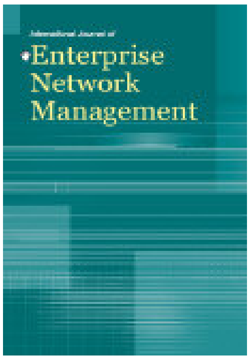

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Adoption of Lean Six Sigma to improve safety culture – a case study of Indian manufacturing unit

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Abstract: Lean Six Sigma (LSS) is a business process improvement strategy widely used to improve efficiencies in the business. LSS, which is an integration of Lean and Six Sigma, has helped decrease various non-value-added activities, including accidents. This research paper discusses the implementation of LSS methodology using 'define, measure, analyse, improve, control' (DMAIC) to reduce accidents in a particular manufacturing unit into consideration. A framework of the LSS-DMAIC approach was proposed to reduce accidents, improve key metrics and improve the overall safety culture. The techniques used were brainstorming, the cause-and-effect diagram, and Pareto analysis. Two sample T-test was used to authenticate the results. The study's primary finding was the successful and effective implementation of the LSS framework in the manufacturing unit. As a result of the exercise, accidents that are non-value-added activities were reduced. The study is novel in nature, not only for theoretical implications, but also for the practical approach applied to the manufacturing units.

Keywords: manufacturing; Lean; Six Sigma; Lean Six Sigma; LSS; DMAIC; safety.

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1 Introduction

Over the last few decades, technical advances and skills have increased market competition dramatically (Nanda et al., 2019; Moktadir et al., 2019). Organisations are struggling at the same time to survive in this market, concentrating on delivering high-quality goods and services, improving their efficiency, and meeting targets, and trying to meet consumer needs (Malviya and Kant, 2019). The pace and complexity of globalisation is making business transformations more difficult and riskier (Santhanakrishnan et al., 2009). Consequently, businesses are progressively on the lookout for better methods for standardising procedures to minimise waste and subsequently increase and maintain productivity and quality (Jasti and Kodali, 2019; Moktadir et al., 2020). Organisations are looking for supply chain methods and instruments to deliver right quality of product at the right time (Manikandan et al., 2011). They are looking for smart and collaborative supply chains (Valkokari et al., 2011).

Technological and management experts have suggested ways to develop or standardise procedures and philosophies such as ‘Six Sigma, just in time, total quality management (TQM), and Kaizen’ (Dursun et al., 2020). TQM increases the ‘perceived business performance measures’ of manufacturing units (Awolusi, 2012). Manufacturers use process management strategies to fix problems such as lack of quality, inefficiencies and eventually costs. Lean Six Sigma (LSS) has been one such methodology often used for improvement of the process. LSS is a well-established set of waste reduction concepts and can also be applied to enhance safety culture. However, the use of LSS to improve safety and reduce injuries is often neglected.

This paper is focused on applying LSS in a manufacturing unit to improve the work culture quality with a focus on the safety aspects. The robust methodology of LSS is ‘define, measure, analyse, improve, control’ (DMAIC) and it has been used to approach systematically the accidents happening in the manufacturing unit. The issue was defined and assessed through a business case. Tools like ‘brainstorming, cause and effect diagram, Pareto analysis, and statistical analysis' were used to take a data-driven approach along with expert opinions.

After the implementation of corrective and preventive measures, a significant improvement was observed, validated by statistical tools. The deployment of LSS methodology in manufacturing has positively impacted the work culture and helped reduce the accidents significantly. One crucial aspect which was identified was safety and safety culture, around which productivity, cost reduction, and other improvement initiatives could revolve. It can also lead to other functional areas in order to improve their efficiency.

2 Literature review

The literature review was conducted by using perspectives on 'Lean, Six Sigma, DMAIC and LSS'. Lean concentrates on reducing process waste and eliminating non-value-added (NVA) activities. Six Sigma primarily focuses on the reduction of process variation. DMAIC is a well-known tool to improve Six Sigma methodology processes. LSS is a combination of 'Lean and Six Sigma', which is referred to in this research to extract Lean and Six Sigma's benefits.

2.1 Lean

Lean was taken from the post-war Japanese production system of Taiichi Ohno. Womack and Jones (1996) highlighted its benefits in 'lean thinking'. They reiterated in *The Machine that Changed the World* (Womack et al., 1990), describing the Lean philosophy as a brilliant way to execute and achieve the best results with little human input, using less equipment, spending less time and utilising limited space while offering customer satisfaction. The philosophy of continuous improvement advocates ongoing quality management and putting the customer first. Creating a flow, adding value to the product, and making a constant effort to pursue continual improvement are the means to implement. The primary objective of the philosophy of Lean is to alleviate and eradicate waste. It is because the waste does not add any significant value or utility feature to the customer. The book *The Machine that Changed the World* (Womack et al., 1990) made it a famous concept by highlighting its benefits. Practically, Lean enhances employee working conditions and alleviates risks at the workplace (Ohno, 1988). Lean, as a concept, is in its nascent stage and evolving as people continue to comprehend it (Hines et al., 2004). However, the primary goal of Lean is to fabricate products of the highest quality while spending minimum costs and very little time, which is done by removing wastages from the process (Dennis, 2017). In the context of Lean, if there is something that does not build-up value or utility feature to the product and for which customers are not ready to pay, it is a complete waste. Over the years, experts have identified seven types of waste. It includes inventory, overproduction, motion, waiting, defects, transportation, and over-processing. These wastes impact products' cost, quality, and productivity in a direct manner. Manufacturing units need to develop a model which can reduce cost of the supply chain keeping in mind the rejections (Gokilakrishnan and Varthanan, 2019). Lately, Lean is becoming a universal phenomenon helping companies to improve their productivity and enhance their customer service while maintaining international quality and saving associated costs (Mishra, 2016). Singh and Pandey

(2015) highlighted how Lean has allowed flexibility within the organisation with the constant evolution of the market situation, showing that a well-formulated Lean strategy can empower an organisation to achieve its targets in a sustainable manner in the rapidly evolving global market. Toyota implemented Lean manufacturing, a management methodology and collection of tools aimed at minimising waste, maximising workflow, lowering costs, and improvising quality (De Koning et al., 2006). "It attained global popularity for its simple but effective methods for eliminating activities that did not add any value to the product" (Muraliraj et al., 2018; Singh and Rathi, 2019; Sindhwani et al., 2019). Lean tools like Kanban and just in time helps in reducing cost and waste (Mahendran et al., 2018). It helps to improve quality, deliver products on time and improve customer satisfaction (Prasad et al., 2019).

Review studies have hailed Lean manufacturing for evolving to be a concept that aims to remove wastages from within the process of operations and catalyse production effectively in a more systematic manner (Alsmadi et al., 2012). By adhering to the philosophies of Lean, manufacturing firms have increased their performance in terms of productivity while maintaining high quality (Kumar et al., 2013). Yusup et al. (2015) shared fundamental guidelines and concepts to guide manufacturing firms to execute Lean in their production. Kumar and Kumar (2016) put forth a concept inclining towards the Lean methodology and showing how it directly affects organisational and operational performance parameters. Recent studies verify the positive outcome of implementing Lean in the production units in the Indian context. Lean also helps in taking care of the various environmental issues (Sawhney et al., 2007).

'Lean manufacturing system' (LMS) is a compelling approach, playing a critical part in how a manufacturing firm responds to the intense competition in the global business market (Wickramasinghe and Wickramasinghe, 2017). Womack and Jones (1996) presented and elucidated the five fundamental aspects of Lean manufacturing. These include specifying a mapping the value stream, value, creating flow, seeking perfection and establishing pull. Global contention, variation in demand, unpredictable and dynamic market scenarios, and higher customer expectations are pushing manufacturing firms to adopt LMS.

LMS systematically focuses on recognising and removing 'NVA' activities from within a manufacturing operation (Scherrer-Rathje et al., 2009). NVA activities or wastage include needless logistics, overproduction, excessive storage, irrelevant motion, down-time in the production, and manufacturing faults. The successful implementation of LMS relies on how organisations reduce these wastes at various grades of their production processes. Many organisations stand benefited by executing LMS with enhanced financial and operational output (Chaplin et al., 2016; Godinho Filho et al., 2016; Yadav et al., 2019). LMS makes an organisation more flexible and responsive to the market requirements by eradicating waste (Wilson, 2010). LMS offers manufacturing organisations a competitive advantage by reducing costs while maintaining quality and boosting productivity (Sisson and Elshennawy, 2015). Manufacturers are implementing LMS to enhance efficiency and produce superior-quality products in a short time-span and at reduced costs.

When companies focus on Lean, they often give more importance to on-time delivery, efficiency, and customer satisfaction. However, if safety is added in Lean, the advantages are manifold. Safety is directly linked to employees and it is assumed that their initiation would be high as they would understand the importance of safety and highlight areas where the initiative of safety was missing (Sadhna et al., 2020). The relationship between safety and Lean is quintessential, and it requires a lucid understanding of an organisation's safe environment. Lean is an essential tool that can improve safety in the projects (Gambatese et al., 2017). The accident rate was reduced by about 45% when the technique of Lean was adopted (Thomassen et al., 2003). The accident rates actually are a point of concern for organisations especially the manufacturing units. "In a manufacturing unit, a non-fatal occupational injury rate was 3.9 on an average of 100 workers in 2013, according to the Bureau of Labor Statistics, compared to 3.6 in manufacturing and 3.2 in private industry. It is estimated that productivity lost due to occupational injuries and illnesses cost businesses $60 billion, while manufacturing was responsible for nearly 20% of all muscles and bone injuries" (Bureau of Labor Statistics, 2013).

There can be binary methods to safety: reactive and proactive. Security indices such as safety accidents, occupational injuries, and absence from the workplace because of injuries are all reactive safety measures. They monitor workplace safety following the accident. According to Johnson (2007), "the descriptive capacity of traditional methods of assessing protection, i.e. reactive, is inadequate, and many other variables are needed to comprehend workplace safety better." On the other hand, "a safe environment is a proactive method of safety" (Clarke, 2006) and is characterised as employee perceptions of safety practices and procedures that represent the importance of safety in an organisation (Neal and Griffin, 2004). Management dedication to safety, occupational hazards, and employee engagement in healthy practices are all part of the safety environment (Mewafarosh et al., 2021; Ikuma and Nahmens, 2014).

The 'UK Health and Safety Executive' (Cox and Cheyne, 2000) created the 'Safety Climate Assessment Toolkit' (SCAT), which lists eight types of safety climate: "management engagement, communication, safety priority, welcoming atmosphere, participation, personal goals, and need for safety, personal awareness of danger, and work environment." The safety environment can educate management about the on-going risk of accidents and recognise places where safety can be improved. In addition to it, improved safety environments are closely linked to lower accident rates (Varonen and Mattila, 2000), indicating that safety environments are significant components to be measured.

2.2 Six Sigma

Motorola designed Six Sigma as a robust and dynamic tool for improving and refining business processes (Matthews, 2006). The leading global organisations have used Six Sigma and executed its methodology in various contexts, scenarios, and operations (Snee, 2004). Six Sigma elevates the process performance and attains high quality by limiting product and process variability and eliminating the defects root causes (Zu et al., 2008). Over the past three-decades, the advanced tool has evolved into a guide to improve business processes (Antony et al., 2004; Arumugam et al., 2013). It is used in many data analyses as a statistical tool to alleviate or limit the variation in a process to meet the production goals. After removing unwanted variation, the natural variation gets predictable, due to which the result can be predicted. Six Sigma also enables to enhance quality to meet the production goals cost-effectively.

This cost-effectiveness helps in savings, thus gaining competitive advantage and boosting value for the stakeholders (Alhuraish et al., 2016; Patil et al., 2017; Muraliraj et al., 2018; Singh and Rathi, 2019). Six Sigma generates value not only within an organisation but also for the next-generation stakeholders. Six Sigma has been successfully implemented at DuPont, Motorola, Honeywell, Bank of America, General Electric, Caterpillar and Samsung. Maleyeff (2014) highlighted that the Six Sigma methodology empowers businesses to enhance profits by eliminating waste, cutting down the cost of bad quality, and improving operational efficiencies to meet the customers demand. Six Sigma (DMAIC) is the need of the hour to achieve business excellence especially for Indian manufacturing units if they need to stand up in the international competition (Paranitharan et al., 2016).

2.2.1 DMAIC

The Six Sigma strategy uses the DMAIC approach, which includes defining, measuring, analysing, improving, and controlling phases. This DMAIC approach finds its application in handling issues with uncertain solutions, especially when an organisation is yet to find the root causes (Antony, 2018). The Six Sigma plan, integrated with the DMAIC approach, serves as a statistical and non-statistical tool, providing manufacturing firms with a framework for process improvement. Organisations achieve desired goals and meet their target by implementing Six Sigma.

It empowers them to deliver high-quality finished products while eliminating internal shortcomings, which help them strive toward flawless organisational conduct (Pandey et al., 2018). However, as a standalone strategy, Six Sigma is not capable enough to fulfil environmental obligations. It upgrades the model implementation via reducing variables in production (Gaikwad et al., 2019). Therefore, an organisation must adopt multiple strategies to improve its productivity and performance significantly.

2.3 Lean Six Sigma

LSS is a strategic tool that finds its application across all functional areas of the unit. LSS can be helpful for any type and any size of the company. LSS tools such as Kanban, 5S work standardisation and visual management helped reducing human errors and accidents (Tortorella et al., 2020).

Lean has been corresponded to as a force of change, while Six-Sigma as the force of continuity (Pillai et al., 2012). Sunder (2016) indicates that LSS offers a spectrum of tools, methods, and strategies to improve the process performance and reduce operational costs for business firms. This is the sole reason why researchers, over the past two decades, have preferred the simultaneous adoption of both Lean and Six Sigma approaches over individual ones. Gradually, LSS has emerged as the most popular tool to achieve operational brilliance with high-quality performance across various scenarios and industrial setups (Zhan, 2016).

Lean primarily focuses on the flow and value stream happening across inter-linked processes. Utilising Six Sigma alone cannot eliminate all types of wastage from an operation. Similarly, implementing Lean in isolation does not remove variation from the process and bring statistical control. Therefore, one must consider implementing LSS, which is a methodology to enhance business operations and focus on operational performance and limit the variation in a process, leading to increased customer satisfaction and an improved bottom-line coupled with increased financial savings.

Around 2000, the concept of LSS was first introduced in the theory of operational management (Antony, 2018). One can define LSS as “a continuous improvement methodology that strives to cut down the costs of poor quality and enhances the bottom-line results, thus creating value for both stakeholders as well as customers" (Albliwi et al., 2014). In one of the research studies, Albliwi et al. (2015) further reiterated the favourableness and significance of LSS as a business strategy. They claimed that organisations consistently use LSS for sustained enhancement in the service, production, and government sectors. Combining Lean and Six Sigma to develop the LSS model has multi-fold benefits for organisations. The primary goal of LSS is to cost-effectively improve quality and organisational output (Singh and Rathi, 2019).

LSS can be deemed an ideal strategy for manufacturing operations, wherein Lean principles are used to recognise and eliminate wasteful activities while simultaneously adding values to the overall process (Rittiner and Brusoni, 2013). LSS strategy revolutionised the manner of doing business in the past century. From small-scale enterprises to large-scale multinational companies like General Electric (GE) and Motorola, organisations worldwide have used LSS to increase productivity, improve performance, boost stakeholder offerings, and enhance customer satisfaction and trust (Yadav et al., 2020).

LSS increases operational competence by reducing duplication and enhancing process consistency if applied correctly (Alagić, 2019). A well-executed LSS is that it strengthens the corporate atmosphere and sense of responsibility of the management for quality and waste management (Alnajem et al., 2019). It serves as a general guide to achieving strategic objectives that the organisation has targeted (Sindhwani et al., 2019). Different research studies have described Lean as an approach that targets to eradicate wasteful activities across processes (Seth and Gupta, 2005; Shah and Ward, 2007), reducing processing cost and the time to complete (Negrão et al., 2017). While doing so, Lean empowers businesses to achieve the best possible quality while spending minimal expenditure (Negrão et al., 2017) and limits the wastes across the production system. As a result, the implementation of Lean leads to improved production and enhanced offerings to the customer in terms of quality and variety of product or service offered, which further enhances customer satisfaction (Thanki and Thakkar, 2011). LSS outlines the guidelines, basic concepts, and techniques for process management. Serving as a robust leadership development tool, LSS enables leaders to oversee the development (Antony, 2018) and manage and minimise the production cost by eliminating the waste. Implementing the holistic model of LSS involves integrating human aspects (like leadership roles, change in workplace culture, and focus on the customer) with process nuances (such as management, process efficiencies and capability, and statistical strategies) for persistent improvement across industrial operations (Bhat et al., 2019). In another research study, Galeazzo et al. (2014) highlighted the standard features between the Lean and Six Sigma model and stated that they both improve operational and environmental performance when implemented simultaneously or sequentially. A research study by Arnheiter and Maleyeff (2005) asserted that organisations adopting Lean or Six Sigma in isolation would eventually experience getting shrinking outputs and have to invest in other strategies for competitive advantages. Lean alone does not guarantee a sustainable competitive advantage or process effectiveness in the long run (Salah et al., 2010).

A study was done by Black and Revere (2006), wherein they put forward a premise in front of the corporates that the processes adhering to Six Sigma do not necessarily mean that they are being operated on Lean philosophy. Businesses need a further application of Lean tools with Six Sigma strategies to achieve more process and operational improvement. Working on this assertion, Corbett (2011) opined that the weaving of Six Sigma and Lean strategies into LSS was significant since LSS capitalised on Lean and Six Sigma methods' strengths. LSS embraced both the robust models' practical aspects, removing their shortcomings that had been recognised over the years. Bhuiyan and Baghel (2005) and then Snee (2010) put forward contrasting yet complementary Lean and Six Sigma features. They emphasised that the objective of the Lean method was to eliminate waste from the manufacturing operation. On the other hand, Six Sigma focused on process improvement.

Salah et al. (2010) ascertained the direct and complementary link between Lean and Six Sigma when eliminating waste in the operations as the waste results from inefficiencies in the process. Lean concentrates on eliminating waste like longer cycle times and downtime, whereas Six Sigma strives to limit the excess variation in the process, such as reworking or scraping. Chaturvedi and Chakrabarti (2017) studied the impact of, a powerful statistical tool used in LSS in manufacturing industries and observed that design of experiments (DOE) application helped industries in identifying key factors and levels that influence process performance and variability. Shrivastava et al. (2018) studied the effectiveness of an implementation strategy of LSS to control and reducing energy consumption in a paint shop. The study provides insights into strategic and tactical level initiatives in energy cost savings through a better management of process capability.

Tortorella et al. (2020) praised the integrated LSS-DMAIC model, stating that it can help organisations manage and implement enhanced performance in a sustained manner. Projects involving the implementation of LSS occur primarily in the manufacturing processes. The LSS with an integrated DMAIC method helps enhance quality features and provide solutions via the efficient implementation of LSS tools like 5 S, VSM and SIPOC (Chakravorty and Shah, 2012). Despite all the advantages of Six Sigma, its benefits augment multi-fold when Lean guidelines are consolidated in various stages of DMAIC (Shah et al., 2008).

3 Research gap

As per the literature review, there existed a possibility to explore and apply the LSS-DMAIC methodology to reduce accidents in the manufacturing setup. There was a scope to adopt LSS to find out the causes of accidents, increase safety, and improve the safety culture. In the study conducted, LSS-DMAIC had been systematically adopted and applied to reduce accidents, which is a NVA activity. This technique would also help in improving the manufacturing unit's safety culture.

4 Case industry

The organisation discussed here as a case is a manufacturer of steel components and is located in the North of India. It manufactures beams, metal sheets and roofing, and its customer base, including project organisation in the construction business, infrastructure, and warehouse building companies.

4.1 Business case

The management of the manufacturing unit was concerned with increasing incidents of accidents, causing dissatisfaction among the workforce and financial losses. They discussed the figures of accidents during the financial year 2019–2020 and were looking for appropriate measures to reduce the accidents.

4.2 Proposed analysis framework

After reviewing the entire business scenario and available literature, researchers proposed the LSS-DMAIC framework. This framework was based on more considerable LSS-DMAIC methodology and included only those logical and systematic tools and techniques apt to the current business problem.

Table 1 Proposed framework

Define phase	• Business problem identification • Defining and description of problem • Project charter formulation • Approval from senior management • Activity plan development
Measure phase	• Sample plan • Data collection for baseline (accident records) • Declaring operational definition for each variable related to accidents • Analysing the base data and defining the base level of accidents • Setting Significant targets for improvement
Analyse phase	• Data Analysis • Probable causes identification • Root cause analysis with data validation
Improve phase	• Identifying possible improvement opportunities • Improvement plans for reducing accidents • Implementation of improvement actions
Control phase	• Corrective actions monitoring • Sustaining the improved practices • Data collections and comparison with base data • Statistical data analysis of accidents • Statistical validation of significant improvement (before and after LSS methodology implementation data)

4.2.1 Define phase

The reported number of accidents were 81 during the year, making seven accidents per month on average. The number of man-days lost during the year were 1,521 (127 man-days per month), and the number of hours lost is a year were 12,168

(1,014 man-hours per month). These numbers were alarming for the company and qualified for a business case, which required enhancements.

During the lockdown period during April–May 2021, the company's top management decided to use this Lean period to identify the root causes, make improvement plans and control the accidents. The LSS-methodology was adopted, and a cross-functional team was formed to study and improve the process. This information sharing results in comparatively better output (Saxena et al., 2009).

The team initiated the improvement project by defining the following terms:

- Number of accidents per month = Total no. of accidents in a month
- Man-hours lost per month = Total no. of lost days in a month × 8
- Accident frequency rate = $\dfrac{\text{No. of accidents in a period} \times 200{,}000}{\text{Man-hours worked in the period}}$
- Accident severity rate = $\dfrac{\text{No. of hours lost dueto accident} \times 200{,}000}{\text{Man-hours worked inthe period}}$

> An "accident frequency rate is the number of accidents that occur per hour in a company compared to the total number of hours worked by all employees. The accident rate helps in comparing the safely across organizations with different sizes and across different time frames. Accident frequency rates are calculated for 100,000, 200,000 or 1,000,000 employee working hours (man-hours) depending upon the country; it is usually given per 200,000 man-hours." (Suglo and Gyimah, 2014)

Once the operations' definition was frozen, the next step was to define the project's scope. One needs to define project scope, key drivers, the voice of customers (VOC) and critical to quality (CTQ) aspects. The scope of the project was limited to accidents happening inside the unit.

Key drivers and VOC

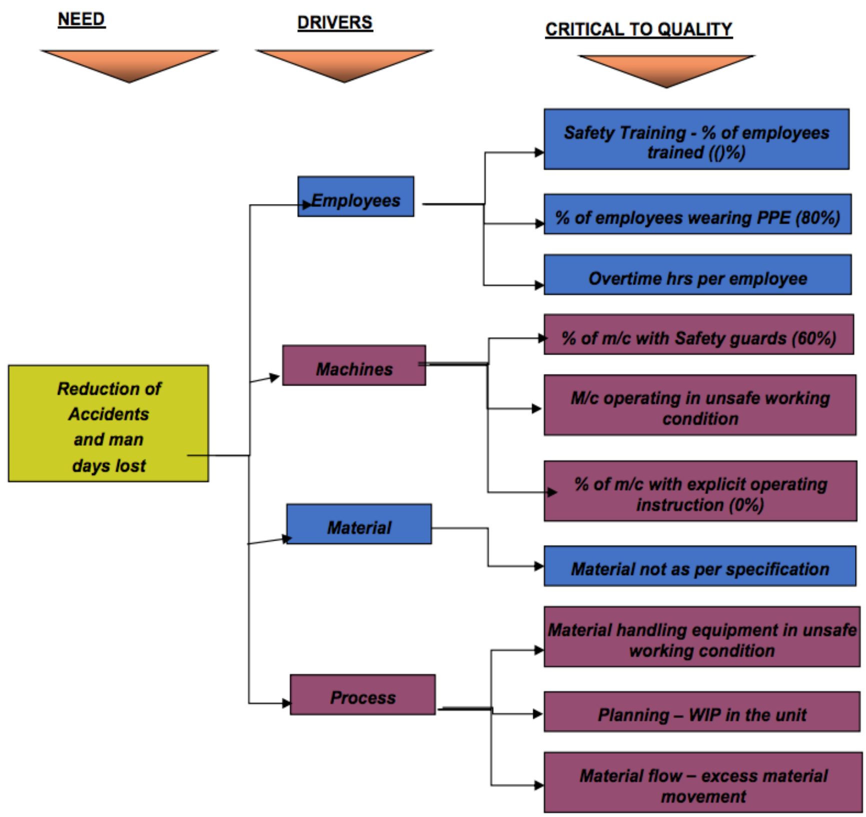
VOC tools were used to identify the key drivers and understand the CTQ attributes related to each key driver. The expert opinion technique was used to identify the various key drivers relating to or contributing to the accidents. For each key driver, the various factors were identified, tabulated and validated. The primary critical drivers identified were employees, machines, material and processes

The next important part was to define the operational definition; this provided a unique understanding of the term to all stakeholders. The operational definitions for the various terms were defined as under:

- Incident: It is an event that has the chance of being converted to an accident or has the potential to cause an accident.
- Near miss: It is an event that may harm the people, damage the property or environment or do not comply with the legal requirement under almost similar circumstances but with some of the other difference.

- Accident: It is an event that occurs unplanned. It is undesirable, harms people and leads to injuries. It may lead to loss of property, material or equipment and damage the environment.
- Lost workday case (LWC): If an employee cannot work on his next scheduled shift because of a work-related injury or illness due to the work environment, the case is a LWC.

Figure 1 Key drivers (see online version for colours)



4.2.2 Measure phase

Data collection: To understand the baseline, the first step was to collect data. A sample of 81 accidents in a year were analysed. All the data of accidents reported were collected and tabulated.

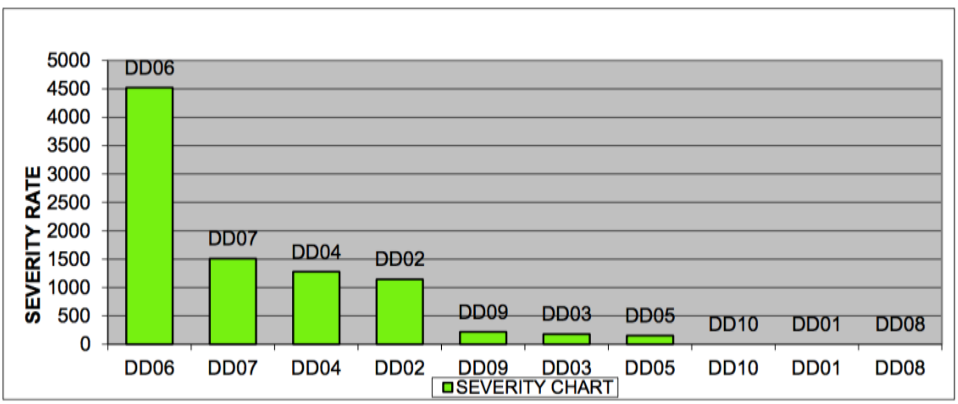
Once the data was collected, the next step was to identify the high accident rate areas. The data was sorted out based on accident numbers, and the top four areas were earmarked for the first phase of the improvement action plan.

The departments were DD06 – sandblasting and paint area, DD07 was shipping area, DD04 was fitting area, and DD02 was shearing area.

Table 2 Accident base line analysis

Department code	*Accident numbers*	*Hours lost*	*Hours worked*	*Severity*	*Frequency*
DD06	41	6,008	941,263	1277	9
DD07	14	3,544	156,706	4523	18
DD04	12	1,328	232,180	1144	10
DD02	6	184	206,305	178	6
D007	5	952	126,195	1509	8
D009	2	104	96,698	215	4
D005	1	48	63,538	151	3
D008	0	0	40,836	0	0
D001	0	0	16,634	0	0
Total	81	12,168	1,880,355	8,997	58

Figure 2 Accident's severity chart (see online version for colours)



4.2.3 Analyse phase

The next step was to analyse the type of injuries and workforce level that would help in identifying any specific injury and level of the workforce that was severely contributing to the accidents. Table 3 represent accident analysis. Fracture and contusion (press) were the top two injuries, and among the workforce, welders and machine operators were getting affected in large numbers.

After getting the details analysis of injuries and workforce designation, a cross-functional team was formed, representing executives and workman from the top four areas identified. The team brainstormed and identified the various causes which are responsible for the accident. When workers are involved in various decisions of the work methods according to their abilities, the number of accidents reduce to a large extent (Camuffo et al., 2017; Bashir, 2013). The famous root-cause analysis (fishbone) diagram was drawn to make the visibility of the work. Figure 3 represents the root case diagram.

Table 3 Accident analysis

Type of injury	*Number*	*Designation*	*Number*
Fracture	33	Welder	25
Contusion (press)	19	M. operator	15
Cut wound	19	Fabricator	12
Burn	3	S. blaster	7
Sprain	2	Helper	5
Dislocation	1	Matl. handler	5
Data not available	4	Painter	5
Total	*81*	Cleaner	2
		Checker	1
		Data not available	4

Figure 3 Root cause analysis (see online version for colours)

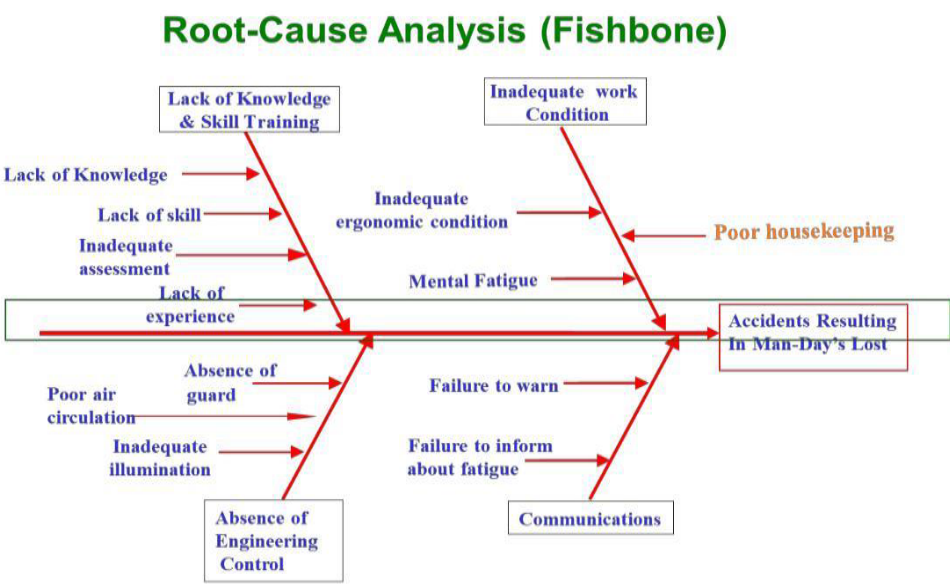


Table 4 Root cause analysis

Cause	*Number of accidents*	*Total man-days lost*
Lack of knowledge and skill training	62	968
Inadequate work condition	9	147
Absence of engineering control	3	175
Lack of communication	3	85
Data not available	4	146
Total	81	1,521

Once the root cause diagram was prepared, the next task was to identify the primary root causes by assigning numbers of accidents to respective causes and analysing them.

Lack of knowledge and skill training and inadequate working conditions came out to be the central area for improvement and taking corrective actions. The above diagram displays only a part of root cause analysis as the full event has not been disclosed due to confidentiality protocol.

4.2.4 Improvement phase

The central part of the work that included preventive and corrective actions were in the improvement phase. The slowdown of activities due lean period during 2019–2020 provided an opportunity to carry out the improvement phase. The team focused on the root causes and identified the corrective action plan and activities.

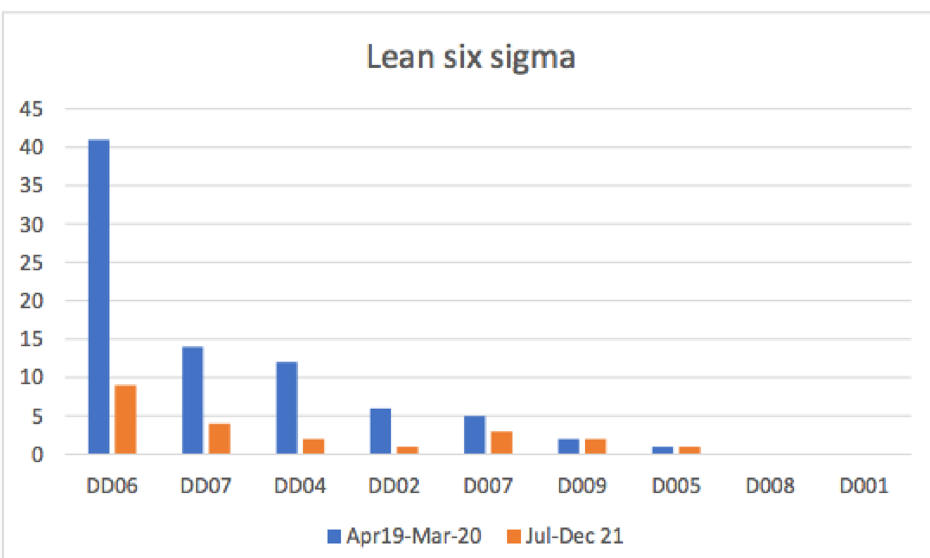
Table 5 Action taken report

Serial number	*Action*	*Responsibility*	*Start date*	*Target date*	*Completion status*
1	Replace the worn-out material handling tools	Engineer	01-June-20	30-June-20	100% completed
2	Improve knowledge and skill of personnel by everyday training program for the crane operations and material handling	Manager	07-June-20	Ongoing	60% operator trained
3	On job awareness of the operators to be improved	Deputy Manager	20-July-20	Ongoing	80 % completed
4	Guards/barriers to be put in place	Engineer	10-June-20	10-July-20	100 % completed
5	Work standard to be improved by introducing the good housekeeping	Deputy Manager	15-July-20	15-November-20	‘5S’ implemented and training provided to all staff
6	Display of safety calendar in the plant	Manager	15-July-20	21-July-20	Annual calendar prepared and displayed
7	Ensure proper coordination among group members while performing task (communication)	Team Leader	15-July-20	Ongoing	Job card is prepared and operational
8	Arrangement for the safety tool kit talk on weekly basis	Deputy Manager	15-July-20	Ongoing	Daily huddle meeting is carried out before start of shift
9	Formation of the Safety committee	Manager	10-June-20	16-June-20	A cross-functional team of five members formed

Figure 4 Action taken (see online version for colours)

Figure 5 Welding with safety equipment (see online version for colours)

Figure 6 Lean Six Sigma (see online version for colours)



4.2.5 Control phase

Once the improvement plans were implemented, the accident reports were analysed to compare the LSS approach's impact on reducing the work area accidents. Figure 6 shows the comparison of the accident before and after the LSS implementation. There were significant improvements, working conditions became safe, and management started monitoring and controlling the efforts continuously. Weekly meeting and analysis were done department wise and monthly report on accidents became part of monthly management information system (MIS) of the unit.

5 T-test

The two-paired t-test was also carried out to check the statistical significance between two sets of data at 5% significance. The result is given in Table 5.

Table 6 T-test: paired two sample for means

	Before (Apr19-Mar-20)	*After (Jul-Dec 20)*
Mean	9	2.4
Variance	169.75	7.7
Observations	9	9
Pearson correlation	0.95	
Hypothesised mean difference	0	
df	8	
t stat	1.88	
P(T< = t) one-tail	0.04	
t critical one-tail	1.85	
P(T< = t) two-tail	0.09	
t critical two-tail	2.30	

A significant difference exists between pre and post data. Thus, improving the working conditions and reducing accidents were making an impact in a positive direction.

6 Conclusions

LSS is widely used to improve business process efficiencies in the manufacturing and service sectors. Manufacturing units use machines for their operations, and safety is widely attached to total productive maintenance (TPM). This paper is unique in terms of LSS-DMAIC methodology to improve the units' safety culture concerning accidents. While using DMAIC methodology in the define phase, the business case developed, and all terms and operational definitions were discussed and then frozen during the measure phase. Historical data was collected and analysed. The Pareto analysis was done to identify the departments which are mainly contributing to the accidents.

Further, the nature of accidents was also analysed in detail. Fracture and contusion were among the top two types of accidents happening in the unit. A cross-functional teams were constituted by engineers, mechanics, technicians, and managers to make improvement plans and then implement them. The team used brainstorming, cause and effect techniques to earmark the root cause. These sessions were backed up by the number of accidents for each cause. A detailed time-bound action plan was prepared and implemented. After completing improvement actions, the major challenge was to sustain the acceptable practices continuously.

Before and after analysis of accidents was carried out to understand and compare the impact of improvement actions. A statistically significant improvement was observed in the phase after the implementation of LSS.

Thus, the DMAIC approach has supported the team in improving safety culture and systematically reducing accidents with a data-driven decision-making approach.

7 Practical implications

The results of successful implementation using the DMAIC methodology of LSS have wide usage in all manufacturing units, including SMEs, to improve their safety culture, impacting financial and employee satisfaction at large. Further studies can be extended in employee satisfaction, employee training, employee engagement and its impact on reducing waste.

This improvement has opened the way for other departments like HR. stores, purchase, quality to use the LSS approach, and making process improvement in their respective departments/cross-functional departments to improve the processes.

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