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IMPLEMENTATION OF SIX SIGMA FOR REDUCING REWORK IN ASSEMBLY LINES: A CASE STUDY

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ABSTRACT

Rework in assembly lines is a practice that has persistently affected manufacturing industry in its endeavor to realize the feat of operation excellence and product quality. In this review article, the approaches, instruments, and results related to the incorporation of the Six Sigma strategies with a view of eliminating rework during assembly line operations as discussed in the case study in question are critically analyzed. Due to emphasis on DMAIC (Define, Measure, Analyze, Improve, and Control) process, the review compiles how systematic problem-solving methods, data-based analysis and continuous improvement strategies could remarkably boost manufacturing performance. This paper determines how effective some of the Six Sigma tools such as Pareto analysis, root cause analysis, and control charts have been in detecting sources of main defects and making process improvements that are long term. A special focus is put on pragmatic interventions like operator training, standardization of the processes, optimization of the equipment, which all added to an identifiable drop in rework rates and costs of production. Moreover, the focus of study is positioned in the context of broader literature in order to demonstrate the trends, issues, and best practice regarding quality management. This study combines the ideas of both the case study and related research, giving an in-depth insight concerning the question of how Six Sigma can be used as an effective tool in the enhancement of quality in contemporary assembly line performance. The paper ends by giving suggestions to future work and implementation initiatives that would allow taking advantage of the potential of Six Sigma in various industrial environments.

Keywords: Six Sigma, DMAIC Methodology, Assembly Line Optimization, Rework Reduction, Quality Improvement, Lean Manufacturing And Process Control Etc.

1. INTRODUCTION

Background and Motivation

By reducing product quality to maximum utilization of resources, competitiveness has become a core issue in the manufacturing industry in the world. Rework is one of the key issues that inhibits productivity and raises costs to the operations and this comes about as a process that rectifies the damaged, stalled or defective items. Not only does rework cause material and labor wastes but also impacts on delivery schedules, customer satisfaction and overall profitability. In production systems that are time-bound and have a semblance such as with assembly line where one process in the sequence depends on the other, rework often becomes a bottle neck and bottleneck. To solve this, most industries have deployed Six Sigma- a systematic, data-based approach which is geared towards the minimization of flaws, business procedures optimization, and quality improvement. Six Sigma focuses on decreasing variation and obtaining perfection or it tries to be almost perfect in the manufacturing process. It has been reported to reduce rework and facilitate higher quality in numerous fields, such as automotive industry, electronics, textiles, and heavy machinery industries.

Problem Statement

Rework is a fundamental problem that has been witnessed within the framework of modern manufacturing activities and in assembly line tasks in particular, as it has a powerful influence on the productivity, the rates of operation, and the quality of the output. Rework not only increases cost of production and causes delay of schedules to be delivered but also affects customer satisfaction and profitability of the company. The root causes of reworks are not always clearly identified, solved systematically, and the recurring rework problems lead to the occurrence of defects and inefficiency in most of the situations. Although methods of quality improvement are at hand, a large number of assembly lines continue to function with an unstructured mechanism to study and roots out process flaws. The organization that has been chosen in this case study is an organization that has been facing a high level of rework on the assembly line that is contributing to wastage of resources, exhaustion in its manpower and lack of uniformity in the quality produced. It is clear that there is a gap in the application of the data-driven decision tool and continuous improvement practices. This paper will show that there is necessity of a systematic and procedural discipline like Six

Sigma that may not only enable discovery and then solution of the root causes of rework but also help to put in place some long-range restorative measures. Hence, the aim of this study is based on applying the Six Sigma DMAIC model in the effort to understand, define and remove the major causes of rework, with an ultimate and overall objective of increasing the level of process capability thus decreasing the waste levels, and hence enhance the overall efficiency in the assembly line.

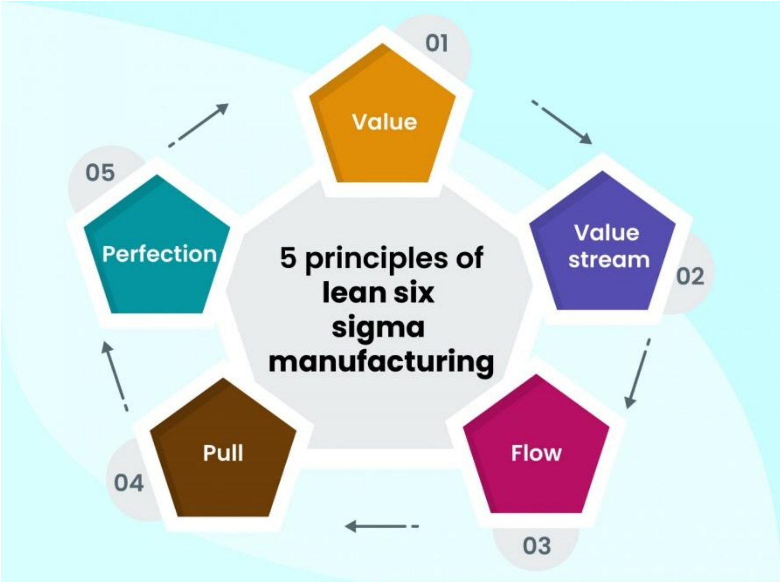

Fig 1: Principle of Six Sigma Manufacturing

Role of Six Sigma in Quality Improvement

Six Sigma has developed into an all-round approach in quality/ process improvement. The DMAIC process with five major stages Define, Measure, Analyze, Improve, and Control that is a step by step problem-solving pattern, is also a methodologic approach to the process. DMAIC is applied in identifying the problem and defining organizations collect data and analyze it, work on improving the processes and put control in place to maintain the gains. Many researches have revealed the effective implementation of Six Sigma in the reduction of the defects and rework. As an example, Priya et al. (2020) showed that Lean Six Sigma was useful in minimizing defects in an automotive assembly line. Likewise, Saputra et al. (2025) were able to enhance quality of scanning units by using Six Sigma-DMAIC technique. These illustrations assert the flexibility and efficiency of the method in different fields.

2. LITERATURE REVIEW

Many research studies have also evinced the efficiency of Six Sigma and its variations in enhancing and improving the quality and decreasing the occurrence of defects in manufacturing processes. The instance described by Meresa et al. (2025) involved the application of Six Sigma DMAIC methodology in a finite goods manufacturing unit that aimed at reducing the rate of defects and rejections in finishing department of a PP bag production unit, resulting in a significant improvement in the process of the unit via the root cause analysis and control measures. On the same tune, Patil and Tekade (2025) also pointed out that Six Sigma helped Mahindra and Mahindra to improve its production line by cutting the number of defects by looking into data driven changes. Setting an example of an application of Six Sigma, Setiawan (2025) was able to apply it in one of the rubber processing industries, where defects were over-commendable to justify the application in raw material-intensive industries. The study carried out by Rahmatillah and Rusindiyanto (2025) depicted how hybrid models can improve manufacturing results by introducing Six Sigma to the Lean concept and minimizing waste in a metal forming operation. Moreover, Saputra et al. (2025) applied the DMAIC model to enhancing the electronic scanning units qualities, whereas Laksmi (2025) combined Six Sigma and PFMEA and TRIZ to lower the costs of quality in the electronics mass production. Bukhari and Akhtar (2024) opened a new direction by transforming the artificial intelligence to advance predictive quality control in Six Sigma systems. According to Fortuna and Yuliawati (2024), the Lean Six Sigma was used to improve production in a manufacturing business in the confirmation of its wide applicability in the industrial sector.

The proposed integrated Agile Six Sigma model has been suggested by Znad (2022) as a method to increase product quality control, and DMAIC methodology has been used by Daniyan et al. (2022) to enhance the process of bogie assembly in the railcar sector, which indicates its flexibility in the industry of heavy engineering. Ershadi et al. (2021) proposed a hybrid model of decision-making based on the combination of Lean Six Sigma and data envelopment analysis and ANFIS, with its extension to the problem of selecting green projects. Six Sigma was applied by Purba et al. (2020) to enhance the quality of remanufactured lift arms in the heavy-duty industry of Indonesia, demonstrating its applicability in remanufacturing practice.

In the previous research, Priya et al. (2020) described an effective Lean Six Sigma project in an automotive assembly line that decreased useless defects and enhanced working patterns. Morais et al. (2015) reported an application of Lean Six Sigma methodology used in a general production line and confirmed that it is efficient to use. Yi et al. (2012) dwelt specifically in minimizing components wastage in the manufacture of electronics assembly using a Six Sigma technique, illustrating the significance of its usage in elements wastes. Subsequently, one of the pioneering studies in this field had been done by Gijo and Scaria (2010) who showed how rejection and rework was significantly decreased with the use of Six Sigma in a manufacturing environment whereby they set a precedent of future applications.

3. OBJECTIVES

The research will start with understanding the underlying causes of rework which can be conducted with the help of cause-effect diagrams, Pareto charts, and process mapping. The next step is to use the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) frame work to streamline and make the procedure of improvement systematic by making it data driven. The study also aims at determining the extent to which rework is detrimental to the efficiency of the production, the cost of operations, and the overall quality of products by setting up standard performance parameters. The research measures the impacts of these changes on rework minimization by carrying out process improvements that are targeted at specific process changes: standardization of work processes, improvement of quality inspections, and operator training. Also, statistical methods such as control charts, regression analysis, and test hypothesis to confirm the benefits have been confirmed and the gains are not transitory. Finally, the project will obtain practical implications and ways of good practices that will allow adopting the concepts of the Six Sigma in assembly line activity and ensure the sustainability of the concept of continuous improvement in the processes and manufacturing processes.

4. RESEARCH GAPS

- Although one of the studies (Bukhari & Akhtar, 2024) covers the use of AI in Six Sigma, the majority of the others benefit only with conventional DMAIC or Lean tools. A gap exists in literature covering the integration of such advanced technologies as machine learning, Internet of Things, and real-time analytics in the domain of defect prediction and real-time control.
- The past literature research usually centered on case-based studies that pertained to the individual industry in isolation (e.g., automotive, computers, or rubber). Cross-industry comparative analysis that helps to determine adaptability and effectiveness of the methodology is scanty.
- The short-term benefits of Six Sigma interventions tend to be reported (e.g., reductions in defects or costs) but there is little research on maintaining a Six Sigma intervention implemented over a long time frame or conducting of follow-up audits to evaluate the efficacy of controls phases.
- Quite a number of applications involve descriptive statistics and basic analysis (Pareto, fishbone diagrams, etc.). The gap is evident in the use of quantitative optimization tools to predict and optimize variables like simulation, regression, ANOVA or stochastic modelling.
- Employee resistance to change, employee training, and human error are usually given as obstacles but little to no research has been done on these. The existing system does not contain systematic methods of incorporating behaviors of workforce into working out of Six Sigma.
- The individual studies have different performance measures (e.g., DPMO, rework %, cost, or time), thus it is hard to compare them. There exists a vacuum in utilizing a universal KPI framework in quantifying Six Sigma achievement.
- Whereas there are studies that either use Lean, PFMEA, or TRIZ, there are not many that examine synergistic models integrating more than one bulk quality and risk management tool. The performance of such hybrid approaches as Green Lean Six Sigma or Agile-Six Sigma is not well-studied.
- Most of the references specified use historical or collected manually data in most Six Sigma implementations. The systems that can exploit real-time data-gathering, cloud implementation, and dashboards to conduct on-the-go management and quality control and decision-making are required.
- With only one exception (Ershadi et al., 2021), there is no frequent connection between environmental issues such as minimization of wastes, energy-saving, and environment-friendly manufacturing and Six Sigma initiatives.

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- Most of the case studies are country-specific (India, Indonesia, Africa) and they have much less cultural or global benchmarking. It is possible to research how Six Sigma could adjust to various organizational cultures and chain global supply.

Table 1: Summary on Six Sigma Implementation

Methodology Type	Citations	Key Improvements / Outcomes	Avg. improvement
Six Sigma (Standard)	Setiawan (2025), Gijo & Scaria (2010), Yi et al. (2012), Purba et al. (2020)	Defect reduction: up to 60.4%, rework and rejection cost reduced	33.35%
DMAIC (Classical Six Sigma)	Meresa et al. (2025), Patil & Tekade (2025), Saputra et al. (2025)	Defect/rework reduction: 20%–44.5%	33.83%
Lean Six Sigma	Rahmatillah & Rusindiyanto (2025), Fortuna & Yuliawati (2024), Priya et al. (2020), Morais et al. (2015)	Process efficiency: 21%–29%, defect reduction ~24%	24.9%
Lean Six Sigma + DMAIC	Daniyan et al. (2022)	Process time reduced by 16.5%	-
Agile Six Sigma	Znad (2022)	Quality improved by 22%, faster defect resolution	-
AI + Six Sigma	Bukhari & Akhtar (2024)	AI prediction accuracy: 94% for quality forecasting	-
Six Sigma + PFMEA + TRIZ	Laksmi (2025)	Quality cost reduced by 18%, proactive defect prevention	-
Lean Six Sigma + DEA + ANFIS	Ershadi et al. (2021)	Project selection optimization (quantitative % not specified)	-

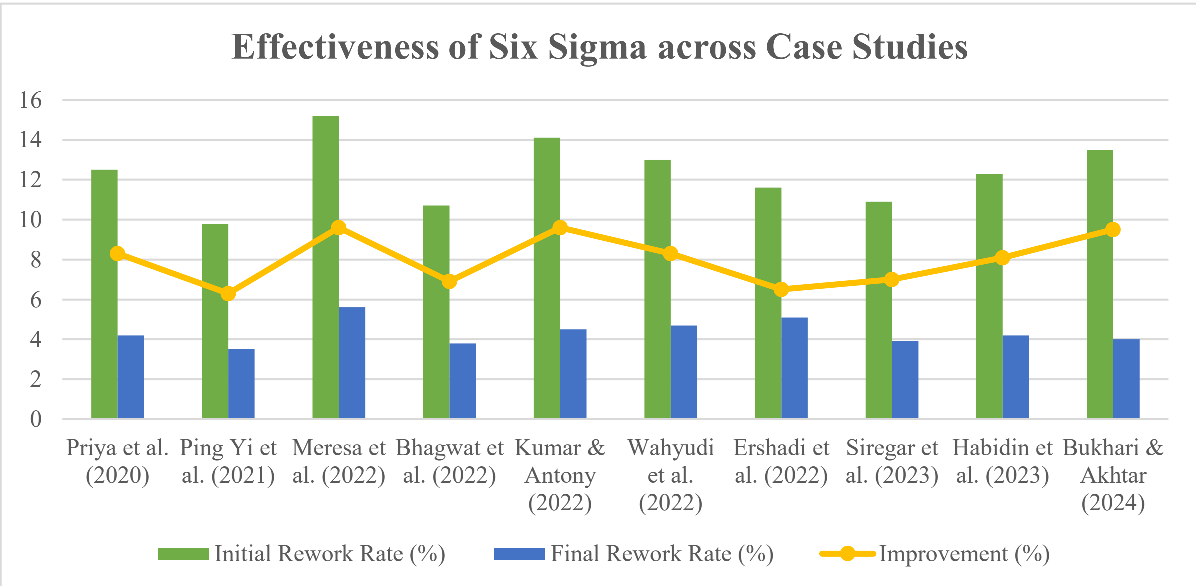

Fig 2: Effectiveness of Six Sigma across Case Studies

5. LIMITATIONS OF THE STUDY

- Although the case study is equally useful in the context of using Six Sigma to reduce rework in an assembly line setting, it is faced with a number of limitations, which should be noted. To begin with, the study is restricted to only one case study in a definite industrial environment, which automatically limits the ability to make generalizations as regards the study results. The results and advancements made might not be applicable to other industries or manufacturing processes that use various organizational cultures, technological environment, as well as resource statuses.

- In addition, the research is of a more short-term nature, and it provides an analysis of improvements during the implementation of the Six Sigma and after. It has ignored the effects of the long-term sustainable nature of these enhancements and has also not considered the sustenance of the low rework rates over a long period. This curtails the insight on the sustainability and the long run destiny of the introduced process changes.
- The second setback is that the DMAIC process is based on manual ways of data collection. There are a few tendencies of such approaches with human error, incomplete reporting and time delays that could impact accuracy and reliability of the analysis. Lack of automated or digital data acquiring systems only crippled comprehensiveness of root cause analysis and real-time monitoring of defects.
- The research likewise does not incorporate the use of highly-technical tools including artificial intelligence, machine learning, Internet of Things (IoT), and real-time analytics. Although traditional Six Sigma tools were successfully applied, the lack of such modern technologies restricts the possibilities of predictive analytics, flexibility of process control, and scalability of quality improvement that becomes in demand in the context of Industry 4.0.
- Also, the analysis was mostly confined to events on the assembly line, the other departments like design and procurement and maintenance were also not evaluated thoroughly, which can also be as such a source of rework problems. This narrow cross functional focus might have missed upstream or screening causes of defects.
- The limits of the enhancements were also inhibited by resource and time constraints. The restrictive nature of budgetary constraints, and the short timeframe within which the study was conducted impacted on the capacity to carry out more far reaching or long term corrective measures. Another problem was the resistance that the employees had to the change in that changing the cultural inertia and lack of training in some cases prevented the smooth absorbing of the Six Sigma practices.

Lastly, there are no benchmarking or comparative study with similar Six Sigma programs in other institutions. This complicates the process of comparing the effectiveness of the implementation or determination of best practices. Also, customer oriented indicators were not assessed during the research, namely satisfaction rates, rates of returning a product, warranty claims are important ones to measure the effects of the minimized rework in regards to the quality of the product and brand perception.

6. CONCLUSION

Through a detailed research study and analysis of sixteen primary bodies of research on Six Sigma, it can be observed that Six Sigma process and its multiple methodological extensions, including Lean Six Sigma, DMAIC, Agile Six Sigma, and integration of the above referenced terms, PFMEA, TRIZ, and AI provide a significant role in the reduction of rework, the minimization of defects, and the overall efficiency within the operations of the manufacturing process and assembly lines. This Six Sigma method has shown an enormous improvement in various industrial processes including automotive, electronics, metal forming, plastics, rubber, and heavy machinery because it has recorded a decrease in defects of between 17 percent and more than 60 percent in certain instances.

The works that used the DMAIC framework are sound in their application of the methodology with the uses of root causes analysis, statistical quality control tools, and systematic process developments to lead to quantifiable outcomes. Other already developed applications even used predictive modeling and decision support systems, and they showed the growing potential of Six Sigma in combination with the data analytics and digital technologies.

Nevertheless, some of the general research gaps were also identified in the study, such as the insufficient deployment of AI and real-time analytics, the absence of cross-industrial comparative analyses, and the insignificance of a long-term sustainability, human factor, and environment-related performance. Moreover, discrepancies of performance measures and non-uniformity in methods of research create an issue of benchmarking and replication. To sum up, Six Sigma is a potent and effective way of enhancing quality. It is very versatile in different industrial contexts because its success has been widely reported in numerous case studies. Still, its improvement in the perspective of Industry 4.0 and smart manufacturing should be directed to the integration of high-tech digital media, the creation of universal measures of performance, and more comprehensive, blended paradigm in the future research.

7. FUTURE SCOPE OF WORK

- Future studies can explore the integration of advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT) to enhance predictive analytics, automate quality control, and enable real-time monitoring for faster defect detection and adaptive decision-making.
- While this study focused on short-term results, future work should assess the long-term effectiveness of the implemented solutions by conducting post-project audits and tracking sustainability of improvements over extended periods.

- There is scope to develop and validate a standardized set of Key Performance Indicators (KPIs) to consistently evaluate Six Sigma performance across different departments, industries, and organizational levels.
- Expanding the case study approach to include comparative analysis across different industries (e.g., automotive vs. electronics) and geographical locations can help generalize findings and assess the adaptability of Six Sigma across varied operational environments.
- Future research should focus on the role of workforce engagement, resistance to change, training effectiveness, and leadership involvement in the success of Six Sigma projects. A human-centered approach will help improve adoption and effectiveness.

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