal elements: identifying and exploring all possible alternatives, employing cost-based criteria to select the optimal solution, planning the required implementation resources, and executing the chosen alternatives. The culmination of the Six Sigma project was the control phase, wherein the implemented corrective actions were diligently monitored using statistical tools. Through a statistical analysis, it was determined that the breakdown time associated with the error message under investigation in this study exhibited a substantial reduction of 93%.

2. LITERATURE REVIEW

2.1 DMAIC significance

DMAIC is a widely recognized and extensively utilized methodology for process improvement. It provides organizations with a structured and systematic framework to address complex problems, optimize processes, and drive continuous improvement [14].

This methodology employs robust tools and techniques [15]. At its core, the DMAIC model emphasizes the importance of defining and understanding the problem through data collection, analysis, and implementing necessary process improvements [16]. Rooted in the principles of Lean and Six Sigma, DMAIC embodies the concept of continuous improvement, making it a powerful tool for organizations to reduce costs, boost efficiency, standardize processes, and ultimately gain a competitive edge in various industries [17-18].

DMAIC (Define, Measure, Analyze, Improve, Control) continues to be highly significant in the automotive industry post-2020. It plays a crucial role in improving quality, cutting costs, and enhancing efficiency. DMAIC aligns with the industry's focus on quality and reliability through data-driven analysis [19]. By optimizing processes, it boosts productivity and supports Lean Manufacturing principles [20]. In an ever-evolving automotive landscape, DMAIC ensures adaptability and continuous improvement [21].

2.2 DMAIC model step by step

The DMAIC model, as outlined by [22], consists of five distinct stages: define, measure, analyse, improve, and control. These stages are intended to be executed in a sequential manner, providing a structured approach to problem-solving and continuous improvement [23]. Each phase of the DMAIC model can be further broken down into key activities and recommended tools.

1. *Define:* The first step in DMAIC is the "Define" phase, where the focus is on clearly defining the problem or opportunity for improvement. This involves precisely

articulating the goals, objectives, and desired outcomes. By establishing a well-defined problem statement, the project team can align their efforts and resources toward a common objective. This phase sets the foundation for a successful improvement initiative.

2. *Measure:* In the "Measure" phase, the project team collects relevant data and metrics to gain an understanding of the current state of the process. Accurate measurements help in quantifying process performance, identifying bottlenecks, and establishing a baseline for improvement. By using appropriate measurement techniques and tools, organizations can gather objective data to drive informed decision-making.

3. *Analyze:* The "Analyze" phase involves a comprehensive examination of the collected data to identify root causes and analyze process variations. Statistical tools, such as Pareto analysis, cause-and-effect diagrams, and process mapping, are utilized to understand the relationships between process inputs and outputs. This phase helps in uncovering critical insights and identifying opportunities for improvement.

4. *Improve:* During the "Improve" phase, potential solutions are generated, evaluated, and implemented to address the identified root causes. This phase emphasizes creativity, innovation, and structured experimentation to identify the most effective improvement actions [24]. Tools such as design of experiments (DOE) and failure mode and effects analysis (FMEA) aid in selecting and implementing the best solutions.

5. *Control:* The final phase focuses on sustaining the improvements achieved during the previous phases. Robust control mechanisms, such as statistical process control (SPC) and control charts, are implemented to monitor the process and detect any deviations or anomalies. This phase ensures that the improvements are sustained over time and prevents the recurrence of the identified problems.

3. BACKGROUND AND MOTIVATION

This section provides an overview of project selection and highlights the importance of employing decision analysis techniques in situations where the scope of improvement is extensive and unclear.

For this case study, an automotive company located in Eastern Europe was specifically selected as the subject of investigation. Data was collected over a period of three months, ensuring a comprehensive and robust dataset for analysis and evaluation.

The aim was to identify the key equipment within the production line specifically dedicated to manufacturing West Gate Actuators (WGAs) that had the highest breakdown time. The criticality of breakdown time cannot be overstated in terms of process performance, as it exerts a direct influence on productivity, efficiency, and overall operational costs. Within the operational level of the manufacturing process, there are nine automatic modules (M02, M05, M10, M20, M30, M40, M50, M60 and M70) involved in the production of West Gate Actuators. Pareto Charts were utilized to plot the collected data, aiming to identify the equipment that played a major role in causing high breakdown time.

Figure 1 depicts the observations revealing that Module 50 (M50) exhibited the highest breakdown time among all modules in the production line, totalling 2896 minutes. Following closely, M20 accounted for 2880 minutes, M60 for 2407 minutes, and M40 for 1998 minutes. Afterwards, an evaluation was conducted to rank the equipment errors related to Module M50. As a result, the error message "Errors detected in camera check connecting element" for the West Gate Actuator product was chosen as the focal point of the Six Sigma project, as it accounted for the longest downtime within M50. This error message accounted for 37.1% of the overall breakdown time for M50.

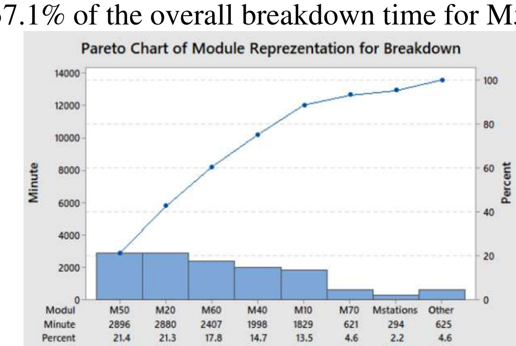

Fig. 1. Pareto Chart of breakdown time for West Gate Actuator production line

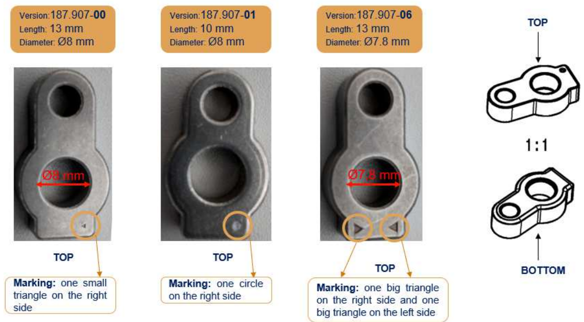

Fig. 2. Description of Connecting Elements

The forthcoming chapters of this study will focus on the sequential phases of the DMAIC approach, which has been employed as a framework within the Six Sigma project. This systematic approach allows for the systematic identification, measurement, analysis, improvement, and control of factors contributing to breakdown time reduction in the WGA production line.

4. METHODOLOGY

4.1. Define phase

The reduction of breakdown time has been incorporated into the company's strategic initiatives, aligning with its overarching goal of achieving “Operational Excellence”. The WGA production line accounted for a significant portion, approximately 42%, of the total breakdown time within the company. The cumulative expenses associated with line stoppages, special freight costs, and overpayments reached an estimated annual cost of €180K. Consequently, the imperative to enhance the performance and reliability of the WGA production line emerged as a primary focus to improve customer satisfaction.

A multidisciplinary team was formed with the purpose of reducing the breakdown time, drawing upon diverse expertise and perspectives from various departments.

The project set a clear objective. The goal was to reduce the breakdown time specifically for Module M50 in the WGA production line attributed to the equipment error "Errors detected in camera check connecting element". The target was to decrease the occurrence of this error from the initial rate of 21.37% to 1.3% by July 2022. This objective was specific, measurable, attainable, realistic, and time-bound, aligning with the principles of the SMART framework.

Initially, an analysis was carried out on the production line to identify the underlying significance of the error message originating from Module M50. The investigation revealed that the camera encountered difficulty in accurately identifying the appropriate connecting element from the three available part numbers (PNs). Figure 2 provides a detailed depiction of the distinctions between the three connecting elements, along with their distinctive markings. To define the process boundaries that could potentially impact the behavior of the M50 equipment and gain a better understanding of the camera activity, a SIPOC (Suppliers, Inputs, Process, Outputs, Customers) diagram was created. This diagram was utilized to provide a visual representation and outline the key components and interactions involved in the process.

4.2. Measure phase

After the Define phase, the team created a flow chart for the Camera Check Station to better comprehend the process. The flow chart effectively identified critical areas for improvement by highlighting in red the steps with potential causes of failures.

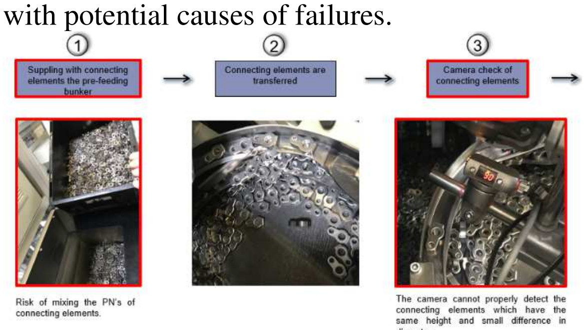

Fig. 3. Flow Chart for Camera Check

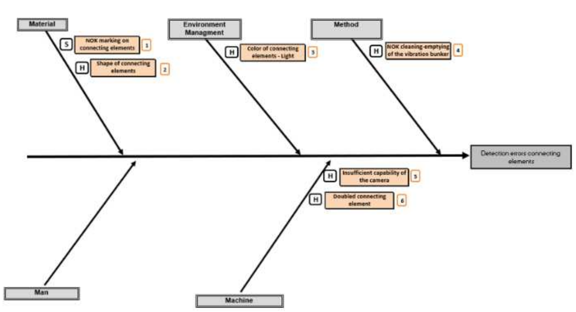

Fig. 4. Ishikawa Diagram

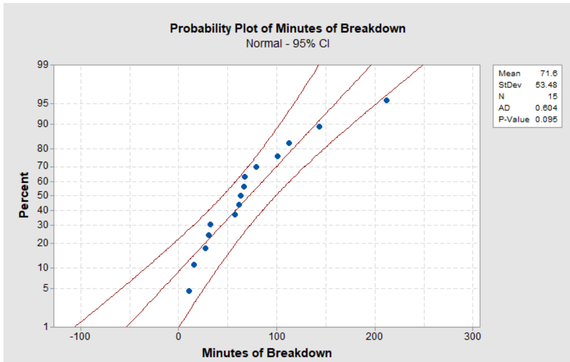

Fig. 5. Probability Plot of Breakdown time for detection of connecting elements

To achieve a more profound understanding of the Camera Check Station, a process mapping was conducted. This mapping exercise offered a comprehensive visual representation encompassing the intricate steps and components involved in the process. It included the identification and analysis of control variables, noise factors, and critical variables, which enabled a thorough comprehension of the interdependencies and complexities within the process.

The Measure phase aimed to provide a clear understanding of the problem's environment, ensure instrument capability, and record the current state of the process.

4.3. Analyze phase

To initiate the Analyze phase, a collaborative brainstorming session was conducted to identify potential causes for the defect. The outcomes of this session were visually represented using an Ishikawa diagram. This graphical tool effectively illustrated the potential issues related to the specific problem of "Detection errors connecting elements" in Module M50. Hypotheses that could impact product failure within the company's manufacturing process were denoted by the letter "H", while causes originating from the supplier were indicated by the letter "S". The Ishikawa diagram served as a valuable reference to pinpoint potential root causes and guide further analysis during the Analyze phase.

Once all ideas concerning the failure “Detection errors connecting elements” were compiled, they were transformed into hypotheses. Each hypothesis was analyzed and documented before confirming or refuting it. A total of six potential causes were considered, with the confirmed causes highlighted in red. The analysis of these causes involved the utilization of both statistical and non-statistical tools.

Hypothesis 1 suggested that the incorrect marking of the connecting element may be the cause. An analysis was conducted, revealing that the connecting element has a TOP side and a BOTTOM side. It was observed that the marking of the connecting element is performed exclusively on the TOP side for all three PN's. However, upon further investigation, it was discovered that the camera responsible for visual inspection examines the BOTTOM side of the connecting element.

To assess the distribution of breakdown times, a Probability Plot was conducted. The concept of probability plots was introduced by Tukey in 1977 and has since been widely utilized in various fields, including engineering, finance, and social sciences.

Based on these findings, the null hypothesis is that the data adheres to a normal distribution. Given that the calculated p-value of 0.095 exceeds the predetermined significance level of 0.05, the decision is made to retain the null hypothesis and conclude that there is insufficient evidence to reject it.

The shape of the connecting element plays a significant role in the occurrence of detection errors during the camera check. Interestingly, the only discernible distinction between the two PN's is a mere 0.2 mm difference in diameter.

A thorough assessment of the customer's requirements was conducted to examine the twisting torque of the connecting element on the shaft. The objective was to identify potential risks associated with modifying the diameter dimensions. Initially, it was anticipated that the reduced material resulting from the knurling machining would necessitate a smaller diameter bore hole on the connecting element to meet the torque requirement. Consequently, a borehole with a diameter of Ø7.8 mm was created.

Given the initial issues encountered with the press forces, conducting a trial using a standard Ø8.0 mm borehole proved to be the solution.

Measurements taken with the Ø8.0 mm borehole indicated a satisfactory safety factor for meeting the twisting torque requirement, and no problems were observed with the pressing machine. However, during mass production, we identified scrap rates attributed to the press forces when using the Ø7.8 mm borehole.

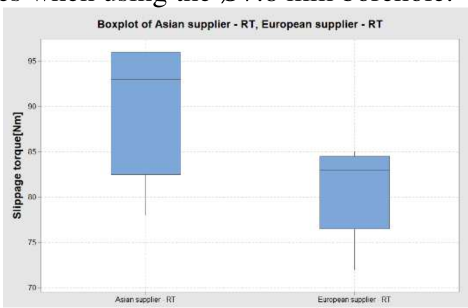

Fig. 6. Box Plot of results.

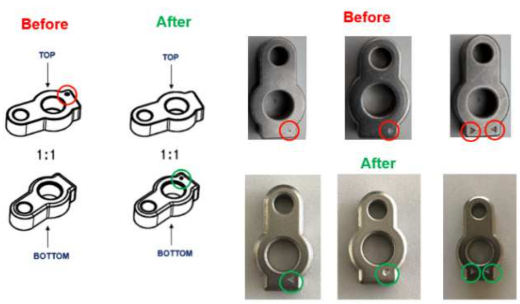

Fig. 7. Before and after - marking of connecting elements

Fig. 8. Remaining PN's

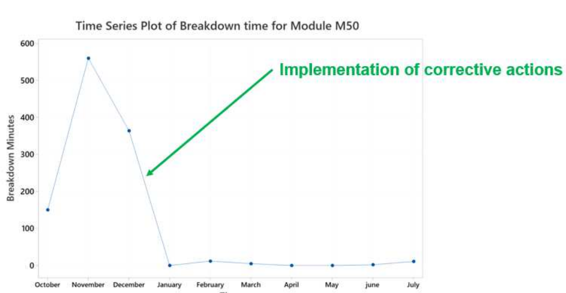

Fig. 9. Times Series Plot

4.4. Improve phase

In the Improve phase, the primary objective was to generate potential solutions for the identified cause using creative techniques. The collected ideas for solutions were structured and evaluated, considering factors such as cost and benefits. Additionally, simulations were conducted to assess the feasibility and effectiveness of the preferred solutions before their actual implementation.

Once the root cause for the equipment error of "Errors detected in camera check connecting element" was identified, appropriate corrective actions were implemented. One of the initial improvements made was to modify the marking method used for the connecting elements.

After comprehensive analysis and rigorous risk assessments, a significant improvement was made by globally implementing the connecting element bore hole diameter of Ø8.0 mm. This strategic change aimed to effectively reduce scrap rates and minimize breakdown time, ultimately leading to the attainment of stable production processes.

To ensure systematic implementation and progress tracking, an Action Plan was employed. By adhering to the specified milestones within the action plan, the corrective actions were successfully integrated into the process.

4.5. Control phase

A time series analysis plot was employed to examine the trend of breakdown time over a specific period. The analysis focused on the number of minutes for the west gate actuators in Module M50. The timeframe considered for the analysis encompassed three months prior to the implementation of corrective actions and seven months thereafter. It became evident that a significant decrease in breakdown occurrences was observed following the implementation of corrective actions.

To maintain control over the process and sustain the reduced breakdown time, all pertinent documents, including FMEA, Control Plan, and work instructions, were revised and updated to reflect the implementation details of the introduced changes. This ensured that the updated documents accurately captured the modified process and provided clear guidance for consistent and effective operations.

At this stage, the project benefits were quantified, resulting in total cost savings of €13,000 in the first year. Furthermore, based on projected future demand, estimated savings of €27,000 for 2023 and €31,000 for 2024 were forecasted. With these favorable outcomes, the project was successfully concluded.

5. CONCLUSIONS

The key motivation for the adoption of the Six Sigma methodology in this project was rooted in the company's strong emphasis on a culture of continuous improvement and an existing Six Sigma framework. The application of the DMAIC approach played a crucial role in significantly mitigating process variation, consequently resulting in a substantial reduction in the breakdown time within the production line.

This demonstrates the effectiveness and validity of the Six Sigma methodology in driving process optimization and quality enhancement within the organization.

The project's objective has been successfully achieved through the implementation of corrective actions within Module M50, resulting in a notable improvement in line stoppages. The improvement in activities led to a significant reduction in breakdown time, surpassing the management target by decreasing it from 21.37% to 1.1%. This substantial improvement resulted in cost savings of €13,000 in the first year, €27,000 in 2023, and €31,000 for 2024.

The project outcomes received approval from both the Sponsor and Champion, and it was recommended for discussion within the lessons learned community.

Furthermore, when considering the reduction in breakdown time and scrap rates achieved by other locations that implemented similar corrective actions, the overall savings are even higher. This case study further reinforces the effectiveness of the Six Sigma methodology in driving process improvements by eliminating waste and non-value adding activities, ultimately resulting in cost savings within the manufacturing industry, specifically in the electronics and automotive sectors.

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Deblocarea excelenței: un studiu comprehensiv six sigma privind optimizarea procesului și îmbunătățirea performanței

Six Sigma, o metodologie puternică de management al calității bazată pe date, a câștigat o recunoaștere semnificativă în toate industriile, inclusiv în sectorul auto. În fața provocărilor legate de calitate, cost și conformitate, industria auto se străduiește să atenueze defecțiunile, care duc la întârzieri costisitoare, nemulțumire a clienților și daune reputației. Acest studiu aprofundează în aplicarea transformatoare a metodologiei Six Sigma în cadrul unei companii germane de automobile din Regiunea de Vestul României. Ipotezele multiple au fost considerate și analizate cu atenție folosind un set de instrumente statistice, inclusiv diagrame cu intervale, diagrame de casete, analiza tendințelor și diagrame cu serii de timp. În plus, instrumente de calitate precum diagrama Ishikawa și analiza Pareto au fost utilizate în modelul DMAIC (Define-Measure-Analyze-Improve-Control). Constatările au fost foarte semnificative, deoarece acțiunile de îmbunătățire implementate au demonstrat un impact pronunțat prin reducerea substanțială a minutelor de avarie cu 93%. Aceste rezultate subliniază eficacitatea măsurilor corective aplicate în atenuarea defecțiunilor și subliniază potențialul metodologiei Six Sigma în îmbunătățirea fiabilității și a performanței operaționale a proceselor auto.

Carina Oana OLENICI, PhD student, Politehnica University of Timişoara, Faculty of Management and Transportation, carina.olenici@student.upt.ro, Strada Remus 14, Timișoara, Romania.

Adrian PUGNA, Professor, PhD, Politehnica University of Timişoara, Faculty of Management and Transportation, adrian.pugna@upt.ro, Strada Remus 14, Timișoara, Romania.