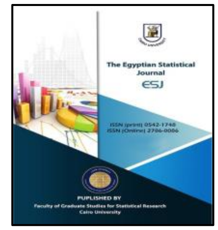
doi:10.21608/esju.2024.246070.1021 *Research Article*

The Egyptian Statistical Journal (ESJ), 68 (1): 45-58

Homepage: https://esju.journals.ekb.eg/

The Egyptian Statistical Journal

Print ISSN 0542-1748– Online ISSN 2786-0086



The impact of integrating LSS and BPR on manufacturing organizational performance

Somaia Attia Gomaa[1*], Mohamed Fahmy[2], Eman Mosallam[1]

Received 04 December 2023; revised 02 January 2024; accepted 18 March 2024

Keywords

Lean Six Sigma; Business Process Reengineering; DMAIC, Continuous Improvement; Manufacturing.

Abstract

Every organization aims to achieve customer satisfaction by delivering high-quality products at a reasonable cost. This research investigates the integration of Lean Six Sigma (LSS) and Business Process Reengineering (BPR) through the DMAIC methodology to enhance the operational performance of manufacturing organizations. The study develops a comprehensive LSS-BPR framework for the manufacturing domain, employing various analysis and improvement tools within the DMAIC methodology. The framework is applied specifically to the production of electrical control panels in Egypt. The implementation results in significant improvements, including a reduction in panel shop drawings cycle time from 3 hours to 2 hours, a decrease in panel lead time from 3.9 days to 1.07 days, an increase in annual panels production from 1986 panels to 4056 panels, a rise in the sigma level from 2.45 sigma to 3.37 sigma, and a decrease in the defect ratio from 17.1% to 3.1%. Additionally, customer complaints decrease substantially from 45 to only 3 throughout the year. The study recommends extending this methodology for application across diverse production processes in various organizations.

1. Introduction

In recent years, the world has witnessed significant transformations due to revolutionary advancements in information and communication technology. This advanced technology has now become a core element of the global economy and international trade. As a result of these transformations and changes, manufacturing industries have had to adapt to the developments to secure their position in the competitive market. Consequently, companies have adopted innovative strategies to meet customer requirements, which is represented in the reduction of project lead times, enhancement of product quality, and reduction of manufacturing costs. The manufacturing stage plays a critical role in the success of manufacturing industries, given its significant impact on a company's efficiency, quality, competitiveness, and reputation. Therefore, manufacturing industries must pay great attention to improving manufacturing processes and applying new technologies to succeed in this stage. Through investments in improving manufacturing processes, companies' lower operational costs, enhance product quality and increase profitability. This continuous improvement of the manufacturing stage by using suitable tools that fit with the company environment contributes to increased productivity, profitability, and competitive advantage for the company within the market.

✉ Corresponding author*: somaiagomaa@gmail.com
[1] Faculty of Graduate Studies for Statistical Research, Cairo University, Giza, Egypt.
[2] Faculty of Engineering, Fayoum University, Fayoum, Egypt.

This paper is structured as follows: The subsequent section provides a literature review examining LSS and BPR. Section 3 outlines the research methodology, focusing on integrating LSS and BPR through the DMAIC methodology. Sections 4 and 5 cover the discussion and results. Finally, Section 6 covers the conclusions and recommendations.

2. Literature review

Continuous improvement is a systematic approach to enhancing processes, products, or services incrementally over time. It is a philosophy that focuses on making small, incremental changes to achieve improvements rather than large, radical transformations (Isniah, et al., 2020). Various philosophies have been applied across the world, including company-wide quality control (Ishikawa, 1984), Plan-Do-Check-Act cycle "PDCA" (Deming, 1986), Toyota Production System "TPS" (Ohno, 1988), Total Productive Maintenance "TPM" (Nakajima, 1989), Six Sigma (Harry, 1998), Lean manufacturing "LM" (Womack, 1990), Total Quality Management "TQM" (Feigenbaum, 1991), Business Process Reengineering "BPR" (Hammer & Champy, 1993) are currently available to help the organization gain competitive advantages in terms of productivity, waste management, quality, time, flexibility, cost (Rajpurohit, 2017). All of these have been referred to as either “quality improvement (QI)” or “continuous improvement (CI)” approaches (Patel, 2020).

2.1 Lean Six Sigma (LSS)

Lean manufacturing and Six sigma are two different approaches for continuous process improvement, their integration began and spread rapidly in the late 1990s. LSS is a structured, data-driven approach that integrates Lean Manufacturing and Six Sigma (Gomaa, 2023). As shown in Fig. (1), the core objective of LSS is to improve the effectiveness and efficiency.

Figure1: Core Objective of LSS, (Gomaa, 2023).

LSS is a two-step business methodology for improving operations, with a focus on removing unnecessary waste and reducing deviations in production and customer service. Lean's goal is to maximize the customer's value and minimize waste, as well as save on resource usage. Six Sigma aims to reduce fluctuations with a well-defined procedure. Together, these two methods form a system of continuing development, which serves as a philosophy of successful business processes (Kęsek, et al., 2019). Table (1) presents a comprehensive survey of LSS studies in the manufacturing domains over the past four years (2020 to 2023), and they are classified based on application, main tools, and key objectives.

Table 1: LSS Studies in Manufacturing Domain

Reference		Application	Main Tools	Main objectives
1	(Mittal, et al., 2023)	Rubber weather strips	CTQ, Process mapping, C&E diagram, Cost-benefit analysis.	• Reducing rejection rate • Reducing production cost
2	(Trubetskaya, et al., 2023)	Compound animal feed manufacturing	VSM, Spaghetti diagram, Pareto chart, Standard work chart, Control charts.	• Reducing inventory stock • Reducing lead time
3	(Sharma, et al., 2022)	Automobile light manufacturing	Process mapping, Project charter, VSM, Waste analysis, Simulation, Pareto chart, C&E diagram, Sigma level,	• Reducing defect % • Increasing production rate • Reducing idle time
4	(Hardy, et al., 2021)	Laminated panel production	Process mapping, CTQ, OEE, Takt time, VSM, Control charts, C&E diagram, Process layout, FMEA.	• Reducing downtime • Improving OEE
5	(Kumar, et al., 2021)	Engine cylinder	ABC, Pareto chart, Process Mapping, Project charter, Process mapping, Control charts, C&E diagram,	• Reducing defect % • Increasing sigma level.
6	(Murmura, et al., 2021)	Iron industry	Project charter, Gantt chart, Risk analysis, SIPOC, Process mapping, VSM, Sigma level, Statistical analysis, 5Whys.	• Reducing lead time • Reducing defect % • Increasing sigma level.
7	(Patyal, et al., 2021)	Chemical company	Project charter, SIPOC, Process capability, 5Whys, How–how analysis,	• Reducing customer complaints
8	(Liu & Yang, 2020)	Footwear manufacturing	VSM, Takt time, VSM, DOE, Taguchi method, Simulation,	• Reducing defect % • Reducing lead time • Reducing WIP
9	(Nandakumara, et al., 2020)	Food industry	SIPOC, VSM, ANOVA, 5S, OEE, C&E diagram,	• Improving OEE
10	(Tiwari, et al., 2020)	Cookware manufacturing	Project charter, KPIs, VSM, Pareto chart, C&E diagram, Action plan, Waste analysis,	• Improving sustainability • Minimizing safety incidents

2.2. Business Process Re-engineering (BPR)

BPR is a significant management strategy developed in the middle of the 1990s by Professor Michael Hammer which define it as “A Fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed”. (Hammer & Champy, 1993). BPR can be implemented using the following steps: 1) Identifying Business process, 2) Selecting Business process, 3) Redesign process, 4) Implementation of new process. (Buthelezi, 2018). Table (2) presents a comprehensive survey of BPR studies in the various domains over the past six years (2018 to 2023), and they are classified based on application, main tools, and key objectives.

Table 2: BPR Studies in Various Domains

Reference		Application	Main Tools	Main objectives
1	(Hameed, et al., 2022)	Malaysian electronics manufacturing industry	Strategic thinking	• Improving performance
2	(Fetais, et al., 2022)	Qatar's Public and Private Service sector	Fuzzy-based & Correlation analysis	• Improving effectiveness
3	(Amri, et al., 2021)	Food manufacturing industry	Android technology with ESIA method	• Reducing cycle time
4	(Bhaskar, 2020)	Manufacturing sector	Quality tools	• Improving efficiency
5	(Hashem, 2020)	Egyptian banking sector	Statistical analysis	• Improving efficiency • Improving effectiveness
6	(Ponde & Jain, 2020)	State Bank of India (SBI)	Business intelligence (Bl)	• Improving performance
7	(Boudouh, 2019)	Design process in electric motors industry	Design structure matrix (DSM)	• Improving quality • Reducing cost • Reducing deign time
8	(Khan, et al., 2019)	Valve manufacturing industry	Filtration algorithm & cause and effect approach & simulation model	• Improving efficiency
9	(Immawan, et al., 2019)	Design process in Sugar Mill Manufacturing	Value stream mapping (VSM)	• Reducing cost
10	(AbdEllatif, et al., 2018)	Inventory management	Ontology-based knowledge Map Methodology (PROM) & Simulation Model	• Reducing failure ratio

2.3. Research gap

Through the previous studies presented in the previous two Table (1) and Table (2), the researcher found that previous studies have focused on the separate application of LSS and BPR within the manufacturing industries and there are no previous studies that specifically focus on the integration between LSS and BPR by using DMAIC methodology to improve the performance of manufacturing industries.

3. Proposed LSS-BPR framework

The proposed framework is based on integrating LSS and BPR by using DMAIC methodology to enhance the performance of manufacturing companies. This integration will be implemented as shown in Figure (2).

Figure 2: Integration of LSS and BPR by using DMAIC Methodology

4. Research application

In our case, the company is manufacturing electrical control panels. Electrical panels have the form of discrete production each panel has its own design and components, so there is no mass production. The major problem is a long cycle time in each department, Failure in the communication system between all departments, Increased cost, defects, and rework. All of these issues cause long lead times, delivery time delays, and loss of customer satisfaction. That's why, it is strongly suggested that the company, while redesigning or reengineering its processes in the manufacturing stage, use a form of integration or various techniques or tools by using DMAIC methodology to enhance these processes and become more efficient and effective.

Figure3: Electric Control Panels

4.1 Define phase

The company focused on the manufacturing stage, as it has a significant impact on the company's efficiency, quality, competitiveness, and reputation. The company's manufacturing phase flow chart goes through many stages until it reaches the final product, starting from the design phase, the planning phase, the manufacturing phase, and finally the quality phase. Through the manufacturing stage. The design department's cycle time and long lead time for the project are the two main issues that led to increased project time.The organization's objective is to decrease design department cycle time, eliminate defects, and reduce project lead time.

4.2 Measure phase

The main factors causing the problem were identified and explained as the following:

Firstly, the design department's cycle time takes an average of 3 hours to draw one panel, which is a long time due to the following reasons:

- The repeated project drawings are redrawn from the start; this is due to the inflexibility of the system.
- There are a lot of changes and modifications due to the unclear drawing layout in the project's shop drawing.

Secondly: through the production stages, the main problem is a long lead time for the project because of a lot of stops, defects, and reworks. These issues will be explained by selecting one type of panel and applying the following Value Stream Map (VSM) to classify the activities as Value Added Activities (VA), necessary but non-value activities (NNVA), and non-value-adding activities (NVA) to be able to determine the wastes faced in the production stage as shown in figure (4).

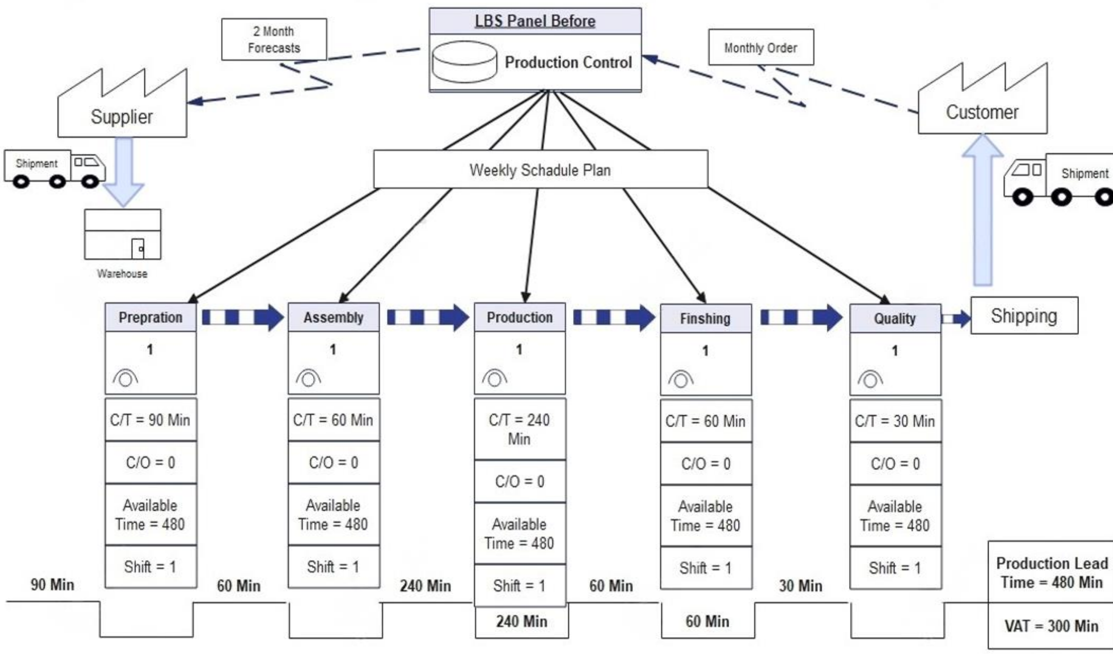


Figure 4: Current Value Stream Map for Production Lead Time, (Before).

The organization applied Process Defect Analysis "PDA", and calculated the current Sigma level (2.45 sigma), additionally it applied Quality Control tools by first making a checklist to collect the defects and the frequency of each defect resulting from the manufacturing department.

4.3 Analysis phase

In this phase, the organization took the following actions to deal with the problem of repeated manufacturing defects by applying Process Defect Analysis and Quality Control Tools as the following:

- According to the defects checklist, a Pareto chart was drawn and the 80/20 rule was applied which displays the relative importance of the causes of a defect and helps to focus on causes that will have the greatest impact when solved as shown in figure (5).

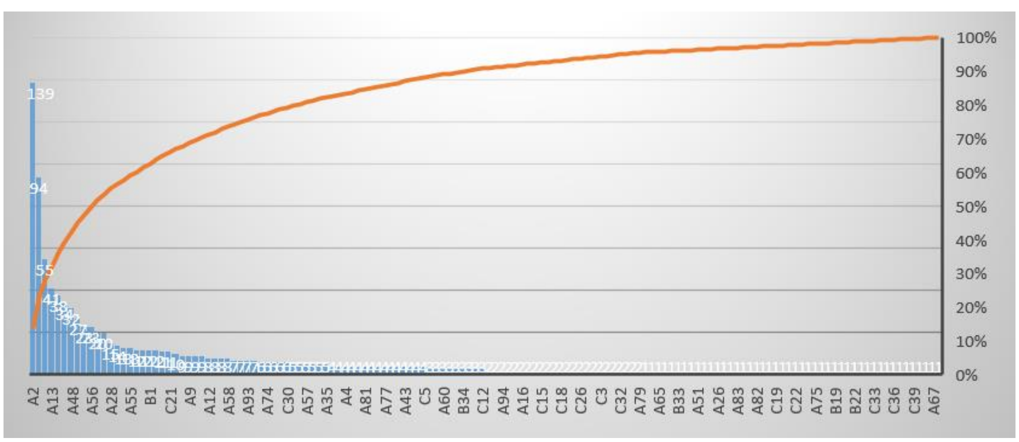


Figure 5: Current Pareto chart

- Based on the Pareto chart and the application of rule 80/20, the most frequent defects were identified, which represent 20% of the defects, so that if they were resolved, 80% of the defects were resolved due to their repetition, and among these defects A2 "Panel

Cleanliness", A13 "Label Control Undefined", A48 "Missing Customer Connection", and A56 "Miss-wiring of control". Thus, the causes and effects of each of the mentioned defects were determined by the Fish Bone Diagram as shown in figure (6).

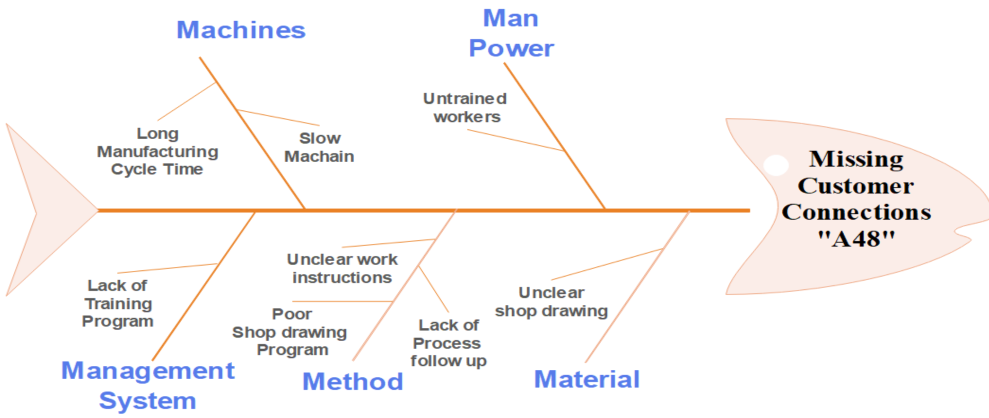


Figure 6: A48 Fish Bone Diagram.

4.4 Improve phase

The first step towards actual improvement was the BPR team's focus on the Design department. During the brainstorming sessions, the team concluded that a new software system was essential to meet the design department's requirements. In the execution of this strategy, the organization used BPR with ICT, yielding significant impacts on the evolution of the Design department by providing a new system called "WSCAD" to the Design department, whose purpose was to enhance the quality of shop drawings and decrease the process cycle time. This system facilitated several key enhancements:

- The shop drawing contains clear and simple symbols without any electrical properties.
- provides Clear specification of the Panel that details all panel characteristics.
- provides colorful and Smart drawings that include Detailed components of control circuits.
- provides 3D shop drawing that includes measurements and Layouts of the cross-section area of copper, and this was a helpful factor in improving the quality of measurements and assisting technicians, especially the copper department.
- provides a virtual shape for the actual panel after manufacturing and finishing and this helps the customer to have the expectation for the final product that he will receive it and determine if he needs to require changes or make some modifications early before starting in the production.
- provides templates for the repeated project which can modify on it, rather than starting the project from scratch.
- The system includes more than one output format for the bill of material (Excel sheet-WSCAD File-PDF).

Subsequently, the team directed their attention to the manufacturing phase, which was facing many stops, rework, and defects, leading to extended manufacturing lead times. The objective for this phase centered on reducing manufacturing lead times, eliminating defects, enhancing project quality, and minimizing wastage. Through collaborative brainstorming sessions, the team determined the imperative for certain modifications through which the following was implemented:

- Implementation of Lean Six Sigma (LSS) principles including Value Stream Mapping (VSM), 5S methodology, and Standardization across all manufacturing stages. This initiative commenced from the warehouse and extended to the project reaching a final product. VSM was initially applied to identify bottlenecks and reasons for stops. Consequently, the 5S methodology was applied to the stores, arranging shelves based on a 'first in, first out' (FIFO) approach and designating specific locations for each item to facilitate quick access to raw material.

- Multiple factory layout designs were drafted to pinpoint the optimal layout for manufacturing phases, thereby minimizing motions and intersections (Spaghetti Diagram).

- The cycle times for each manufacturing process were calculated and standardized, and standardized templates were generated for utilization.

- The company used BPR with ICT “Information & Communication Technology”, yielding significant impacts on the evolution of the manufacturing phase by providing a new system called "ERPAG", whose purpose was to enhance integration between sales, planning, finance, purchasing, and stores departments. Additionally, this system streamlined the process of promptly supplying project components and efficiently managing their issuance from storage.

- The company has additionally introduced a standardized operational aid, guiding technicians in achieving a smooth and error-free process by providing Prisma leaflets at assembly locations, along with copper leaflets and tables detailing Busbar Cross-section Area (C.S.A.) at copper locations.

- In order to reduce the number of trips a production worker must make from the production area to the store, the organization has applied basic Kanban concept by providing racks for nails and other consumables in the production area. These racks are filled once or twice a week, which results in time and effort savings.

- The organization used BPR with Training by applying competency-based training for the technicians, which is a teaching strategy that determines whether the technicians have the skills and information required for performing their tasks successfully. it focuses more importance on the development of actual skills and abilities instead of only providing academic knowledge. The aim is to identify skills gaps and provide training to fill them.

Consequently, this led to a decrease in the production lead time to 310 minutes, down from the previous 480 minutes, as shown in the following Value Stream Map (VSM).

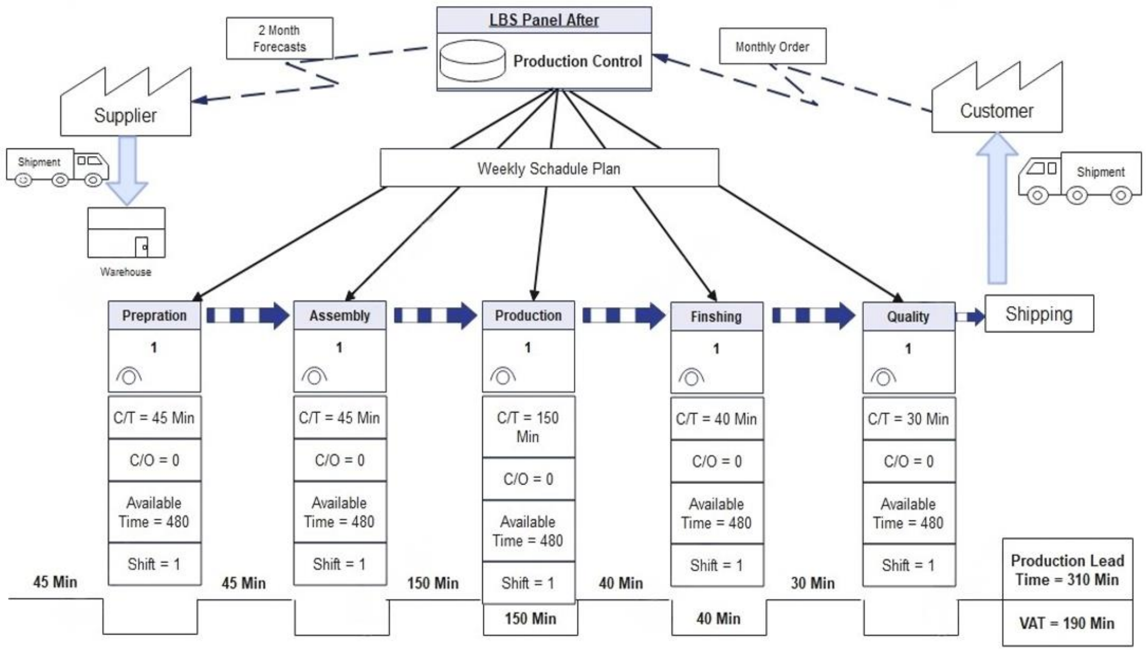


Figure 7: Result Value Stream Map for Production Lead Time, (After).

4.5 Control phase

In this phase, the organization creates a monitoring and follow-up plan to ensure the continuation of the improvements created and enhanced in previous phases, the continuation of the employee advanced training plan, and the continuation of the use of kaizen and other LSS tools.

Additionally, the organization created standard work documentation to be a set of guidelines and procedures that enhance the improvement of processes, quality control, and performance. it also conducts periodic internal audits of the processes to ensure the sustainability of the improvements.

5. Research results

The result of the ICT "Information & Communication Technology" application in the design department: The results in Table (3) showed a significant decrease in the process cycle time, where the panel shop drawing takes an average of 2 hours instead of 3 hours.

Table 3: Variance Analysis of Design Cycle Time

Years		N	Mean	Std. Deviation	T	p-value
Time	2020	356	3.2627	5.19572	3.300	P-Value < 0.05
	2022	603	2.1694	4.52508		

This led to an increase in the total number of panel shop drawings during the year, as the number of panel shop drawings the year became 5438 panel instead of 2979 panel as shown in Table (4).

Table 4: Variance Analysis of Number of Panels Shop Drawing

Sample	X	N	Sample p
2020	2979	8417	0.35
2022	5438	8417	0.646
Estimate for difference: -0.292147	Z = -39.63 P-Value < 0.05		

The result of competency-based training for the technicians: The result of applying competency-based training for the technicians on the decrease of production defects is shown in Table (5).

Table 5: Variance Analysis of Total Number of Defects

Sample	X	N	Sample p
2020	1018	1144	0.889
2022	126	1144	0.11
Estimate for difference:0.779	Z = 37.30 P-Value < 0.05		

The results indicated a significant reduction in production defects. The defect number decreased to 126 observed in 126 panels out of a total of 4056 panels, instead of 1018 defects observed in 340 panels out of a total of 1986 panels. Consequently, the defect ratio decreased from 17.1% to 3.1%, and the sigma level increased from 2.45 sigma to 3.37 sigma.

Due to the integration of LSS and BPR by using DMAIC, the impact on decreasing design cycle time, minimizing defects, enhancing sigma level, and eliminating wasteful processes. Consequently, this brought about a reduction in the duration of project lead time and a significant reduction in customer complaints as indicated in Table (6) and Table (7).

Table 6: Variance Analysis of Panel Lead Time

Sample	N	Mean	SE Mean
2020	1986	3.90	0.36
2022	4056	1.07	0.10
Estimate for difference: 2.870	T-Value = 7.70 P-Value < 0.05		

The findings demonstrated a significant reduction in project lead time. The average time required for a single panel, from the initiation of the production order to its final product stage, diminished to 1.07 days from the previous 3.9 days. This equates to a substantial 72.5% decrease in panel lead time. This reduction subsequently translated to an increased production of panels over the year. there is a significant upswing in the annual panel production, with the number surging to 4056 panels, in contrast to the previous count of 1986 panels.

Table 7: Variance Analysis of Customer Complaints

Sample	X	N	Sample p
2020	45	48	0.937
2022	3	48	0.062
Estimate for difference: 0.875	Z = 8.57 P-Value < 0.05		

The findings demonstrated a significant reduction in customer complaints. Specifically, the number of customer complaints dropped from 45 throughout the year to 3 complaints only.

6. Conclusion

This paper focuses on the integration between Lean Six Sigma (LSS) and Business Process Reengineering (BPR) by using DMAIC methodologies. In this study, a generic LSS-BPR framework using DMAIC for the manufacturing domain is developed using various analysis and improvement tools. The proposed framework has been specifically implemented in the field of electrical control panel production in Egypt. The primary objective of this study was to decrease project lead times, which were extending due to prolonged process cycle times, defects, rework, and interdepartmental communication gaps. This research employed an integration of LSS and BPR using the DMAIC methodology. This integrated approach facilitated a reduction in panel shop drawings cycle time to 2 hours instead of 3 hours, a reduction in panel lead time, extending from the initiation of production orders to the final product's delivery to customers, from 3.9 days to a be 1.07 days, increasing the annual panels production from 1986 panels to 4056 panels, increasing the sigma level from 2.45 sigma to 3.37 sigma, and decreasing defect ratio from 17.1% to 3.1%. With note, this research is confined to the application within a single company, which is acknowledged as a limitation. As a suggestion for future studies, the methodology could be implemented across diverse production processes within various organizations.

References

AbdEllatif, M., Farhan, M. S. & Shehata, N. S., (2018). "Overcoming Business Process Reengineering Obstacles Using Ontology-Based Knowledge Map Methodology". *Future Computing and Informatics Journal*, 3(1):7-28.

Amri, S., Napitupulu, H. L. & Nazaruddin, (2021). "Business Process Reengineering Android-Based Sales: Case PT.XYZ". *IOP Conf. Ser.: Materials Science and Engineering* 1122 012048 : 1-9, doi:10.1088/1757-899X/1122/1/012048

Bhaskar, H. L., (2020). "BPR Application Scale". *International Journal of Economic and Business Management* - ISSN: 2384-6151 - 8(4): 30-40. doi: 10.14662/IJEBM2020.050

Boudouh, T., (2019). "Reengineering of the Design Process: An Industrial Case". *IOP Conf. Ser.: Materials Science and Engineering* 564 012103 : 1-7.

Buthelezi, T., (2018). "Business Process Reengineering During Technology Implementation in Power Plants". *University of Johannesburg (South Africa) ProQuest Dissertations Publishing,* 2018. 28281502.

Deming, W., (1986). *Out of the Crisis, MIT Press. MA Institute of Technology, Center for Advanced Educational Services, Cambridge, MA, Cambridge, MA.*

Feigenbaum, A., (1991). "Total Quality Control". *3rd ed., McGraw-Hill Book Company, McGraw-Hill, New York, NY, USA.*

Fetais, A., Abdella, G. M., Al-Khalifa, K. N. & Hamouda, A. M., (2022). "Modeling the Relationship Between Business Process Reengineering and Organizational Culture". *Applied System Innovation* ,5(66): 1-16: s.n.

Gomaa, A. H., (2023). “A Systematic Review of Lean Six Sigma in Manufacturing Domain”. *Engineering Research Journal (ERJ),* 52(4): 139-148.

Graafmans, T. & Turetken, O., (2021). Process Mining for Six Sigma. *Process Mining for Six Sigma, Business and Information Systems Engineering* 63(3):277–300.

Hameed, N. S. S., Salamzadeh, Y. & Rahim, N. F. A., (2022). "The Impact of Business Process Reengineering on Organizational Performance During the Coronavirus Pandemic: Moderating Role of Strategic Thinking". *Emerald Publishing Limited Foresight* - 24(5): 637-655, doi: 10.1108/FS-02-2021-0036 - ISSN 1463-6689

Hammer, M. & Champy, J., (1993). "Reengineering the Corporation- A Manifesto for Business Revolution. New York, NY". *Harper Business Editions*.

Hardy, D. L., Kundu, S. & Latif, M., (2021). "Productivity and Process Performance in A Manual Trimming Cell Exploiting Lean Six Sigma (LSS) DMAIC – A Case Study in Laminated Panel Production". *International Journal of Quality & Reliability Management* - 38 (9): 1861-1879.

Harry, M., (1998). "Six Sigma: A Breakthrough Strategy for Profitability". *Quality Progress,* 31 (5): 60-64.

Hashem, G., (2020). "Organizational Enablers of Business Process Reengineering Implementation An Empirical Study on the Service Sector". *International Journal of Productivity and Performance Management* - 69 (2) : 321-343, doi:10.1108/IJPPM-11-2018-0383

Immawan, T., Shafira, N. & Cahyo., W., (2019). "Business Process Re-engineering in a Sugar Mill Manufacture: The Preliminary Study for Designing a Portable Machine". *IOP Conf. Ser.: Materials Science and Engineering 505* – 012137: 1-8.

Ishikawa, K., (1984). *Quality Control Circles at Work, Asian Productivity Organization, Tokyo*.

Isniah, S., Purba, H. H. & Debora, F., (2020). Plan Do Check Action (PDCA) Method: Literature Review and Research Issues. *Jurnal Sistem dan Manajemen Industri* - 4:72-81 - Available onlineat: http://e-jurnal.lppmunsera.org/index.php/JSMI.

Kęsek, M., Bogacz, P. & Migza, M., (2019). "The Application of Lean Management and Six Sigma Tools in Global Mining Enterprises ". *IOP Conf. Series: Earth and Environmental Science* 214 (012090): 1-10. - doi:10.1088/1755-1315/214/1/012090

Khan, M. A. A. et al., (2019). "Integration of Data-Driven Process Re-Engineering and Process Interdependence for Manufacturing Optimization Supported by Smart Structured Data". *Designs,* 3 (44):1-24.

Kumar, P., Singh, D. & Bhamu, J., (2021). "Development and Validation of DMAIC Based Framework for Process Improvement: A Case Study of Indian Manufacturing Organization". *Int. Journal of Quality & Reliability Management,* 38(9):1964-1991.

Liu, Q. & Yang, H., (2020). "An Improved Value Stream Mapping to Prioritize Lean Optimization Scenarios Using Simulation and Multiple-Attribute Decision-Making Method". IEEE Access, 8 : 204914- 204930.

Mittal, A., Gupta, P. & Kumar, V., (2023). "The Performance Improvement Analysis Using Six Sigma DMAIC Methodology: A Case Study on Indian Manufacturing Company". *Heliyon,* 9 (14625):1-11.

Murmura, F., Bravi, L., Musso, F. & Mosciszko, A., (2021). "Lean Six Sigma for the Improvement of Company Processes: the Schnell S.p.A. case study". *The TQM Journal*, 33 (7):351-376.

Nakajima, S., (1989). *TPM Development Program: Implementing Total Productive Maintenance, Cambridge MA Productivity Press, Productivity Press, Portland, OR, Portland*.

Nandakumara, N., Saleeshyab, D. P. & Harikumar, P., (2020). “Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology". *Materials Today*, 24, :1217–1224.

Ohno, T., (1988). *Toyota Production System Beyond Large-Scale Production, Productivity Press*.

Patel, A. S., (2020). "Critical Review of Literature on Lean Six Sigma Methodology". *International Journal of Lean Six sigma* - 12 (3): 627-674 doi: 10.1108/IJLSS-04-2020-0043

Patyal, V. S., Modgil, S. & Koilakuntla, M., 2021. “Application of Six Sigma Methodology in an Indian Chemical Company”. *International Journal of Productivity and Performance Management”,* 70 (2): 350-375.

Ponde, D. S. & Jain, D. A., (2020). "BI & BPR: Modern Tools for Performance Management in Vuca World". *Economic Challenger//* ISSN 0975-1351(87): 1-6.

Rajpurohit, L., (2017). "A Study of Selection of Lean Tools in Manufacturing".doi: 10.13140/RG.2.2.30983.50080.

Sharma, A., Bhanot, N., Gupta, A. & Trehan, R., (2022) "Application of Lean Six Sigma Framework for Improving Manufacturing Efficiency: A Case Study in Indian Context." The *International Journal of Productivity and Performance Management*, 71 (5):1561-1589

Tiwari, P., Sadeghi, J. K. & Eseonu, C., (2020). “A Sustainable Lean Production Framework With A Case Implementation: Practice-Based View Theory". *Journal of Cleaner Production*, 277(123078):1-42.

Tjahjono, B. & Ball, P., (2010) Six Sigma: A Literature Review. *International Journal of Lean Six Sigma*, 1(3):216– 233.

Trubetskaya, A., McDermott, O. & Brophy, P., (2023). "Implementing A Customised Lean Six Sigma Methodology at A Compound Animal Feed Manufacturer in Ireland". *International Journal of Lean Six Sigma, IJLSS* - doi:org/10.34961/researchrepository-ul.22116446.v1.

Womack, J. J. D. a. R. D., (1990). "The Machine That Changed the World: The Story of Lean Production". *Macmillan, New York, NY*.