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Quality Improvement through DMAIC: A Case Study of Wire Harness Tape Manufacturing

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Abstract

The goals of this research were to identify problems, find solutions and implement DMAIC to improve the high defect rate in the weaving process that was causing high operation cost at a wire harness tape manufacturing in Thailand. In this study, qualitative research was used with samples collected, and the paper gives an insight into the 16-week journey of applying a DMAIC (Define-Measure-Analyze-Improve-Control) of Six Sigma framework to achieve reducing defects in the weaving process. The study utilized the Six Sigma tools such as brainstorming, SIPOC, affinity diagram, Isikawa diagram, Pareto chart and checklists. As a result, the root cause of significant defects were first, the human problem was defined, human error, no motivation, not enough training. Then an improvement plan was constructed, that included training of SOP, ISO 9001:2015, and CTQs. Next, the problem with machines were defined such as machines were not in the appropriate condition causing them to breakdown and shortages of spare parts to fix the machines. Implementing the preventive maintenance, daily checking, and monthly scheduled maintenance will stop these issues from occurring. Last, the raw material issue, which lacked full inspection, lack of vendor site inspection, and lack of qualified products, the issues can be prevented by implementing a system of value chain management and supplier relationship management with vendor site inspection planning. The ISO 9001:2015 is the significant tool implemented to ensure the company meets quality control and quality assurance. In the end, the desired achievement to reduce 6% to zero defect rate was achieved. The value of this study presents an industrial case that demonstrates how the deployment of Six Sigma and DMAIC can assist manufacturing productivity to achieve quality improvements in their processes.

Introduction

The mass production of the textiles industry sector during the 18th century was a powerful industry of the first industrial revolution, and the first to use modern production methods. The industries rapidly became economic powerhouses and contributed to economic growth (Ashton, 1948). Today, the textile industries are fundamental to the economic and social enhancement of many people and emerging countries, being the access point to global supply chains and export markets. In 2018, The international textile industry sector was forecasted to be approximately USD 920

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billion, and it is projected to reach approximately USD 1,230 billion by 2024 (Grand View Research, 2020). Thailand's textile industry has achieved supremacy over the past five decades, despite challenges from leading global textile producers. As a strong history base of silk and cotton operation, Thailand's textiles and apparel industry are increasingly growing and evolving to keep up with changing customer preferences (Board of Investment, 2018). The economy's slowdown as a result of the coronavirus outbreak has an effect on automotive companies, with projections for 2% export growth and 3% domestic declines in 2021. Although the next three years are projected to see a 3-4 percent growth rate (2021-2023), sales are expected to fall due to a slow recovery in buyer spending.

Motorola established the Six-Sigma system in the 1980s, with the goal of achieving a challenging failure rate of 3.4 parts per million (Barney, 2002). Six Sigma seeks to optimize business processes in such a way that the standard deviation of a process is so small that any value within six standard deviations of the mean can be considered non-defective, in order to reduce the number of defects (Graafmans, Turetken, Poppelaars, & Fahland, 2020). Other approaches to a successful management system exist. However, the introduction of the Six Sigma method in the 1980s resulted in significant improvements, especially in the areas of reliability, service quality, and overall management (Ertürk, Tuerdi, & Wujiabudula, 2016). Six Sigma was initially used to improve industrial operations Currently, Six Sigma is use to improve marketing, purchasing, billing, invoicing, insurance, human resource and customer, the Six Sigma approach is also being used in call answering functions with the goal of constantly reducing defects throughout the organization's processes (Patil & Inamder, 2014). Define-Measure-Analyze-Improve-Control ("DMAIC") is a Six Sigma framework, which is a very effective tool for the process of optimization, and is one of the most often used Six Sigma methodologies (Khandker & Sakib, 2018). In the context of Thailand, the application of Six Sigma is considerable. There are amounts of losses due to a high degree of defect in the wire harness tape manufacturing in Thailand. In order to continuously improve the wire harness tape manufacturing, the related techniques must first be applied as discussed above. The Six Sigma DMAIC is helpful in ridding any production's wastes and defect. Moreover, there is no previous longitudinal research conducted that explores wire harness tape production based on Six Sigma DMAIC over a series of years. The company's benefits and increased customer satisfaction would be possible to apply the Six Sigma quality control system. In this case study the DMAIC methodology was used to improve the wire harness tape manufacturing process. This study was performed based on data from internal customer complaints in a wire harness tape manufacturing in Thailand. In the weaving process, there was a problem with product quality, with non-standard fibers being woven into fleeces, which were frequently damaged by thickness, mixed wastes, lumps, and weight. Organizations need to implement quality control techniques and methodologies like DMAIC to achieve broad enhancements in quality, productivity and customer satisfaction, as well as cost reduction. One of the most critical concerns for wiring harness manufacturers is the elimination of critical quality defects such as fleece weight being too much or too little and mixed wastes. Not only does an organization waste its resources and time to re-check or re-work the products, but it also leads to the loss of customer satisfaction and trust. The research points out the potential value of distinguishing defects of wire harness tape quality.

Objectives

1. To determine and improve the defects of wire harness tape quality in the supply chain management in the wire harness tape company in Thailand.

2. To implement a six-sigma approach of DMAIC to identify process gaps and to measure performance improvement and offer practical strategies based on the findings.

Conceptual framework

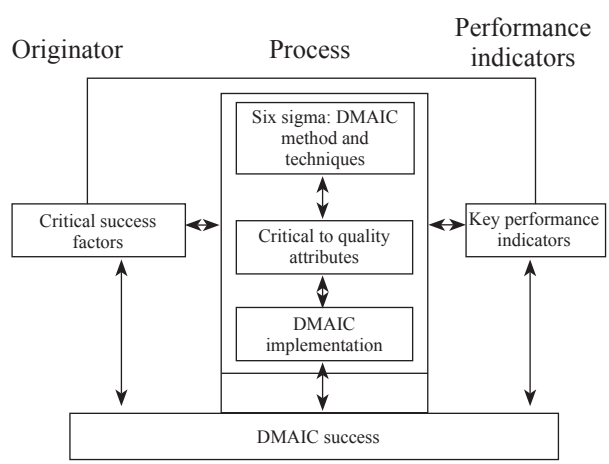

Figure 1 Conceptual framework

Research methodology

The objective of the project was to improve the quality of the product by eliminating or reducing the existence of the defects causing poor product quality with the purpose of achieving the quality advancement and meet the customer expectations. The main intention of this study was to reduce the defects, quality and productivity improvement by the application of Six Sigma using the DMAIC methodology in the process of product quality control in the wire harness tape operation.

1. Collection methods

1.1 This study is qualitative research using observation and semi-structured interviews of the production process and actual events in the manufacturing.

1.2 Brainstorming by managers, supervisors, QC operators.

1.3 The data sheets were obtained from the end line quality inspectors' record books from the wire harness tape production lines. Six Sigma DMAIC approach was implemented.

2. **Population and research sample**

The population in this study were wire harness tape and the samplings were data from reject production as a fleece fiber result of the QC process carried out by wire harness tape manufacturing. This study used data sheets collected for four months during August 2019 to November 2019. The research methodology is presented in the following sequences.

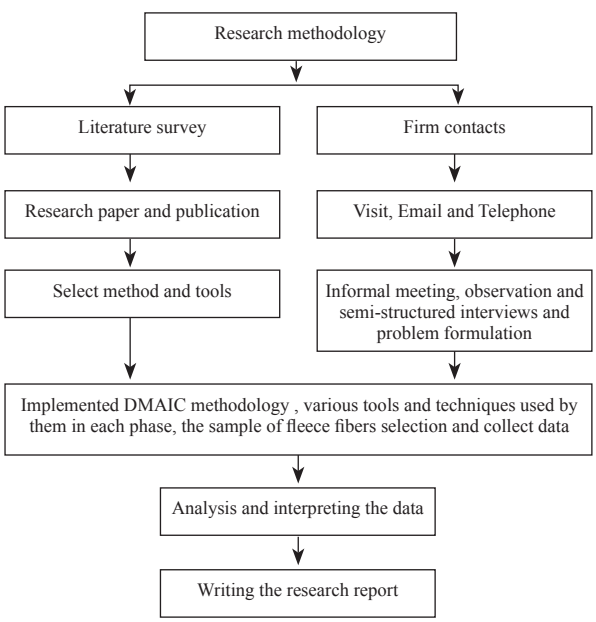

Figure 2 Research methodology

The implementation of the project conforms to the five phases of DMAIC. An illustration consists of the following.

Define: Define the process and opportunities for change from a company and consumer standpoint. The first step is to determine the customer (internal and external), analysis the voice of the customer to find out the service level, which are critical to their view of quality, called critical to quality (CTQ). Next step is performing an SIPOC (Supplier, input, process, output and customer) analysis to learn the suppliers to the operation under study, the inputs given by those suppliers, the production, and finally identifying the customers or market segments for the outputs at a very high level of abstraction of the process flowchart under analysis. The final stage is comprehensive process flow, which is similar to high-level process flow but maps each process segment in greater depth. Finally, state the issue, the scope of the project, and the team's objectives.

Measure: The issues, scope and objectives are set, next the need to follow by three measure stage; first set the performance indicators to measure, specify what needs to be calculated, with an emphasis on upstream leading steps. Next, collect base line data, this makes it clear how data will be collected and sets down definitions and procedures. Last, develop baseline performance measurement, this provides an evaluation of how the company's current process is performing. This will be compared to what happens when changes are made later. Therefore, the project team needs to validate the problem, refine problem and keep step input. With the help of pareto chart, control charts, SPC methods.

Analyze: Analyze's goal is to examine current data and identify root causes and opportunities for improvement. Determine true sources of variance and possible failure modes that lead to consumer dissatisfaction by identifying and validating root causes to ensure the removal of "actual" root causes. Understanding why defects have occurred, as well as comparing and prioritizing prospects for improvement in the future. To define and validate the problem's root causes, the project team will use data analysis methods and process analysis techniques. They are using different analyzing techniques like FMEA, cause and effect diagram, pareto chart, and processing mapping, affinity diagram, Ishikawa diagram.

Improve: The steps generate potential root-cause solutions, as well as define, analyze, and choose the best improvement options. Develop a change management

strategy to help the company respond to the changes brought about by solution implementation. The goal of the improve stage is to find and implementation of solutions that will eliminate the causes of problems, reduce the variation in a process, or prevent a problem from recurring. So, the project team needs to develop ideas to remove root causes, test solutions, and standardize solution result. The use of quality tools are implemented like bar chart, histogram, pareto chart, brainstorming, ISO 9001:2015, and SOP.

Control: To comprehend the significance of preparing and executing against the strategy, as well as to decide the path to take in order to ensure the achievement of the desired outcomes. They use of control charts, create specifications, flow charts, check lists, and other tools to ensure continuity during the improvement process. As a result, they increase the sigma level for their specified projects after successfully implementing the DMAIC methodology (Sindha & Suthar, 2017).

Results

The project was directed to the area of production, from raw material receiving, warping, weaving, calico, heat treatment, inspection, sorting, packing, store, and delivery of the product. The operation, in which the improvement project was implemented, is a part of the production division of a wire harness tape plant with a long tradition. Wire harness tape from the production division is used in the automobile, engineering and construction industries, as well as in the production of white kitchen appliances. Meanwhile, the process of wire harness tape, starts with; fleece and yarn warping from a bobbin is synthetic and yarns are woven together, calico, the fabric is heat treated by Teneter Frame, after heat-treatment, the wire harness tape must have the required quality mechanical and physical properties inspection, sorting, store, and delivery to the customer. In operations, there was a problem with product quality, the weaving non -standard fibers, the fleeces were often degraded by thickness, mixed wastes, lumps, and weight. The phases in the DMAIC framework include define, measure, analyze, improve and control is performed via roadmap as shown in figure 3.

1. Define phase

The research began with a meeting in the company to discuss the problems. A thorough examination of the entire manufacturing process was conducted. The defined phases of a six sigma DMAIC model were used to identify the product quality characteristics which is critical to the customer (CTQs) in which the weaving process was selected as a process that requires improvement due to the high defect rate of fleece and high operations failure costs. If the fleece does not meet the requirement of an internal customer, it is returned to the previous processing stage for re-adjustment. The observation of the fabric tape production process found that wastes that occur in the production process will occur in the weaving process of fibers that do not meet the specified standards. Though, causing waste in the subsequent process, the Calico weaving machine could not weave raw calico, due to the tearing of the fleece or the waste while weaving into calico. Therefore, the study determined the acceptable waste levels at ± 3 6 from the acceptable level of original waste of ± 5 6. The alternative tool for the define phase was SIPOC (supplier, input, process, output, customer) analysis shown in figure 4. Goal definition: the goal of the project was to reduce the number of failed fleece quality from 6% to zero and to reduce the processing costs. Project implementation time was scheduled for 4 months, from August to November 2019.

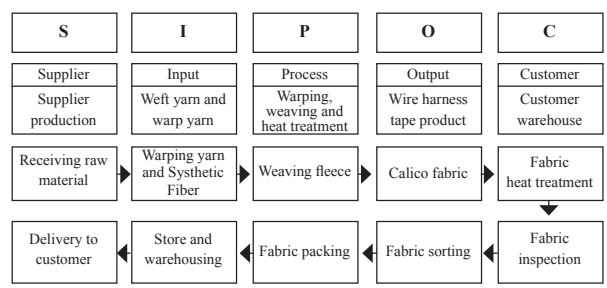

Figure 4 Supplier-Input-Process-Output-Customer Diagram of Wire Harness Tape

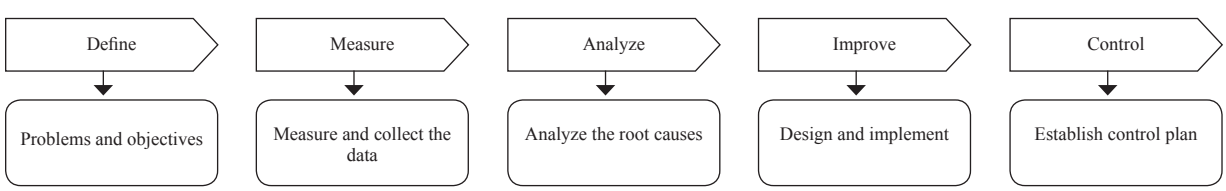

Figure 3 The stages of DMAIC methodologies

2. Measure phase

From the study, it was found that waste defects occurred in the weaving process. For the project implementation time was scheduled for 4 months, the fleeces in the fiber weaving department produced amounts of defects by on average of 6% per week. The Pareto chart is shown in figure 4, The collected data was obtained with a check sheet and researchers identified the fleece fibers defects as follows; thickness 48%, wastes mixed 22%, lumps 16% and weight 14%.

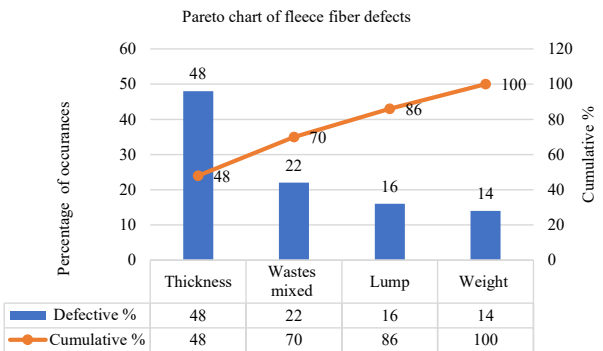

Figure 5 Pareto chart of fleece fibers defects

3. Analyze phase

Through the analysis phase, the affinity diagram performed with fourteen participants all with knowledge about the defect, working in two-shift and various positions, Problem Title: What is the cause of Wire Harness Tape Defects?", the result of the initiative defect analysis is shown in figure 5.

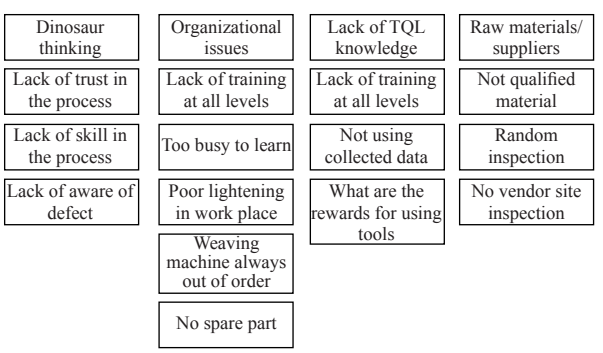

Figure 6 Potential causes as a results of affinity diagram

In order to display and classifies the practicable causes of the defect, a cause-and-effect diagram was constructed. The cause-and-effect diagram (Ishikawa Diagram) is known as a regularly questioning method for seeking the root causes of problems. The analysis of the Ishikawa Diagram signifies the potential causal linkages between the factors and the examined problem. It was essential to investigate the defined elements by observation and validate the root cause by logical analysis as shown in figure 7.

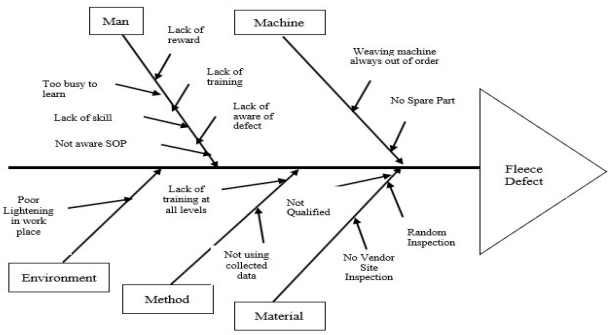

Figure 7 Ishikawa diagram-fleece defects

3.1 Man-Out of the 14 fleece causes of defects, 6 were from human error. To minimize errors and develop lost time caused by "the man", training is required for employees to work correctly and efficiently with minimizing waste time. The causal relationship of the employee with the fleece defect was revealed by observation. The employee was in an unsatisfactory technical skill condition. The lack of time management to learn new things, lack of proper skill training, no training for awareness and SOP. Employees do not understand how to do their work properly because there is little or insufficient teaching, and none of these objectives can be met. This leads to low morale among employees, which results in employee turnover, production defect and wastes. There were no announcements to recognize proper duties and no commitment to offer rewards. Hence, a lack of employee motivation and increase in fleece defects. It is usual for every employee to like having his or her achievements recognized by other employees. Even though personal satisfaction will come from meeting a predetermined goal, it is always more meaningful if the company is there to share the success.

3.2 Machine-The loom interruptions occurred because of various reasons and the regularity of such incidents determined the rate of loom suspensions. The opportunity of damaging the weft yarn is further influenced by the variations of environmental conditions and hence these conditions are highly responsible for the weft yarn tears during the weaving process. The loom frequently needs to be serviced by replacing the worn-out

parts of machines. The production was affected when failure to find spare parts to fit the machines occured.

3.3 Environment-From the employees'' perspective, poor lighting at work affects health such as eye-strain, fatigue, headaches, stress, and accidents. Too much light can cause safety and health troubles such as "glare" causing headaches and stress. This can lead to faults at work, unsatisfactory quality and weak productivity. The psychological health benefits and welfare of employees should be reviewed in order to retain a long-term workforce.

3.4 Method-The production division, the failure of data utilization that causes inaccurate information in real-time. In addition, insufficiency in all levels of training.

3.5 Material-The current process flow chart showed that the warehouse received raw materials from suppliers without full inspection and delivery to production. No other preventive measures were in place and there were no qualified raw material flow in the production line such as random inspection. This indicates that the process requires an adaption and changes to add control and preventive measures to ensure that raw material match and are qualified for wire harness tape production division requirements. Current control was not enough to prevent the occurrence of defects indicated by the figure of 6% defects, meaning that traditional workflow cannot achieve a reduction in defects and cost - effectiveness targets.

4. Improve phase

The corrective action for the root causes problems were carried out at this stage. The root causes of many types of trouble have been identified, as well as solutions, as indicated in Table 1.

Table 1 no. 2 The root cause of problems and the comparison of improving process

The root causes of problems	Before improving process	Customer critical to quality (CTQs)	Operator method	After improving process
Man	- Human error in weaving process due to not enough training to work properly. - No employee motivation	The workers work properly and no production defect and wastes.	- The training and development of the quality awareness program of SOP, ISO system and CTQs. - The employee recognition program, the rewarding staff for the hard-work, rise profits for both parties.	- The worker has a deep understanding of the SOP, ISO system and CTQs. - Workers are more effective, their positive reaction when management presents appreciation for their great work or achievement.
Machine	The loom always breakdown and spare part shortage.	The machines utilization of 100% and increase productivity, effectiveness and efficiency.	Set up the preventive maintenance and routine schedule maintenance can reduce the looming break down and reduce waste in the weaving line.	Decreasing the looming breaks down and reduce waste in the weaving line. Moreover, the machines and equipment can expand the life of machines and scrap decreases and control dramatically.
Environment	Poor lighting effect to eye-strain, fatigue, headaches, stress, and accidents and too much light cause safety and health troubles.	A healthy and safe work environment.	Install blue-enriched light bulbs in meeting and/or recreation room.	Reduce fatigue and increase happiness and work efficiency.
Method	The production division, the failure of data utilization. It cause inaccurate information in real - time.	Friendly with big data analytics tools.	Establishing the big data tools.	The enhancement of quality levels and reduction quality-related expenditure, creates constant potential for optimization, cost saving, and preclusion, as long as the proper tools are accessible for data analysis.
Material	Yarn defect 6%. Yarn quality issues; no yarn full amount quality inspection in material supply chain by supplier, warehouse and production, and no other preventive method.	No defect and wastes, and quality assurance to achieve the AQL ± 3 6,	Established the system of value chain management and supplier relationship management with vendor site inspection plan and develop inspection test plans (ITPs).	Material defect reduction from 6% to 0%.

5. Control phase

Six Sigma uses five key philosophies to ensure products meet customers' requirements and have zero defects. After the implementation of these solutions into the operation, the results were tested and measured for

one month. A significant decrease in the production defect category to zero defects in the fleece was achieved. Quality Assurance with quality control, however, ISO 9001:2015 works for businesses large and small and can be suitable to enhance operations. It provides the means for establishing a long-term quality assurance policy, ensuring that everything from raw materials to inspection procedures is of the highest quality. Issues and defects from unsatisfactory quality substances or third-party components are all but eliminated. The new methods become standardized in practice and lessons learned are documented :

5.1 Training of warping, weaving and calico operators on the appropriate standard operating procedure and on the new modified processes.

5.2 Training of maintenance technicians on the new modified processes and tool release process.

5.3 Update the control plan with the revised changes in the process.

5.4 Perform event case process release to ensure that warping, weaving and calico process is controlled and actions are maintained.

5.5 Reducing errors from humans and machines by creating checklists. The goal of establishing checklists was to verify that workers clean the working area and check conditions of safety equipment as well as routinely checking materials before starting work. Moreover, the setting of parts of the machine should be tested, fixed, and maintained after one order of production is finished, which usually takes one month. Therefore, the checklists were divided into 2 forms: daily machine checklist and monthly machine preventive maintenance checklist. Preventive maintenance should be used to investigate and report monthly about the problems. Then, the steps in DMAIC can be repeated to resolve new problems. To monitor and support the results, the management system at the company should allow and motivate leadership at each level to work together with the worker more, in order to examine difficulties in the production process and improve the documentation system.

Discussion

This paper presented a successful case study of defects reduction in wiring harnesses tape manufacturing processes by applying Six Sigma DMAIC methodology. Nowadays, Six Sigma is increasingly popular among organizations from different industries (Laureani & Antony, 2019). It emphasize is mainly on improving production procedures which increases the cost-effectiveness of the company. Achieving the Six Sigma levels demands from organizations an awareness of the reasons for processes variance, performing their study of cause and effect and the evaluation of their costs. The application of DMAIC, which is one of the tools of quality enhancement used in Six Sigma, can grow the effectiveness while properly reacting to the emerging problems First, the human problem was defined, human error, no motivation, not enough training. Employees' lack of experience, qualification, and expertise, as well as their predisposition, culture, and enthusiasm for work, all contributed to the production process's low efficacy. The employees were unaware that their everyday behaviors had a significant impact on the organization's overall performance. The absence of motivation for work was obvious due to the lack of a rewards system. (Smętkowska & Mrugalska, 2018). Then an improvement plan was constructed, it included training of SOP, ISO 9001:2015 and CTQs. Warinah & Nusraningrum (2019), addressed that the corrective activities, such as conducting training and revising SOPs, are used to try to improve the fault in the study and aim to lessen the quantity of imperfections in the assembly by utilizing the Six Sigma (DMAIC) strategy. Next, the problems with machines were defined such as the inappropriate condition of the machines causing them to breakdown and shortage of spare parts to fix the machines. The preventive maintenance, daily checking, and monthly scheduled maintenance will stop these issues from occurring. The research of Six Sigma DMAIC for machine efficiency improvement in a carpet factory by Phruksaphanrat & Tipmanee (2019), mentioned that the daily machine checklist and the monthly preventive maintenance of the machine should be used to analyze the problem and report on in monthly. Last, the raw material issue, the lack of full inspection, lack of vendor site inspection and not qualified products, those issues can prevent action by the system of value chain management and supplier relationship management with vendor site inspection planning. This was established through work arrangements with suppliers, obtaining production material procurement commitment, and assist employees in QC. Astini & Imaroh (2021) research used DMAIC with thermal bags and stated that the ISO 9001:2015 is the significant tool for implementation to ensure the company meets quality control and quality assurance.

Advantages from the DMAIC enforcement is overviewed as follows: filled the internal customer’s

requirement concern of delivering the product with the required quality to the following production departments, minimize and saving of costs associated with the re-adjusting of non-conforming products and take advantage in the field of safety and protection of employees. Not only on the qualitative degree but also on the usefulness on the economic and safety level can be achieved. At the end of the project deadline, the case study was able to achieve the desired reduction of 6% to zero defect rate. Finally, all types of assignable causes were able to be controlled by reducing defects and implementing continuous improvement processes. The findings of this study show that the DMAIC approach, which is based on the Six Sigma principle, can be used to increase output efficiency in the wiring harnesses tape industry. In dynamic manufacturing, top management must be aware of new concepts such as value chain management and supplier relationship management, which can increase customer satisfaction while lowering costs and risks. It also can be a guiding principle for fixing problems inside the manufacturing of wiring harnesses tapes in different factories. In addition, it can be used in the manufacture of other products.

Suggestions

Companies can increase quality control by strengthening raw materials, machines, and staff during the manufacturing process. The same technique is also used by the organization to explore and enhance other equipment. This case study will benefit practitioners who are dealing with inefficient machines or processes.

Future studies should devote more than 4 months to gain a deeper understanding of the problems in order to gain more insight into the importance of data collection for the purpose in DMAIC methodology. Furthermore, the next study should focus on human resource management theories such as motivation to work, why employees lack motivation, and how to motivate them. As these factors influence quality and performance, extend the TPM theory (total preventive maintenance) and the supplier relationship management theory. The findings of this study can be used to conduct additional research into increasing production quality while still being environmentally sustainable.

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