Six Sigma Roles for the Improvement of Company Manufacturing Processes and Waste Reduction

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ABSTRACT

A problem with an estimated annual loss of $50,000 was reported to a stator manufacturing company, so a Six Sigma team we formed and followed the Six Sigma steps to identify the root causes of the problem through its stages: identification, measurement, analysis process, and improvement and control stage, and indeed, the improvement will be implemented most effective in research by reducing production cost and developing the manufacturing process. Through Six Sigma tools, the root causes of the problem have already been identified, measured, and analysed using a range improved and controlled. So, the results of the study have identified the root causes of the problem which have represented improvements in reducing process wire loss from stator manufacturing , compensate for the differentiation of define, measure, analysis, improve, control phase. A actual company's case study is performed in support of the reported wire loss by Green Belt Team.

1. Introduction

The desire to achieve reducing production cost and developing the manufacturing process in the stator manufacturing company assumes the management commitment to develop and deliver perfect solutions, products or services. This commitment is to promote the "Zero Defects" and first time right production philosophy. It also includes the integration of environmental protection in all its activities, such as design and production. Additionally, the commitment involves training, motivating and involving all staff in the effort towards excellence. Supporting this, research has highlighted the critical success factors for implementing Lean Six Sigma principles, including commitment from management and employee involvement [1]. The importance of instilling the "zero defects" and "right first time" philosophy throughout an organization to drive continuous improvement has also been emphasized [2].Additionally, studies have explored the integration of environmental considerations into manufacturing processes and product design [3]. The role of training, motivation, and employee engagement in successful TQM implementation has been further underscored [4]. Aligning maintenance strategies with customer

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requirements, regulatory compliance, and resource optimization in manufacturing operations has also been identified as key [5]. In this context, it is considered that the Six Sigma methodology is the best way for improving quality and reducing waste. Six Sigma helps organizations to produce products and services better, faster, and cheaper. [6]. Six Sigma is defined to be a program aimed at the near-elimination of defects from every product, process and transaction [7]. Six Sigma is defined to be a strategic initiative to boost profitability, increase market share and improve customer satisfaction through statistical tools that can lead to breakthrough quantum gains in quality [8]. Addition, Six Sigma is believed that is a new strategic paradigm of management innovation for company survival in this 21st century, which implies three things: statistical measurement, management strategy and quality culture [9]. Six Sigma is believed that a rigorous, focused, and highly effective implementation of proven quality principles and techniques. . Six Sigma is aimed for virtually error-free business [6]. the waste have managed in longitudinal submerged arc welded (LSAW) steel pipes by the utilization of Lean Six Sigma (LSS) tools, with an emphasis on promoting sustainability through waste reduction[10]. The DMAIC methodology has demonstrated significant efficacy in systematically reducing visual errors in the production of water filters, thereby enhancing overall quality and operational efficiency [11]. The Lean Six Sigma framework provides a comprehensive approach to waste reduction and process improvement, integrating Lean principles, Six Sigma tools, and the DMAIC structure for effective problem-solving [12]. Implementing Six Sigma and DMAIC methodologies can lead to substantial increases in productivity while effectively meeting customer requirements within manufacturing operations [13]. The DMAIC methodology serves as a critical tool within Lean Six Sigma for pinpointing and addressing root causes of delays, thus guiding efforts to reduce waste and improve processes in project management [14]. Lean Six Sigma emphasizes the importance of waste reduction and process improvement through the DMAIC framework, which encompasses defining, measuring, analyzing, improving, and controlling processes to enhance efficiency [15]. The application of Six Sigma principles can significantly minimize waste in molded plastic parts, utilizing the DMAIC methodology to improve product quality and reduce defects [16]. The DMAIC framework effectively directs the design of experiments in the electrostatic powder coating process, focusing on waste reduction and process improvement through various Six Sigma tools [17]. The Lean Six Sigma approach facilitates waste reduction in the food manufacturing industry by identifying problems, analyzing processes, and implementing solutions to enhance efficiency and ensure customer satisfaction [18]. A Six Sigma framework can be effectively utilized to improve the deep drawing process, concentrating on key factors that impact quality, which is systematically analyzed during the DMAIC process [19]. Lean Six Sigma targets process improvement through the DMAIC framework, focusing on critical-to-
quality factors to reduce waste and enhance overall quality in healthcare systems [20]. The studies reviewed highlight a consistent emphasis on the integration of the DMAIC methodology within Lean Six Sigma practices, showcasing a collaborative approach to achieving "zero defects" and continuous improvement, thereby significantly contributing to the theoretical framework and scientific understanding of quality enhancement in manufacturing processes. The studies reviewed highlight a consistent emphasis on the integration of the DMAIC methodology within Lean Six Sigma practices, showcasing a collaborative approach to achieving "zero defects" and continuous improvement, thereby significantly contributing to the theoretical framework and scientific understanding of quality enhancement in manufacturing processes.

2. Research Objectives

1. Identify Root Causes: Determine the root causes of production inefficiencies in the stator manufacturing process.
2. Reduce Costs: Aim to reduce the estimated annual loss of $50,000 attributed to wire waste.
3. Implement Six Sigma Methodology: Apply the DMAIC methodology to enhance operational efficiency and product quality.
4. Promote Zero Defects Philosophy: Foster a culture of "Zero Defects" within the manufacturing process.

5. Establish Continuous Improvement Framework: Create a sustainable framework for ongoing process enhancement.

3. Problem Statement

The stator manufacturing company is currently facing significant production inefficiencies, resulting in an estimated annual loss of $50,000 due to excessive wire waste during the manufacturing process. This loss not only affects profitability but also hinders the company's ability to maintain competitive quality standards. Addressing these inefficiencies is critical for improving overall operational performance and ensuring long-term sustainability.

4. The DMAIC Six Sigma methodology applied to an assembly process

4.1 Define Phase

According to the company's annual report actual case study, for example, if loss resulting of stator wire manufacturing is $50,000 per year, it will need the actual manufacturing improvement case study to be implemented to reduce waste. So, the work team was formed, and the work team had set a start time to be completed and evaluated as soon as possible tasks them. Steps of a complete stator process from the winder process have illustrated until a fully function stator product is completed (Fig 1). Steps 1 showed amount of wire left over in winder after the winding process. Next, the amount of long wire which is left over is cut off for the next stage of setup and wiring clip onto the stator in step 2. Lastly, in step 3 of the pictures shows that the installation of wire clip onto stator is complete and ready to be used as a functioning product.

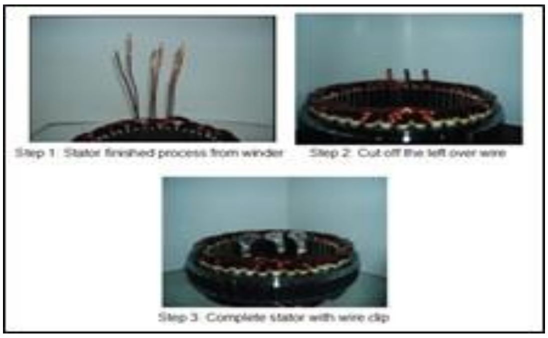


Figure1: stages of Wire stators manufacturing

As a result, the amount of left over wire which needs to be cut off is a kind of waste which has defined in manufacturing process. A project planning management team has been setup to achieve outputs that needed in the IPO diagram. Therefore, project management team managed to use one of the sigma tools which are just in time (JIT) theory to reduce process wire loss on manufacturing.

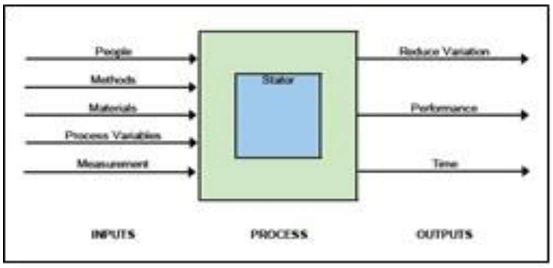


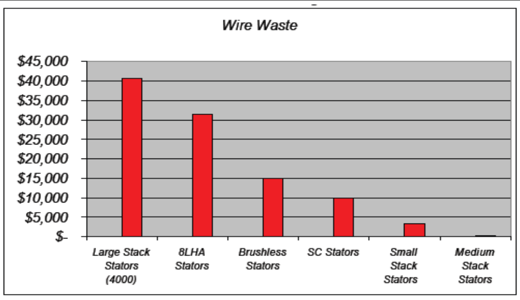
Figure 2: IPO Diagram for Process Plan

Figure 2 is that above illustrates an IPO diagram of a process plan. It is defined as a tool to do analysis for Six Sigma. Obviously, it represents activity between relationships of input, process and output respectively. List of outputs are generated by the stator process plan through the list of input. It can be defined as mean of program documentation for reducing process wire loss on stator manufacturing. The process itself solved the problem of the inputs data item then generated outputs produced or modified by the steps in the process through the stator process. The inputs are people, methods, materials, process variable and measurement. Outputs generated by process are indicated as reducing variations, performance and time respectively that affect the manufacturing system in general. The expected output is the productivity and quality is better aligned with the main objective of Six Sigma to deliver goods more quickly in respective to cost and quality.

4.2 Measure Phase:

It has been decided to concentrate improvement efforts on process which causes the highest number of defects.

The purpose of this phase has measuring and collecting data from process in order to do more investigation in analyse phase and find the root causes. A useful sigma tool that can help to collect data is Statistical Process Control (SPC) to measure the variation in the process. In this way, we can collect large amount of data involve total wire lose in manufacturing system, so that we can study and learn which is the highest wire lose stator in the manufacturing process, and find the root causes that can use in analysis phase. To collect data, control chart can be used to make data clear between winder machines. For example, we can collect data of amount of wire cut off in each winder by taking randomly 30 pieces of stator in different winder machines. Then, these collected data may be converted into other kind of analysis chart like Pareto chart, 6 sigma chart, and SPC chart. Clearly, the maximum potential saving has showed of waste and the large stack stators are the most priority in the case Figure.3



Large Stack Stators (4000)	$	40,763
8LHA Stators	$	31,417
Brushless Stators	$	15,055
SC Stators	$	9,998
Small Stack Stators (2500)	$	3,230
Medium Stack Stators (Hvy Std)	$	230
TOTAL	$	100,693

Figure 3: Pareto analysis for maximum potential saving of waste

4.3 Analysis Phase:

The analysis phase involves a systematic examination of the collected data to identify patterns, anomalies, and root causes of inefficiencies in the manufacturing process. Preliminary data, as shown in Figure 3, indicated that large stack stators (4000) accounted for the highest wire waste (41.4%), followed by 8LHA stators (23.8%). This suggests potential variability in material handling or production parameters. To trace the root causes effectively, an Ishikawa (Fishbone) diagram (Ishikawa, 1985) was utilized. This tool categorizes contributing factors such as Man, Machine, Method, and Material and facilitates a targeted investigation of causal relationships. Its application revealed that [briefly state key findings, e.g., "inconsistencies in wire tension from Machine X were the primary driver of waste

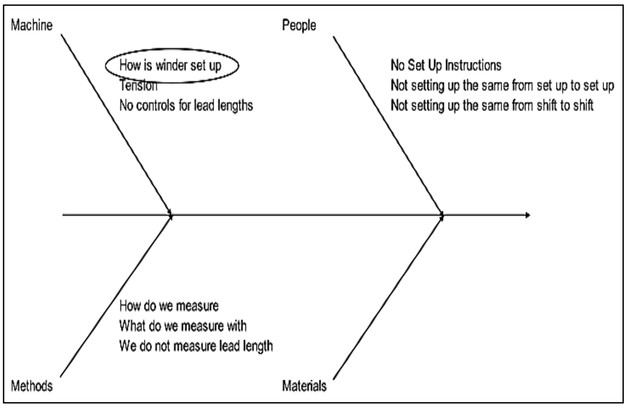


Figure 4: the main cause on four inputs

The team identified four primary root-cause categories, as illustrated in Figure 4: Machine, Methods, Materials, and People.

In terms of Machine, the analysis revealed several key issues, including inconsistent winder setup procedures, a lack of winding tension control by operators, and unregulated lead lengths during production. These factors contribute significantly to inefficiencies in the manufacturing process. Regarding Methods, it was found that operators lacked the necessary knowledge for measuring wire lengths per stator. Additionally, there was an absence of standardized special tools designed for precise measurements, and lead lengths were not verified across different stator variants, further complicating the production process. As for People, missing setup instructions were identified as a crucial factor. This absence leads to variability between shifts and production runs, impacting overall quality and consistency. The Ishikawa diagram systematically organized these causes, enabling the team to prioritize targeted solutions effectively. By addressing these root causes, the team can implement changes that enhance operational efficiency and reduce waste.

A functional process flow chart based on the "Critical to Quality" (CTQ) tree has been recommended to reinspect the problems encountered during the stator manufacturing process. This flow chart allows for a step-by-step analysis of issues related to excessive spending in the process. The steps involved in the stator manufacturing process include:

1. Lamination bonding
2. Insulating
3. Winding
4. Coil placement
5. Finishing coil end turns
6. Varnishing Machining
7. Electrical testing and final inspection

Improvement efforts have concentrated on reducing wire loss in stator manufacturing, with a specific focus on the winding and coil placement steps. This method serves as an additional approach to assist in identifying the root causes of the problems. The team can utilize this method to recheck the suitability of their production process and to find solutions to the issues, as illustrated in Figure 5.

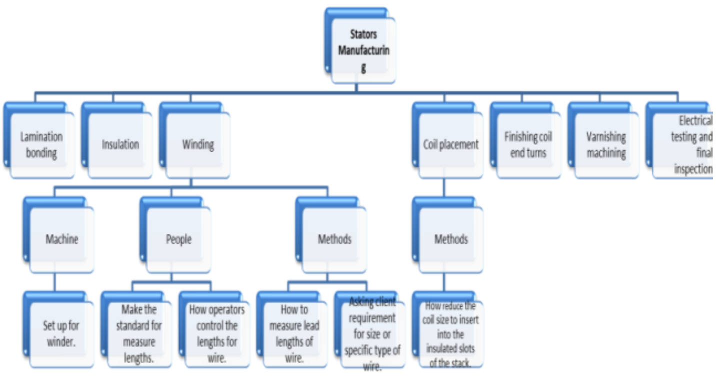


Figure5: Using the CTQ tree to analysis process

4.4 Improve phase:

The Improve phase is critical as it involves implementing changes to the process by developing solutions to address identified problems. At this stage, the company evaluates the effectiveness of these changes and determines whether additional modifications are necessary. In this context, the team recommends utilizing the CHECK process tool, facilitated by supervisors during the manufacturing process. To achieve satisfactory results without incurring losses, it is essential to gather comprehensive data from real-time production lines before applying the CHECK process tool. This data collection should focus on the root causes of instability within the manufacturing process, particularly concerning the issue of wire waste during the stator manufacturing. To ensure operations adhere to the required standards and specifications, the team has identified several steps aimed at reducing wire waste and controlling product quality. These steps include the establishment of clear standards and specifications, which serve as guidelines for minimizing waste.

The primary objective of the CHECK process is to ensure that all process elements remain under control. The checklist for this process is presented in Table 1 below:

Table (1): Checking process list

1. Correct: Confirm the list are using suitable working condition.
The staffs are trained on process of manufacturing before they go for work.
The staffs understand that the working process and production standard.
Working process having vision in work area.
Checking lead lengths and wind diameter then do record data.
Checking specific requirement on history record data from client before manufacturing.
2. Workstation management: Confirm clean and systematic workstations.
Make sure workstations are clean and systematic.
Make sure the workstations are safety.
The staffs have good visual on working area.
3. Equipment: Confirm all equipment and tools are standardise and operating sequence.
Using standard of reference before production manufacturing.
Using standard lead lengths for scale measuring.

4. Contain: Confirm the process step is accuracy before into next process manufacturing. Approval all process step are accuracy. Checking production regular intervals during manufacturing. 5. Daily Checking: Check process manufacturing routine.
The check process on data (day/month/year) and (time)

4.5 Control phase:

The Control phase represents the final step of this project, with the main objective being to equip the company with the tools necessary to sustain improvements. To achieve this, the team adopted Six Sigma as a standard improvement methodology. This approach facilitates a comprehensive re-evaluation of the project, leading to the standardization of processes that will be implemented moving forward. Once the implementation plan is established, the focus shifts to continuously improving performance and reducing wire wastage. A key tool in this phase is Failure Modes-Effects-Criticality Analysis (FMECA), which combines Failure Modes-Effects Analysis (FMEA) with Criticality Analysis (CA). FMECA serves as a functional analysis tool that identifies risks in manufacturing and engineering processes. The FMEA component helps determine the necessary actions to minimize waste and reduce capital costs, while the CA aspect provides relative measures of the significance of failure modes, including their impact on safe and successful operational requirements. The FMEA/FMECA process typically requires a thorough assessment of items, functions, failures, effects of failure, causes of failure, current controls, recommended actions, and other relevant details. FMECA offers project management a concise summary for the management planning team regarding sigma waste in the manufacturing process. It is crucial that the FMECA be updated based on the results from process performance evaluations. Finally, the information gathered from this analysis should be documented and communicated to team leaders, facilitating their understanding and assessment of the performance of the newly implemented plans. To illustrate how FMECA is applied in this project, the team created tables that demonstrate the use of Lean Six Sigma tools for analyzing problems and risks, ultimately leading to effective solutions. Tables 2 to 4 present the scale ratings for severity, detection of failure effects, and occurrence. The data in these tables is based on real situations within manufacturing firms. Following the FMEA analysis, the results demonstrated the potential to significantly reduce process risks and generate cost savings. Consequently, the findings presented in Table 5 highlight the opportunities for mitigating issues encountered during the manufacturing process.

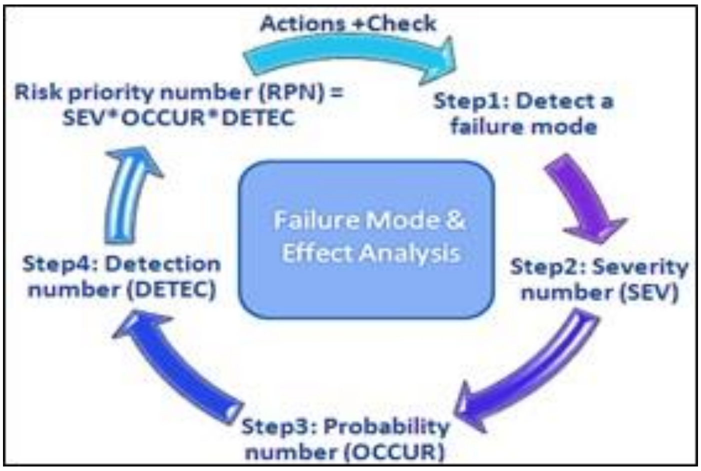


Figure 6: FMECA step

Table (2): Severity Rating Scale for System Malfunctions

Rating Scale: Severity	
1	No Effect
2	Insignificant minor malfunctioning
3	Minor malfunctioning of the system
4/5/6	Moderate break down of the performance
7/8	Products functionality unstable and high defectiveness unsatisfactory
9/10	Product standard illegalness and human body safety and regulation unawareness

Table (3): Rating scale: Occurrence

Rating Scale: Occurrence	
1	Unknown
2/3	Once every 2 to 3 months
4/5/6	Once for 3 to 4 weeks
7/8	Once a week
9/10	Once or several times a day

Table (4): Rating Scale: Detection

Rating Scale: Detection	
1	Failures can be avoidable
2	Inspection automatically
3	Statistical process control is done to examine the causes of failures after the prevention measures are

	introduced
4/5/6	Statistical process control is done for all unit checked manually and prevention measures for the failure
7/8	The units must be checked daily or frequently
9/10	Impossible or undetectable to discover the cause of failure

Table5: QUANTITIVE Failure Modes Effects Criticality Analysis (FMECA)

QUANTITIVE Failure Modes Effects Criticality Analysis (FMECA)

Fun	**Failu re**	**re Cau**	**re Effe**	Occu rrenc	Seve rity	Dete ction	Risk PN	**Rec om**	Occu rrenc	Seve rity	Dete ction	Risk PN	**Rem ark**
Patt ern	hed win	teg y	due to	5	6	8	240	the n	2	2	3	12	
A Stat	n win	ma n	ect patt	3	6	8	144	me asu	1	2	2	4	
k Stat	aks bef	ten sion	due to	5	2	7	70	afte r	1	2	3	6	
Patt ern	met er	ma n	e and	3	2	7	42	lab el	2	2	4	16	
k Stat	ng the	on mat	the con	3	7	7	147	ls pur	1	8	3	24	

* RPN Risk Priority Number = Severity * Occurrence * Detection, Notice that RPN is calculated both before and after Corrective Action.

4.6 Result phase:

The Results Phase is a critical culmination of our team's efforts in implementing the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology. This phase highlights the tangible benefits achieved through collaborative work, showcasing significant advancements in efficiency and cost reduction.

Our analysis of wire waste before and after implementing improvements demonstrates the effectiveness of our strategies, as illustrated in the table below:

Stator Type	Before Waste ($)	After Waste ($)	Savings ($)
Large Stack Stators	40,781	26,800	13,981
8LHA Stators	31,740	20,000	11,740
Brushless Stators	3,194	2,000	1,194
SC Stators	1,391	800	591
Small Stack Stators	250	100	150
Medium Stack Stators	230	100	130

This table illustrates the wire waste for each stator type before and after our improvements. The total waste before the improvements was $100,693, reduced to $26,546 post-implementation, resulting in total savings of $74,147. This represents an impressive 26.37% reduction in overall wire waste, validating the effectiveness of our team's collaborative strategies.

The results underscore the power of the Six Sigma framework in driving process optimization and waste reduction. By rigorously applying the DMAIC principles as a cohesive team, we achieved our targets and demonstrated the transformative impact of these quality management tools on manufacturing operations.

The data presented in this analysis provides clear, data-driven evidence of the significant financial benefits realized through our Six Sigma initiative. This highlights the strategic value that such methodologies can deliver in enhancing operational efficiency and profitability, ultimately paving the way for future improvements.

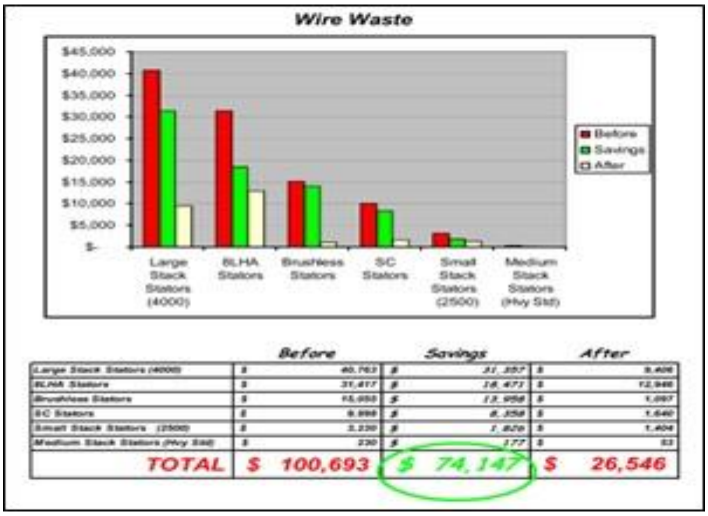


Figure 7: Final results of saving

5. Conclusion:

In conclusion, the project team leveraged a comprehensive suite of Six Sigma and Sigma Logic tools to drive this initiative through its various stages. At the outset, the Define phase saw the utilization of an IPO (Input-Process-Output) diagram to map out and analyze the project scope. Moving into the Measure step, the team employed Statistical Process Control (SPC) to meticulously assess the variation within the manufacturing process, enabling them to uncover the root causes underlying performance gaps. The subsequent Analysis phase then deployed powerful problem-solving techniques such as the fishbone diagram and CTQ (Critical to Quality) tree. These analytical tools provided valuable insights, pinpointing specific areas of waste and inefficiency within the stators production process. With a clear understanding of the key issues, the Improve step saw the implementation of targeted process checks and supervisor oversight to enhance operations and drive optimization. Finally, the Control phase utilized Failure Modes and Effects Analysis (FMEA) to determine the most effective actions for minimizing waste and reducing capital expenditures.

By seamlessly integrating this robust Six Sigma methodology across the project's lifecycle, the team was able to achieve remarkable results, ultimately delivering a remarkable $74,147 in cost savings for the stators manufacturing operations.

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دور ستة سيجما لتحسين عمليات التصنيع في الشركة والحد من النفايات

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الملخص

تم الإبلاغ عن مشكلة بخسارة سنوية تقدر بـ 50.000 دولار إلى إحدى شركات تصنيع الجزء الثابت، لذلك سيتم بتشكيل فريق **Six Sigma** واتباع خطوات ستة سيجما لتحديد الأسباب الجذرية للمشكلة من خلال مراحلها: التحديد، القياس، عملية التحليل، ومرحلة التحسين والسيطرة، وبالفعل تم تنفيذ التحسين بشكل أكثر فعالية في البحث من خلال تقليل تكلفة الإنتاج وتطوير عملية التصنيع. ومن خلال أدوات ستة سيجما ، تم بالفعل تحديد الأسباب الجذرية للمشكلة وقياسها وتحليلها باستخدام نطاق محسّن ومسيطر عليه. لذا، فقد حددت نتائج الدراسة الأسباب الجذرية للمشكلة والتي تمثلت في تحسينات في تقليل فقد أسلاك العملية من تصنيع الجزء الثابت، والتعويض عن التمايز بين مرحلة التحديد والقياس والتحليل والتحسين والتحكم، وهي دراسة حالة فعلية للشركة هي تم إجراؤه لدعم فقدان الأسلاك المبلغ عنه بواسطة فريق الحزام الأخضر

الكلمات المفتاحية:

DAMIC, IPO diagram, SPC, Ishikawa diagram, CTQ tree, FMEA..