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Green Lean Six Sigma for Improving Manufacturing Sustainability: Framework Development and Validation

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Abstract

In the past few decades, a competitive landscape, learned customers and rigorous regulations have forced manufacturing industries to focus on sustainability alongside operational efficiency. The main objective of the present study is to develop a systematic Green Lean Six Sigma (GLSS) framework for improvement in operational efficiency together with environmental and social sustainability. Further, the proposed framework was tested in a leading manufacturing company. The framework was designed with insights gained from the literature and industrial personnel and encompasses the systematic application of different tools of the Green paradigm, Lean, and Six Sigma, from the identification and assessment of the problem to the sustainment of the adopted measures. A systematic application of lifecycle assessment and social lifecycle assessment was used to assess environmental and societal performance. The sustainability focused GLSS framework enhances the environmental capability, process performance and provides a new perspective for researchers and practitioners to support GLSS projects to achieving higher sustainability dynamics.

Keywords: Green Lean Six Sigma; Framework, Manufacturing; Sustainability; Lifecycle assessment

1. Introduction

Manufacturing industries are prominent producers and sponsors of environmental pollution, posing a threat to environmental sustainability. However, the majority of previous sustainability studies pertaining to manufacturing are restricted to the environmental and fiscal dimensions of sustainability, omitting societal aspects. This approach only leads to short term gains and lacks long term sustainable benefits. The consideration needed on a healthy work environment and best labour practices demand the inclusion of social aspects in industrial practices. Hence, societal and ecological concerns have made a call for organizations, particularly manufacturing enterprises, to meet sustainability goals (Tewari et. al. 2020). Stringent government policy on climate mitigation measures for manufacturing organizations in developing nations like India has led to the development of policies such as the Perform, Achieve and Trade (PAT) and Zero Effect Zero Defect (ZED) to mitigate greenhouse gases (GHGs) (United Nations Framework

Convention on Climate Change, 2018). Through the lens of new policies, industries have to reconsider operations and the assessment of environmental and associated wastes. Besides the environmental concerns, companies have to enhance traditional quality characteristics related to production capacity and productivity to deliver sustainable products. For this, companies have to change their traditional business practices to sustainable ones. Manufacturing organizations have an inherent capability to adopt environmentally-friendly approaches in their operations (Yacob et al. 2019).). Since the last few decades, various strategies have evolved (Garza-Reyes et al. 2018) to manufacture high specification products (Pandey et al., 2018).

Lean is valued due to its ability to quantify waste, but it is not able to quantify environmental impacts and possible environmental hot spots (Cherrafi et al. 2019). Thus, at this juncture, green technology can fill this gap and estimate the environmental impacts of generated waste. Green technologies are those set of measures and methods that leads to lesser environmental degradation through the incorporation of clean technologymeasures (Baum 2021). It includes different metrics related to environmental footprints (e.g. eutrophication, acidification, GHGs content, energy intensity). Although Green Lean (GL) is able to recognize wastes and quantify ecological impacts, it does not provide an actual method to reduce wastes and defects associated with processes (Garza Reyes, 2015). Six Sigma (SS) is a data-driven approach that fills this gap and provides a concrete stepwise methodology to reduce waste (Sreedharan et al. 2020). Although SS reduces wastes through the reduction of defects, it does not recognize different wastes and environmental impacts (Hussain et al. 2019). Furthermore, Lean Six Sigma (LSS) leads to improved organizational efficacy through the reduction of wastes and defects but is not able to estimate and improve the societal and environmental dimensions (Garza-Reyes et al. 2016). Thus, it is obvious that an individual strategy is not able to cope with all the dimensions of sustainability but that each approach (Green technology, Lean and Six Sigma) supplement each other to achieve sustainability. So, the concept of GLSS came to the foreground as a significant driver that allows gaining insight from different individual approaches (Lean, Six Sigma, and green technology), their boosting integration among them for improved organization sustainability.

GLSS is still in its infancy stage, so it is imperative to comprehend the different features that foster its implementation (Sony and Naik, 2020; Belhadi et al. 2021). Researchers have paid less attention to explore GLSS role in sustainability improvement measures using theoretical and practical frameworks (Kaswan and Rathi, 2021b; Ershadi et al. 2021). GLSS is a project-based approach, and literature suggests that nearly 40% of the projects fail due to lack of understanding of GLSS features like tools and implementation frameworks (Gandhi et al. 2021). So, this research work answers the question pertaining to different features and elements related to implementation of GLSS in order to improve industry sustainability. Moreover, GLSS framework studies related to construction, mining, and healthcare exist in the literature but no study related to GLSS framework for improved sustainability exists in manufacturing. For this, the present study attempts to answer the research question of GLSS framework development related to the manufacturing industry. In response to said research questions, this paper aims to develop a novel GLSS framework along with different toolset pertaining to manufacturing. Afterwards, the said framework was tested in a manufacturing company to support its applicability and ability to support GLSS projects for improved environmental and social sustainability. The rest of the article is organized as follows. Section 2 presents a literature review that pertains to GLSS. Section 3 deals with the adopted method for this research work. Section 4 depicts the proposed GLSS framework, whereas Section 5 presents the testing of the framework within an industrial setting. The results, discussion, and theoretical and practical implications are presented in Section 6. The final section establishes the conclusions and future research agenda.

1.1 Research Gaps

The literature suggests that LSS implementation leads to constructive outcomes on ecological and financial performance. However, inclusion and implementation of Green technology with LSS are not deprived of challenges. Lack of finance for clean technology projects, poor organizational support system, deficiency of resources, unavailability of tools and practices, and uncertain gains, further hinder effective execution of sustainability-oriented projects. It has been found through examination of existing studies that focus has been restricted to the environmental and fiscal dimensions of sustainability but that societal aspects have been overlooked. The consideration needed on healthy work environments and best labour practices demand the inclusion of social aspects in GLSS practices. Moreover, manufacturing organizations in developing nations need to tap the full throttle of their capacity for reducing operational costs and delivering high-quality sustainable products. To the best of the authors' knowledge, no study has provided a dedicated framework of GLSS that leads to a reduction in environmental emissions and enhanced capacity utilization alongside enhanced societal aspects. These research gaps provided an impetus to conduct the present study for a more sustainable and empowered society.

2. Literature review

To select pertinent research articles a Systematic Literature Review (SLR) was conducted (figure appended in supplementary file). SLRs contribute to the conceptual development of a theoretical base and explore different grey areas for future research work (Kaswan and Rathi, 2021a). The articles relevant to the present study were identified using keywords, title and abstract together. Keywords, 'Green Lean Six Sigma'; 'Framework'; 'Manufacturing'; 'Sustainability'; 'Lifecycle assessment' were used to find pertinent articles. The articles were accessed using the Scopus database. More than 110 articles were screened initially. They were further scrutinized based on the interaction of Lean, Green, and Six Sigma, Lean with Six Sigma and sustainability aspects adhered to GLSS. Finally, 42 articles were selected for further analysis to develop a systematic knowledge base for the formulation of research objectives and the proposed framework.

2.1 Exploration of grey areas of GLSS

The development of GLSS can be traced back to the evolution of the Lean production system. Lean reduces wastes from processes or systems by streamlining those (Ghobadian et al., 2020). However, Lean is not able to mitigate environmental damage associated with the system under consideration (Cherrafi et al. 2018). This drawback has been overcome through incorporation of green or clean technologies. Green technologies mitigate the associated carbon footprint through the use of advanced technologies like additive manufacturing and near dry machining (Bond and Dusik, 2019). Both Lean and Green approaches primarily focus on waste reduction: Lean reduces the associated seven lean wastes, whereas Green technology focuses on reducing environmental wastes (Garza-Reyes, 2015). Based on this common characteristic, Green and Lean have been integrated into a single unique approach called Green Lean (GL).

Although integrated GL approach mitigates numerous wastes, it is not cable of producing products that meet specifications every time (Cherrafi et al., 2019). Therefore, there was a need for incorporating an approach that reduces defects and variations in processes. SS is a process improvement methodology that reduces errors in existing processes (Niñerola et al., 2020). LSS makes organizations competitive through reduction of wastes and defects (Juliani and de

Oliveira, 2020). The integration of SS with the GL approach has led to evolution of a sustainable development approach named GLSS. It is an eco-friendly approach that improves productivity, profitability, and environmental sustainability through incorporation of 3'R (Kaswan and Rathi, 2020) (Figure 1).

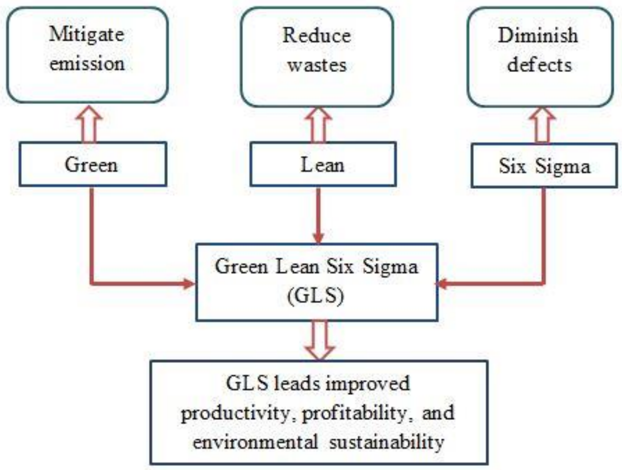

Figure 1: Green Lean Six Sigma model

Table1: Resemblances between Lean Six Sigma and ecofriendly manufacturing strategies

Parameter	**Lean Six Sigma**	**Ecofriendly manufacturing strategies**
Focus	Enhancing organizational productivity	Increasing environmental sustainability
Competence and gain	Increased profitability and competence through the reduction in wastes and defects	Increased competences and profitability dynamics through mitigation of emissions
Waste measure	Waste should be removed for improved productivity and reduced expenses	Wastes should be at a minimum level to reduce the emission of GHGs
Customer gratification	Higher customer gratification through a reduction in operations costs and defects	Higher customer satisfaction by reducing the cost spent on resources and production of eco-friendly products
Inventory	Inventory should be kept at a minimum level to reduce wastes	Inventory level must be the lowest to minimize resource consumption

The integration of sustainability with LSS has led to improvement in environmental sustainability together with traditional performance measures of quality and productivity (Cherrafi et al. 2017; Parmar and Desai, 2020). Table1 depicts resemblances between LSS and ecofriendly manufacturing strategies. Besseris (2011) developed a systematic model to deal with process efficiency and environmental facets together in a Green Lean project using LSS tools. A design of experiments (DOE) tool kit was employed to frame and modulate controlling parameters. Habidin and Yusof (2012) conducted an exploratory study to comprehend contextual relationships among LSS, environmental measures, and organizational performance metrics. A contextual relationship between GLSS and management innovation for the Malaysian automotive industry was developed using interpretive structural modeling (Zamri et al. 2013). It was determined that management innovation works as an intermediary to introduce effective GLSS practices. A conceptual framework to integrate Lean, Green technology and SS with an overall layout of the DMAIC improvement model was formulated by Banawi and Bilec (2014) to improve process metrics. The developed model was validated in a construction process. Garza-Reyes (2015) proposed a new business strategy Green LSS that integrates GL with Six Sigma methodology. Kumar et al. (2015) developed a systematic framework for merging Green technology with Lean and SS. Fatemi et al. (2016) investigated the application of sustainable Lean and Green technology strategies with the Six Sigma approach for the reduction of wastes and emissions in manufacturing sector. Cherraffi et al. (2016) conducted a state of the art literature study of three management systems, i.e. Lean production, SS, and Sustainability. The authors unearthed various challenges and opportunities for their integration and recommended future research directions. Kumar et al. (2016) framed a hierarchical structural model of barriers of GLSS in product development process using ISM. They found that lack of management commitment is one of the key barriers to the successful execution of GLSS programs during the product development process. Sagnak and Kazancoglu (2016) established the limitations of the GL approach and proposed a systematic model to overcome these through inclusion of SS. They found that variation in processes that cannot be overcome by GL can be overpowered by SS through the application of measurement system analyses and gauge control. A VSM-DMAIC based LSS model with environmental facets to assess ecological impacts in food processing industry of Norway was proposed by Powell et al. (2017). Table 2 represents prominent studies pertaining GLSS with their contributions and limitations.

Table 2: Prominent studies pertaining Green Lean Six Sigma

Authors	**Year**	**Main contribution**	**Limitations**
Banawi and Bilec	2014	Proposed a framework to integrate Lean, Six Sigma and Green strategies for the construction industry to mitigate environmental footprint.	The framework was developed only for the construction process and incorporated no social sustainability measures.
Sagnak and Kazancoglu	2016	Suggested model to integrate Green Lean with Six Sigma based on limitation of Integrated Green Lean approach. Moreover, measurement system analysis and gage control were used to reduce environmental	The proposed integration model needs further validation. Moreover, no measures were provided for how integrated GLSS improves economic and social sustainability.

		metrics flue gas emissions.	
Kumar et al.	2016	Explored and analyzed barriers of GLSS in the product development process. An ISM model was developed based on expert opinion and removal measures were suggested.	The study was only focused on GLSS barriers, not pursuits towards realization of a GLSS framework.
Powell et al.	2017	Investigated application of Lean Six Sigma in the continuous process industry, taking insight into the food processing industry for reduction in waste and energy.	The study was limited to the food industry. Further, the study contained limited focus on green tools and no application measures to improve social sustainability.
Ruben et al.	2017	Developed a systematic framework of Environmental LSS that led to reduction of environmental impacts to 33 Pt from 42 Pt.	The developed framework did not incorporate societal metrics improvement measures. Moreover, limited focus on economical dimension of the sustainability.
Cherrafi et al.	2017	Proposed an Integrated GLSS model to reduce energy and water consumption.	The developed model needs further validation in terms of improvement in other environmental metrics. Moreover, societal metrics were not incorporated in the developed model.
Belhadi et al.	2018	Proposed a framework of lean and green integration in a SME producing different types of pumps.	Firstly, the model was limited to SME and does not incorporate Six Sigma. Furthermore, no consideration was given to social aspects of sustainability.
Zhu et al.	2018	Proposed a process framework of LSS with environmental measures that defines specific dimensions and synergies between lean and green, for exploration of green lean supply chains in healthcare.	The developed framework was limited to the healthcare sector, and did not incorporate societal measures or specific applications of green tools such as lifecycle assessment.
Erdil et al.	2018	Developed a model to embed sustainability into any LSS project building on current practices.	The model does not encompass application of green technology tools and contained limited focus on social aspects of sustainability.
Kaswan and Rathi	2019	Critically investigated GLSS enablers for all industrial sectors using systematic application of ISM-MICMAC analysis.	The study was limited to the enablers, and gave no emphasis on how to execute GLSS for improved organizational performance.
Hussain et al.	2019	Explored and investigated barriers of GLSS in the construction process using systematic application of ISM and MICMAC. It has been found that critical barriers to GLSS are an unstable political environment, lack of government policy, lack of customer involvement, and lack of top leadership support.	The study focused only on the barriers that restrict GLSS application in the construction sector. The study did not provide an implementation framework and realization of the same within an industry.

Sony and Naik	2020	Proposed a generic framework of GLSS to reduce dust pollution in a coal mine.	The developed framework was limited to the mining industry and did not incorporate application of extensive green technology tools. Moreover, no emphasize was given on social sustainability.
Ali et al.	2020	Examined LSS barriers using ISM to comprehend contextual relationships of barriers and facilitate effective execution of this operational excellence approach. Further, MICMAC analysis was used to cluster barriers based on their dependence power and driving power. The suggested framework has been tested using a dataset from a real-world clothing manufacturing company in Bangladesh.	The study only identified the barriers that hinder LSS execution, but did not incorporate green technology measures to improve environmental metrics. Moreover, study did not provide a framework that includes social and environmental aspects of sustainability.
Ershadi et al.	2021	Provided measures to identify and estimate performance of GLSS projects using a hybrid approach of technology readiness level, data envelopment analysis, and ANFIS.	The study was constricted to project selection and did not provide a method to execute GLSS within an industrial setting for improved organizational sustainability.
Kaswan et al.	2021	Explored and investigated barriers that hinder execution of GLSS in the manufacturing industry using integrated application of IF-DEMATEL and BWM. The authors provided measures to overcome critical barriers.	The study only emphasized the barriers to GLSS execution, but did not provide methods to execute GLSS in the manufacturing industry.

Ruben et al. (2017) proposed a DMAIC based LSS framework with environmental aspects to reduce defects and carbon footprint in the automotive industry. Pandey et al. (2018) analyzed and prioritized enablers of GLSS using a multi-criterion decision making (MCDM) approach for the smooth execution of GLSS programs. The authors made pursuits for facilitation of GLSS execution in different industrial sectors. A systematic method for the removal of different barriers in execution of GLSS programs was developed for construction sector (Hussain et al. 2019). Thus, existing literature indicates lack of a GLSS framework, in the manufacturing sector, which leads to improvements in the triple bottom line and also embeds different tools of Green, Lean and Six Sigma.

3. Research method

This study explores the benefits of GLSS in manufacturing by developing and testing a framework within an industrial setting. To support this, the research design, see Figure 2, consisted of developing a conceptual framework and validating it using information from a panel of experts (LSS personnel, academicians, and experts from leading manufacturing companies). The framework was designed, rolled out, and tested through two phases: prototyping and implementation. During the prototyping phase, a first version of the GLSS framework was developed based on cross-disciplinary bibliographical research and the insights from participants based on their experience in implementing GLSS projects. First, the literature search was conducted using the keywords "Green Lean Six Sigma"; "Framework"; "Manufacturing;" "Sustainability;" and "Lifecycle Assessment." The authors compared different tools and techniques of each component for the selected papers and papers were re-read and synthesized before a decision was reached whether to include them in the initial framework. Afterwards, the authors consulted a panel of experts. Accordingly, 36 experts were identified from various departments of the said company (see section 5 of this paper), other companies and academicians. From this initial group, 13 industrial experts were consulted to provide inputs to the framework. The panel included senior managers, general managers, master black belts, project leaders from the considered company, and experts from academia. Each expert on the panel had more than sixteen years of industrial experience. The experts provided valuable inputs and critiques to enhance the prototype's applicability and maturity. Next, the framework was tested in a leading manufacturing company. The aim was to collect relevant observations, analyze weaknesses, and fine-tune the framework.

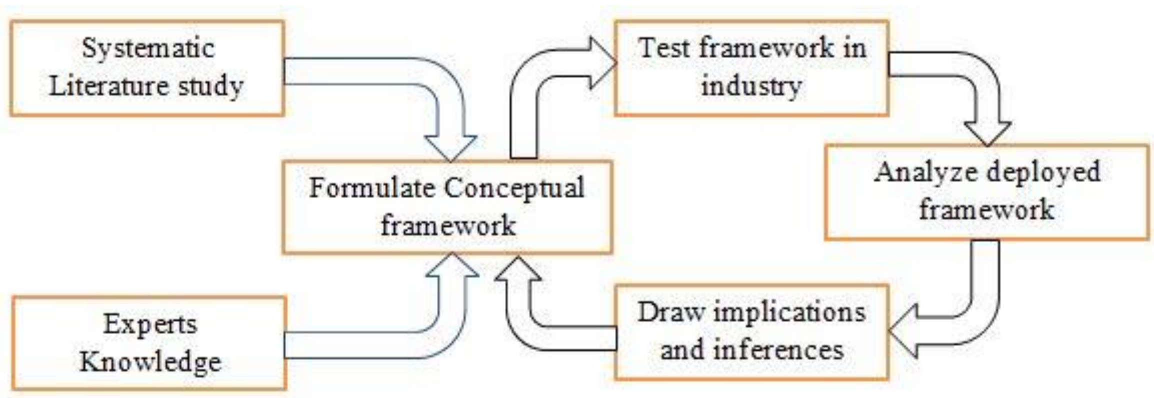

Figure 2: Research Method

4. Proposed GLSS framework

The proposed framework (Figure 3), was developed to address issues related to environmental and quality measures of projects and improve the operational dynamics of manufacturing companies. Each phase of realization of GLSS has different activities that reduce wastes and associated environmental impacts. The theoretical elements of the proposed GLSS framework are discussed below:

Step 1: In the first phase of the framework, the problem under consideration for the selected firm is elaborated as a suitable GLSS project [S. 4.1]. A clear picture of the goals and boundaries of the project are established utilizing Voice of the Customer (VOC), Voice of the Business (VOB), and SIPOC diagram, and ultimately captured in the project charter, which documents the problem, scope, objectives, and project team.

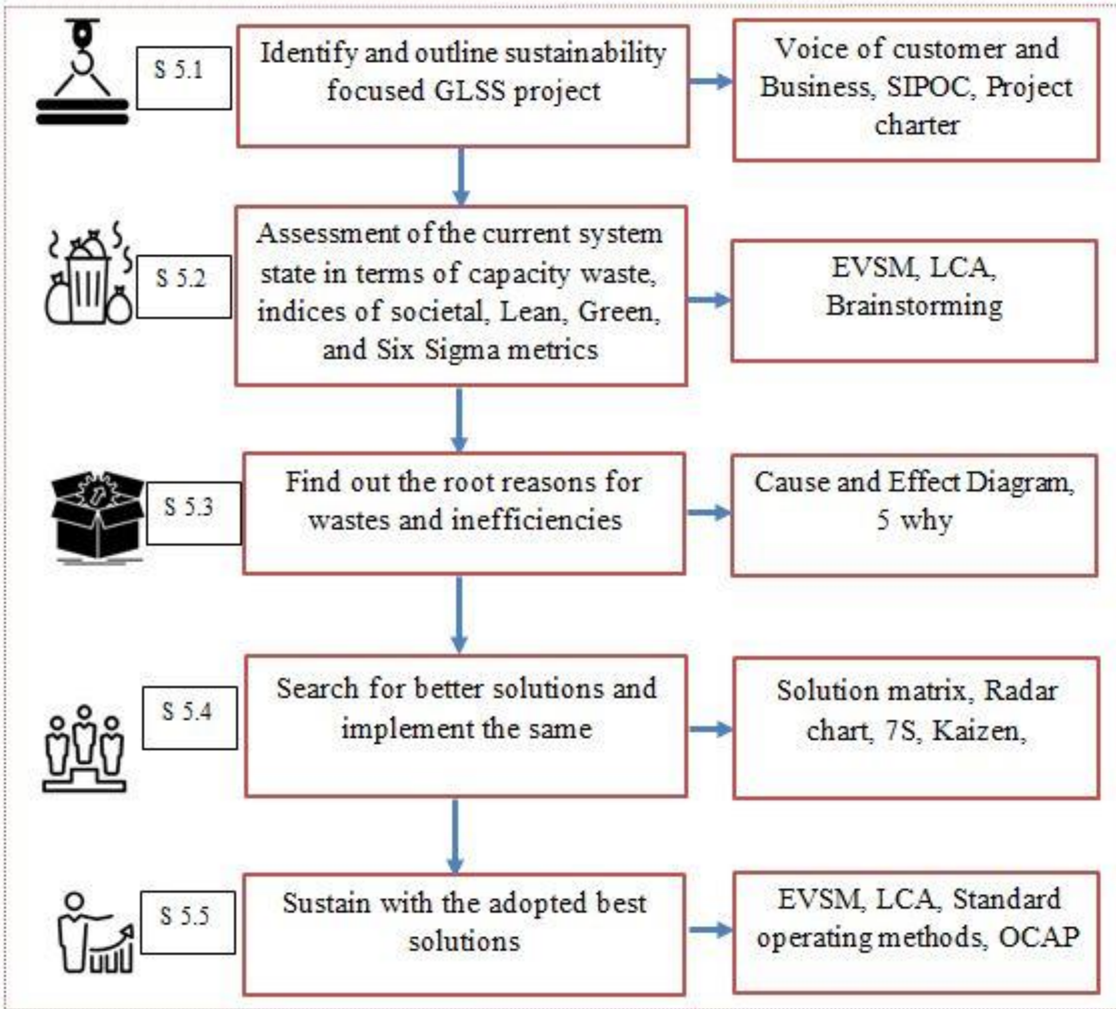

Figure 3: GLSS proposed framework

Step 2: In the second phase, the current state is estimated in terms of different metrics [S. 4.2]. Data pertaining to different wastes, environmental footprints, and societal aspects are collected in quantitative terms. To assess current levels of various associated wastes, environmental value stream mapping (EVSM) serves as a useful lean tool. EVSM provides an estimate of cycle time and material consumption across different stages and provides a check against normal consumption of time and money. Furthermore, life cycle assessment (LCA) is used during the measurement process to evaluate the environmental impact and social sustainability.

Step 3: The next phase identifies leading causes related to high-level wastes, emissions, and defects. First, value-added and non-value-added activities are identified both from customer and business points of view. Meanwhile, a complete analysis is made to identify bottlenecks and constraints. Then, possible reasons for wastes, emissions, variations, and defects are identified.

Tools such as, brainstorming, cause and effect analysis (C&E), failure mode effect analysis (FMEA) and 5 why analysis are used at this juncture to find potential causes for defects. Once possible causes have been explored, the search is now confined to find the few prominent reasons for inefficiencies. Tools like Pareto chart, hypothesis testing, regression analysis, and brainstorming are used to find critical root causes. This results in identification of leading causes of inefficiencies to be addressed for improving system under consideration [S. 4.3].

Step 4: Once leading causes for wastes and inefficiency are identified, potential solutions are proposed and the best solution applied to address prominent causes. In this phase, high creativity is desired from organizational personnel. After selecting the best possible solution, the existing EVSM is revised to reflect what the process will look like after changes are made. Time-saving, improved quality and improvements in environmental measures are also estimated. The best solution is then launched as a pilot solution in the selected section of the concerned organization [S. 4.4].

Step 5: In the final phase, actions for sustainability enhancement of the company are maintained by incorporating performance measures that monitor, control, and improve the societal aspects, quality, and environmental performance [S. 4.5]. The entire process is re-evaluated using EVSM and LCA to find the level of waste and emissions reduction. In this step, various observations, data collection, and control charts are used to re-assess quality levels as well as water, electricity, material consumption. If re-assessed performance parameters are better than in the measuring step, then the selected solution is adopted and sustained. Otherwise, the Out of Control Action Plan (OCAP) is initiated to select an appropriate solution. Once a potential solution for pilot project has been sustained for a long duration, same is commenced in other sections of the company.

5. Framework testing

To test the GLSS framework, the authors considered a manufacturing company located in the national capital region of India. The organization is an original equipment manufacturer of fastening components, ISO: 9001.2008 and QS14001 certified and aims to have high customer satisfaction through the delivery of high specification components.

5.1 Identification and outline sustainability-focused GLSS project

A GLSS project execution needs a well-dedicated team possessing complementary skills. Here, the team comprised an LSS expert, a controller from top management, and three organizational members. The management of said company depicted its concern for capacity waste, emission reduction for a fastening component of a fuel injection system, and assessment of the social sustainability. The firm was not only concerned about traditional operational excellence parameters but also about environmental and social performance. The total installed capacity of the plant was 335,000 components per year. However, data from the last three years revealed the company was operating at 54.7% of total capacity. The company also had a high level of environmental emission with pt 26.75, and there was no measure for the assessment of social sustainability.

The manufacturing sequence of the fastening component for a fuel system starts with arrival of material at the central location for storage. The parts pass through different stages on the shop floor and, after due inspection, are delivered to final customer. To demonstrate a clear picture of input materials, suppliers, process flow, output, and customer, a high-level SIPOC diagram was constructed (Figure 4). Finally, project charter was created to document project objectives, goal, scope, the problem under consideration, and team members.

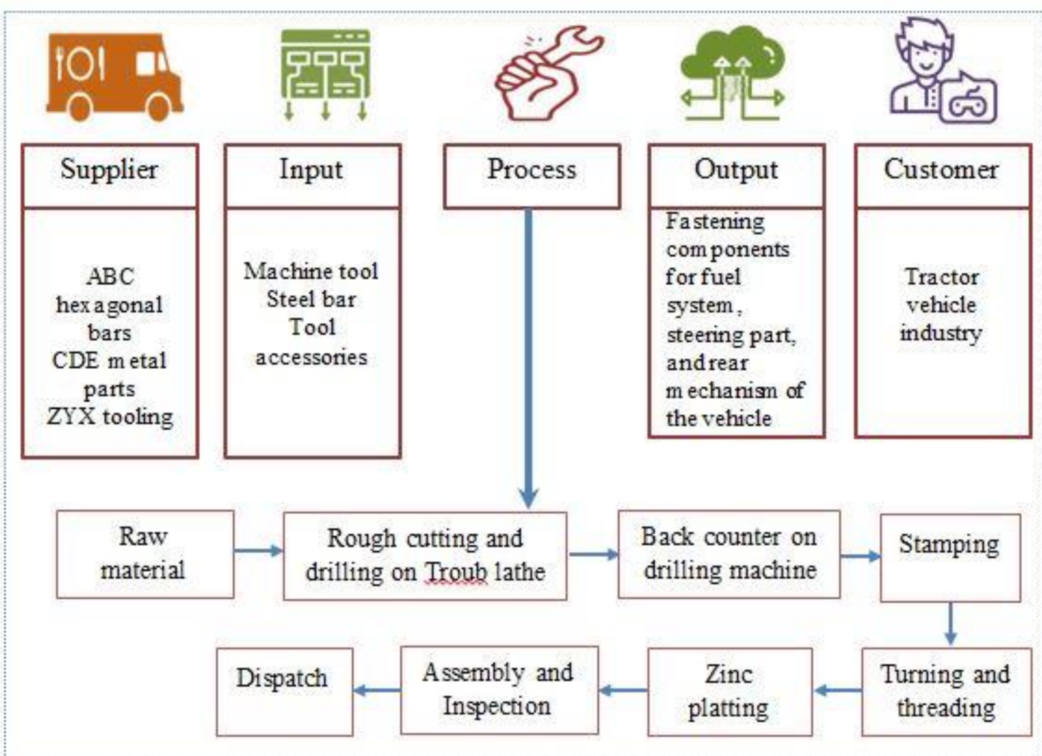

Figure 4: SIPOC diagram

5.1.1 Identification of critical parameters for capacity waste

Critical parameters to capacity waste were identified in consultation with experts (senior managers, general managers and production engineers) and industrial visits, and depicted in a radar chart illustrating percentage contribution of each waste (Figure 5). Based on the clear dominance of material handling waste, material handling actions in different sections were further investigated using a Pareto chart (Figure 6). The Pareto analysis suggested that the assembly section and lathe shop were the major contributors to ineffective material handling and capacity waste of the said organization.

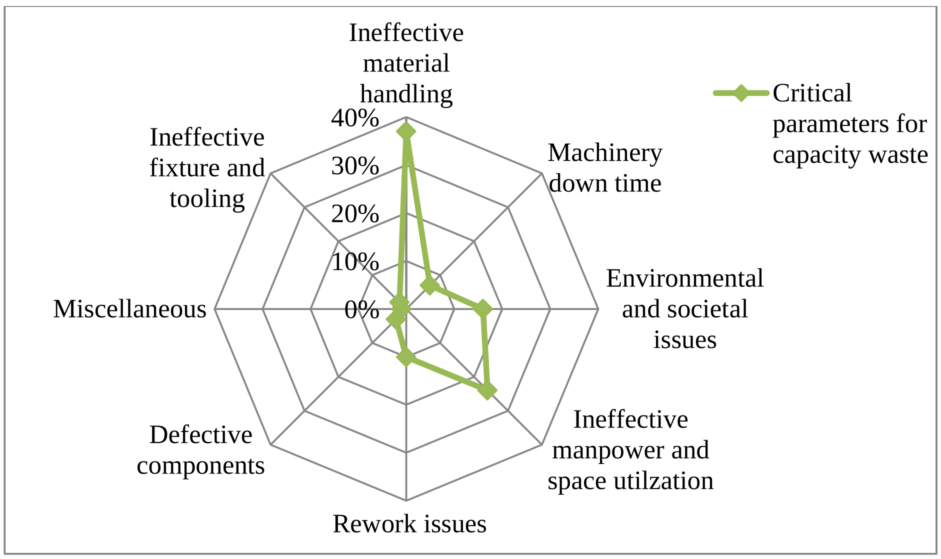

Figure 5: Critical parameters for high capacity waste

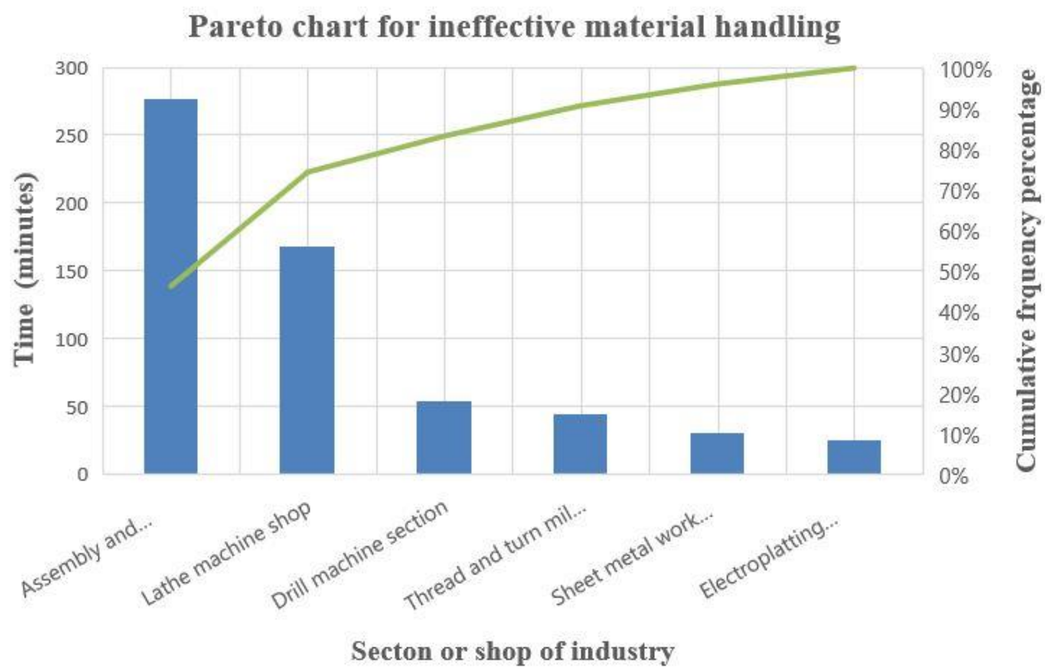

Figure 6: Pareto chart for material handling time of different shops/sections

5.2 Assessment of the current state of the system

Data was collected to determine the number of defects, and to conduct the EVSM analysis and the LCA. The EVSM analysis assessed the current state of the system in terms of lead time, raw material, water consumption, etc. Figure 7 illustrates the current state mapping while Table 3 presents critical process metrics.

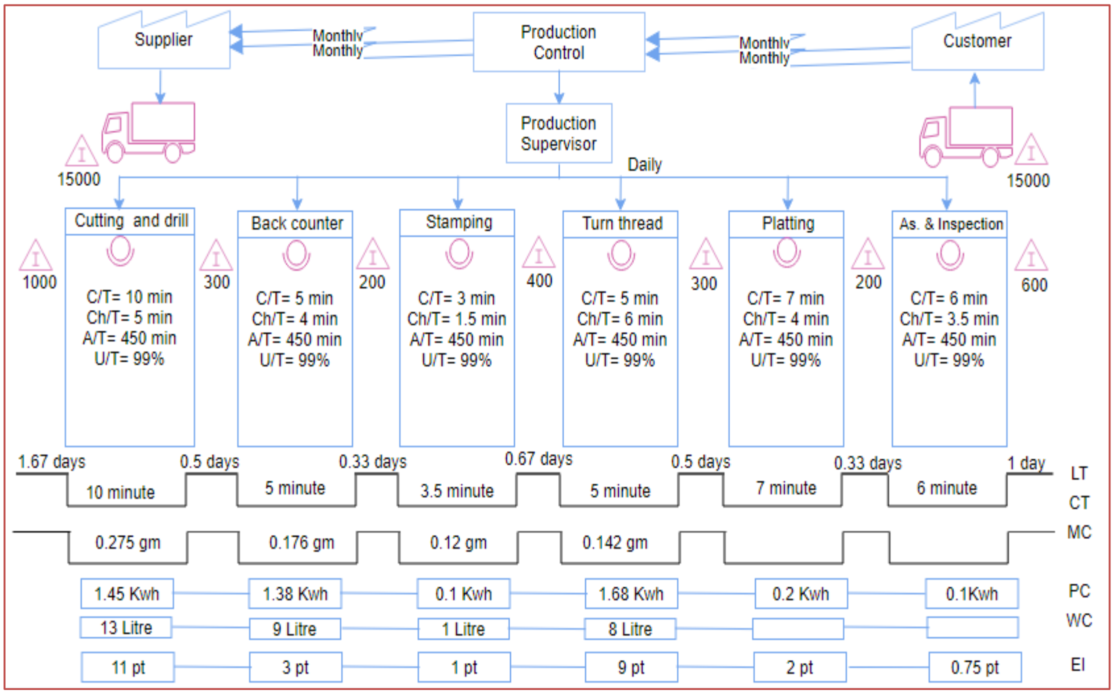

Figure 7: Environmental current state value stream mapping

Table 3: Process metrics

Metrics of process	Units
Cycle time	36.5 minutes/lot
Lead time	5 days
Water consumption	31 liters
Power consumption	4.91 kwh
Sigma level	3.62

LCA was used to assess the current environmental impact of the process by considering raw material, water, and power consumption. The environmental impact was expressed in a unit named Pt (point), which is a unitless number that depicts the intensity of impact (Ruben et al. 2018). Figure 8 categorizes the environmental impacts of the considered product considering all stakeholders: steel, water, electricity, turning process, drilling process, and threading processes. The overall environmental impact for current process was found to be 26.75 pt.

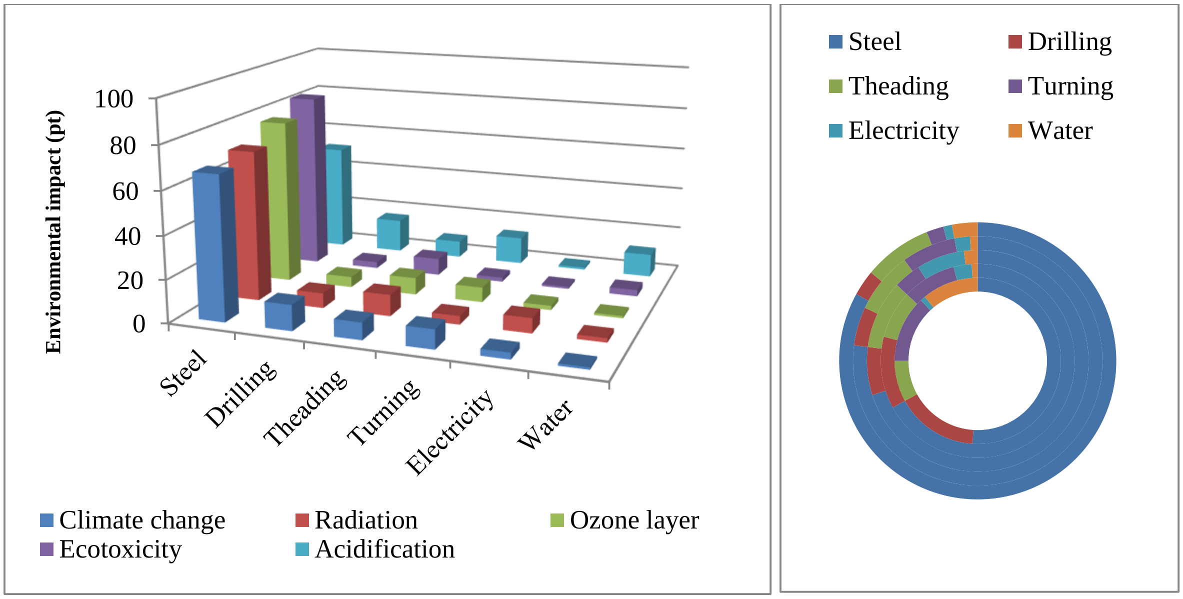

Figure 8: Categorized environmental impact using LCA

Monthly data related to the number of parts requiring rework in different sections of the company were also collected (Figure 9). This data indicated that two sections (lathe machine section and drill machine section) primarily contributed to rework in the company's operations.

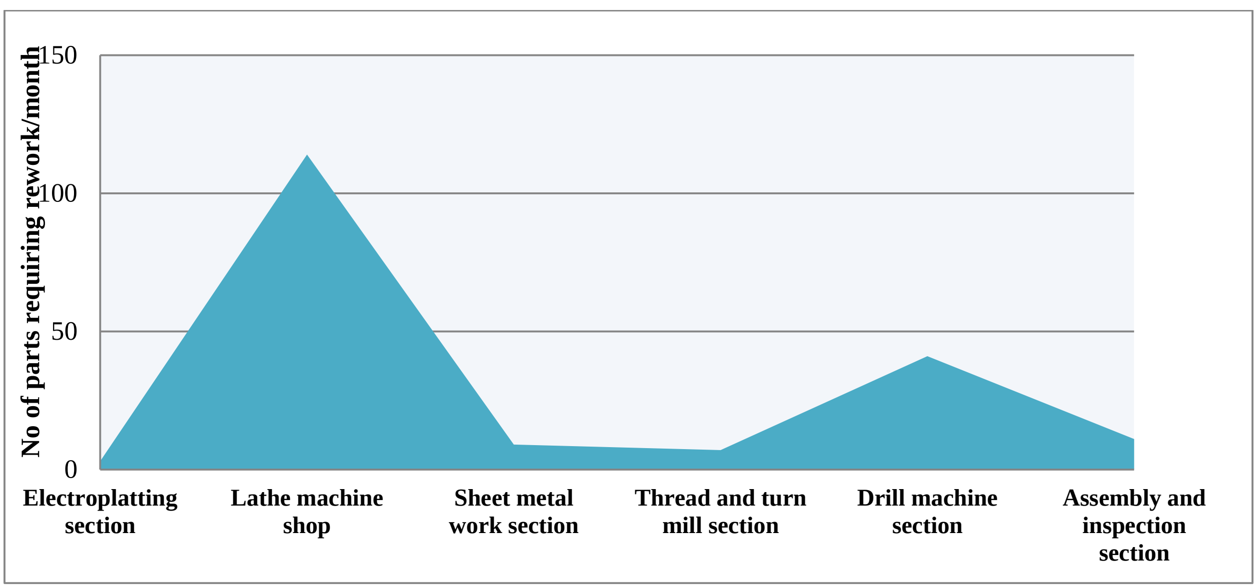

Figure 9: Section-wise number of parts requiring rework

Moreover, a social lifecycle assessment (SLCA) was conducted to assess the current social sustainability level of the considered industry, as presented in Figure 10. Social performance data was obtained through a questionnaire completed by experts (3 general managers, 2 workers, 2 academicians, and a local government officer). These opinions were then used to determine the contextual adjustment factor (CAF), contextual risk class (CRC), product social risk factor (PSRF), the weights of the social impact categories, and, ultimately, the social sustainability indicators of the company were then calculated (Table 4).

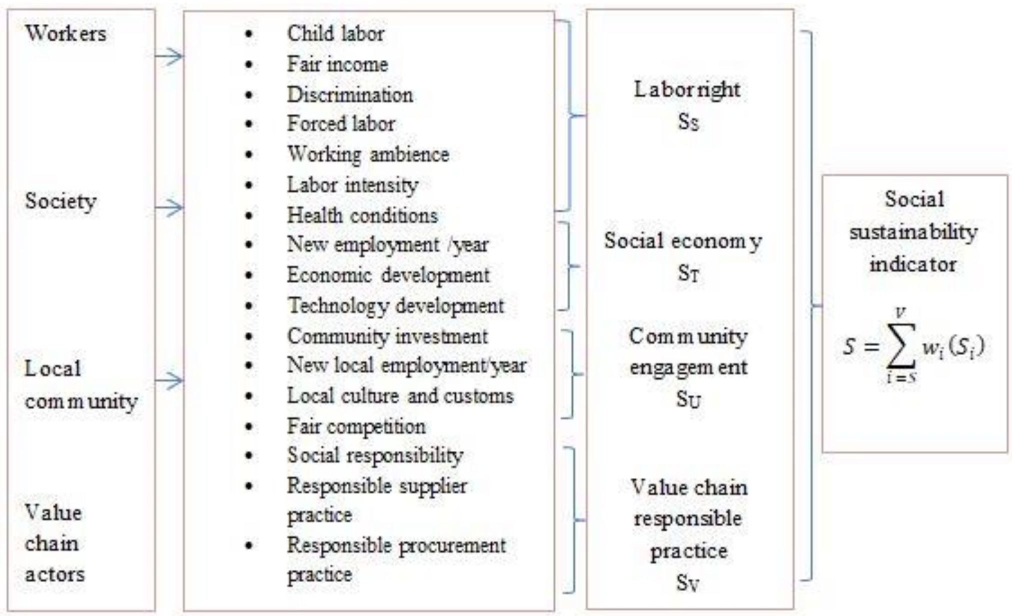

Figure 10: Social sustainability assessment mode

Table 4: Social sustainability indicators of industry

Category Impact	Z	ZZ	ZZZ	Z*ZZ*ZZZ	CSPS	$CSPS_{max}$	CFR	CAF	CSR	PSRF	PSRS	S_s	w	S
S1	0.7	2	2	2.8										
S2	2	0.7	1	1.4										
S3	4	1.2	1.2	5.76										
S4	0.7	2	2	2.8	46.36	112	0.58	0.4	0.23	0.6	0.16	0.84	0.2	
S5	4	2	1	8										
S6	4	1.2	2	9.6										
S7	4	2	2	16										
T1	0.7	1.2	2	1.68										
T2	4	1.2	1.2	5.76	15.44	48	0.67	0.7	0.26	0.7	0.18	0.82	0.4	81.9
T3	2	2	2	8										
U1	2	1.2	1.2	2.88										
U2	2	1	1.2	2.4	10.08	48	0.79	0.5	0.39	0.6	0.23	0.77	0.3	
U3	2	1.2	2	4.8										
V1	4	2	2	16										
V2	4	2	2	16										

V3	4	1	1.2	4.8	39.2	64	0.38	0.4	0.152	0.5	0.08	0.92	0.1	
V4	2	1	1.2	2.4										

It was determined that the said company had marginal social sustainability and positively contributed to society. Table 3 indicates that the company exhibited better social performance in ‘labour right’ and value chain responsible practice, whereas it presented a lower performance in both social economy and community engagement.

Combining the data from all the analyses led to the identification of the following areas as focus for further investigation in the next phase:

- Ineffective material handling: Inspection and assembly section
- Unnecessary employee movement and space utilization entire company
- Rework: Lathe machine shop and drill section
- Environmental footprint: entire company
- Social sustainability: Society and local community parameters

5.3 Determine the root reasons for wastes and inefficiencies

A cause and effect (C&E) analysis was initiated to explore ineffective material handling in the assembly section (Figure 11). The brainstorming sessions were conducted with middle and top managers of the company.

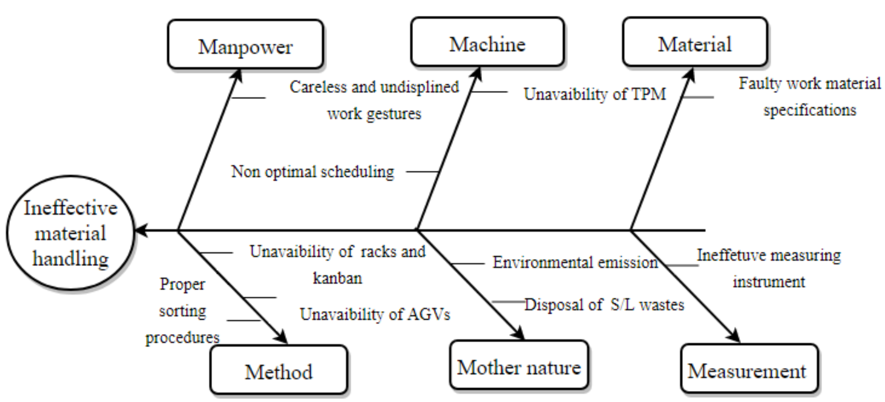

Figure 11: Cause and effect diagram of ineffective material handling

It was determined that ten causes/factors were responsible for poor material handling (Table 5). To determine the critical factors among those identified, a grey relational analysis (GRA) was performed. GRA offers distinct advantages over other methods as it provides opportunities for change in the number of parameters and transformation into a computer algorithm for a quick solution (Li et al. 2019). Table 6 depicts the ranks of factors responsible for ineffective material handling, revealing ‘unavailability of racks and Kanban system’ and ‘proper sorting procedure’ as the most critical factors.

Table 5: Factors responsible for poor material handling

No.	Factor responsible for ineffective material handling	Label
1	Faulty work material specifications	FR1
2	Non-optimal scheduling	FR2
3	Unavailability of TPM	FR3
4	Unavailability of AGVs	FR4
5	Proper sorting procedures	FR5
6	Environmental emission	FR6
7	Careless and undisciplined work procedures	FR7
8	Unavailability of racks and Kanban system	FR8
9	Disposal of S/L waste	FR9
10	Ineffective measurement system	FR10

Table 6: Prioritization of ineffective material handling factors using GRA

Label	CR1	CR2	CR3	CR4	Grey Relational Grade	Rank
FR1	0.333	0.500	0.500	0.600	0.483	7
FR2	0.538	0.429	0.400	1.000	0.592	5
FR3	0.368	0.500	0.667	0.500	0.509	6
FR4	0.636	0.750	1.000	0.545	0.733	3
FR5	1.000	0.600	1.000	1.000	0.900	2
FR6	0.333	0.333	0.667	0.353	0.422	9
FR7	0.368	0.600	1.000	0.429	0.599	4
FR8	0.778	1.000	1.000	0.857	0.909	1
FR9	0.538	0.500	0.400	0.333	0.443	8
FR10	0.467	0.375	0.333	0.429	0.401	10

Chips collections at tool-work piece interface and burr marks at work surface were identified as root causes for rework by using the 5Why analysis. The project team also conducted a 5Why analysis to investigate ineffective manpower movements and space utilization. This analysis determined a faulty plant layout led to ineffective manpower movements as well as space utilization.

Furthermore, the project team critically investigated different sections of the company and conducted different brainstorming sessions with the supervisor and working personnel, from which they identified excessive material, water, and power consumption as major sources for poor environmental performance. It was also established that, for increased social sustainability, the company should work on the society and local community aspects. Table 7 presents the outcome of this phase of GLSS execution and the various areas and reasons that needed attention in the next step of the framework.

Table 7: Prominent reasons to address for improvement in sustainability

o.	Areas	Section/Aspects	Prominent reasons
1	Ineffective material handling	Inspection and assembly section	Unavailability of racks and Kanban, part sorting procedures
2	Ineffective employee movement and space utilization	Overall	Ineffective plant layout
3	Rework	Lathe machine shop and drill machine section	Accumulation of chips at tool-workpiece interface and burrs at the work surface
4	Excessive raw material, water and power consumption	Overall	Incorrect machining parameters, non-availability of proper recirculation system and cleaning system, ineffective tooling
5	Social performance	Society and the local community	Community investment, new employment overall, new employment from the local community

5.4 Search for the best solution and implement the same

Based on project team observations, and in due consultation with stakeholders and management of the company, several solutions were implemented, as discussed in the following sections.

5.4.1 7S implementation for ineffective material handling

A comprehensive discussion with middle and top-level management led to a suggestion for adoption of 7S measures in the assembly and inspection section to improve the company’s sustainability dynamics. 7S (5S+ Sustainability + Safety) principles were used to create an organized, clean, safe, and environmentally friendly workplace. In 7S implementation, during Seri, all parts and equipment were sorted to reduce search time. After sorting, parts were set to arrange work items in line with shop floor’s physical workflow, and make them easy to retrieve for use. To have a conducive and clean work environment, regular cleaning of workplace to remove dust and grim were initiated. Figure 12 depicts work area of assembly section before and after execution of 7S.

(a)

(b)

Figure 12: Work area of assembly section before and after implementation of 7S

The execution of 7S led to a daily saving of nearly 120 minutes in the company's operations. The adopted work practices were standardized to create a consistent way of implementing tasks performed daily, including sort, set in order, and shine. Standardization made the process and methods more realistic and accurate to make the right things, the right way, and right every time. Visual process control systems were adopted to facilitate workers and other organizational members keeping things at designated places. The work standards for a regular check of medical kits and regular updating of rules on environmental sustainability according to current regulations were regularly adopted to ensure success of 7S. To ensure sustainability and safety in company, apart from practice of 5S, checks for removal of accidents and covering of areas of machine tool prone to high-temperature chip were also performed. A 7S audit sheet was constructed to eliminate wastes and associated risks at the workplace. The elements that got 'No' on the audit sheet were checked, and an action plan was initiated to convert the same into a 'Yes' in a sequential order starting from sort to sustainability. After action plan implementation, the audit was reconducted to ensure that all responses were in the form of 'Yes'. Finally, the updated audit sheet was displayed in the work area for ongoing use. The 7S audit enabled the organization to link its lean initiatives with safety measures and provided ways for constant success through sustainable profits.

5.4.2 Kaizen activities

Kaizen activities were planned to reduce setup time, rework issues, and enhance social sustainability.

5.4.2.1 Kaizen activity for reduction in set up time

Initially, raw materials bars were transferred with an overhead crane system to a dedicated cutting machine in the lathe section. The raw material bar was put into a dedicated fixture and then placed on the cutting machine to be cut into small parts after providing proper clamping and location. The clamping and setting work consumed considerable time as bar size changes. Thus, there was a need to provide a quick changeover and reduction of set up time. For this, an investigation and change for better analysis of three probable techniques were conducted, as depicted in Table 8.

Table 8: Investigation of set up techniques

Technique	**Description**	**Adoption feasibility**
Advance part preparation	Equip with a slew dedicated fixture to reduce changeover time	Can be used for a short duration when handling and total production cost is high
Equipment modularization	Make changes in the existing fixture to meet functional requirements	Time reduced for set up but demands quick modifications
Equipment modification	Perform redesigning of fixture and replace the existing one with the modified one	High saving in set up time through redesigning and modification of existing fixture

So, as the industry has to meet the regular demand of the customer and based on the long term gain the said fixture was redesigned and refabricated to replace the existing one with a modified one.

5.4.2.2 Kaizen activities pertaining to rework issues

Accumulation of chips at the tool-workpiece interface and burrs at work surface were major factors behind rework in the lathe machine section. To address this, various kaizen activities were conducted such as a carbide tool was placed, locators were provided and pins aligned properly to reduce the dislocation of parts. To facilitate removal of chips and burrs from workpiece and tool interaction areas, pressurized air guns were incorporated for enhanced tool life and reduction of rework (Figure 13). Initially, chip acculturation rate at tool workpiece interface was high but due to installation of air pressure gun it reduced considerably, which resulted in high tool life and better surface finish

(a)

(b)

Fugure 13: Lathe machine tool before and after incorporation of air pressure gun to remove burrs at tool work piece interface

5.4.2.3 Improvements for societal dynamics

SLCA revealed that said industry exhibited marginal social sustainability and was lagging in employment and community investment. In order to improve social sustainability various kaizen activities have been suggested. As effective community performance in long-term drives shareholder value creation, industry should invest more in community, such as through supporting local non-profit organizations. The industry must provide on the job training to the students of the local areas in different aspects of production so that the same trained students can be potential engineers for the said industry. Such actions will increase the organization's ability to recruit potential talent from the local community, leading to improved social sustainability. Besides, the industry can also plan other kaizen activities pertaining capacity building through education to the local people in different sub parts, parts, and other components in terms of their usage and disposal. Such activities will enhance the awareness of the local community, which in the long run will increase the sales of the products. The organization should develop a memorandum of understanding with academic and research institutes to get opportunities for technical knowledge, and capacity enhancement through the training programs. This collaborative strategy will lead to a reduction in the organization’s expenses that otherwise go in vain by providing training from the outer agencies.

5.4.3 Reduction in environmental impacts

Reduction in the overall environmental impact was achieved through a decrease in the use of raw materials, lubricant consumption and power usage (Table 9). Incorporation of power-saving measures led to the reduction of power from 4.91 kwh to 4.06 kwh. The overall cost of the product was also reduced due to savings in overall power consumption. Water consumption was also reduced from 31 lt to 23 lt due to incorporation of a recirculation water system and non-sticky lining for the water tank. From the materials sustainability perspective, different analyses and tests were performed for the fastening component to obtain an optimum design. This led to reduced raw material consumption from 0.713gm to 0.586 gm. After implementation of all the improvement actions pertaining to green technology, environmental impacts were again calculated using LCA (Figure 14), indicating a reduction from 26.75Pt to 19.7Pt.

Table 9: Actions for improvement in environmental sustainability

Factors	**Implemented green technology actions**	**Suggested actions**
Material usage	Excess scrap material usage minimized by altering process parameters	Use a different material that leads to lesser environmental impact
	Input material consumption reduced by changing product features	
Water usage	Closed-loop water circulation system incorporated to reduce coolant consumption	Adopt conventional techniques of cleaning with the use of steam to minimize water consumption
	Reduction of water loss due to evaporation from water storage tank achieved by lining tank with a non-stick material	
Power usage	Experiment and investigation were done on lathe and drill machine tools with different feed, speed and commissioning of the electrical unit	Incorporate power management system (PMS) to recognize, track, and improve wasteful energy practices

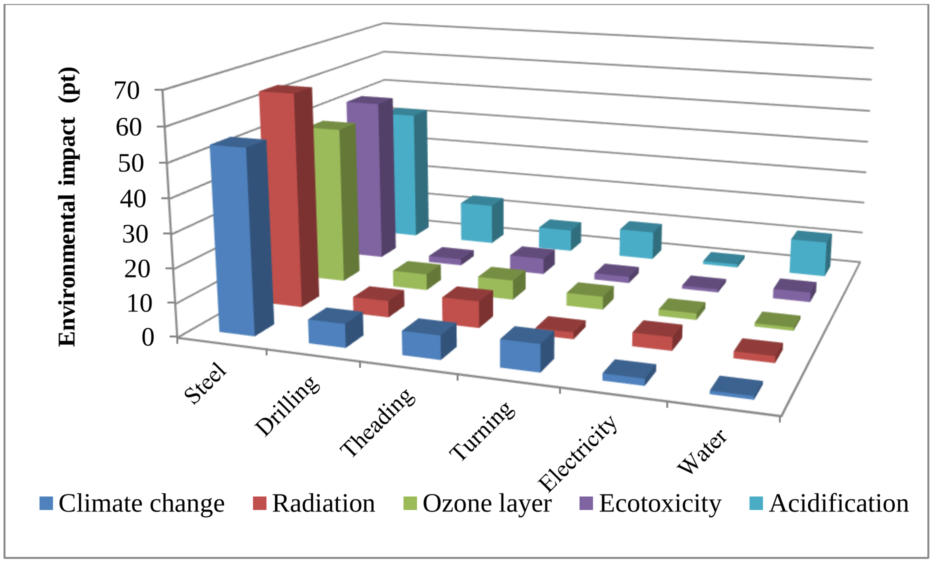

Figure 14: LCA after incorporation of improvement measures

5.5 Sustaining the adopted solutions

Following the improvement actions, follow-up activities and data were noted for the next six months to check whether improvement actions were sustained in the long term. Different metrics related to wastes, environment, and defects need to be assessed again to check for any deviation from the improvement phase. The gains obtained from the execution of the GLSS project were communicated to all members involved in the project and a flow chart of their roles and responsibilities was prepared to sustain improvements. Performance measures in terms of observation, interaction, data collection and charting were formulated to track the performance of the system. Based on investigation of the current state VSM, further improvement actions were planned and implemented to improve different process metrics. After the successful execution of suggested actions, the future state of VSM was constructed (Figure 15).

It is also essential to provide sufficient training and education to personnel in methods required to sustain adopted best practices. In the present study, tools such as Poka Yoke, visual management, total productive maintenance, and 'out of control' action plans were used to control key input-output variables related to operational and environmental practices. The said organization will continue following recommendations made and visually monitoring prominent deliverables to exhibit better control over the process. This will enhance the likelihood to further improve the operational, social and environmental dynamics of the company.

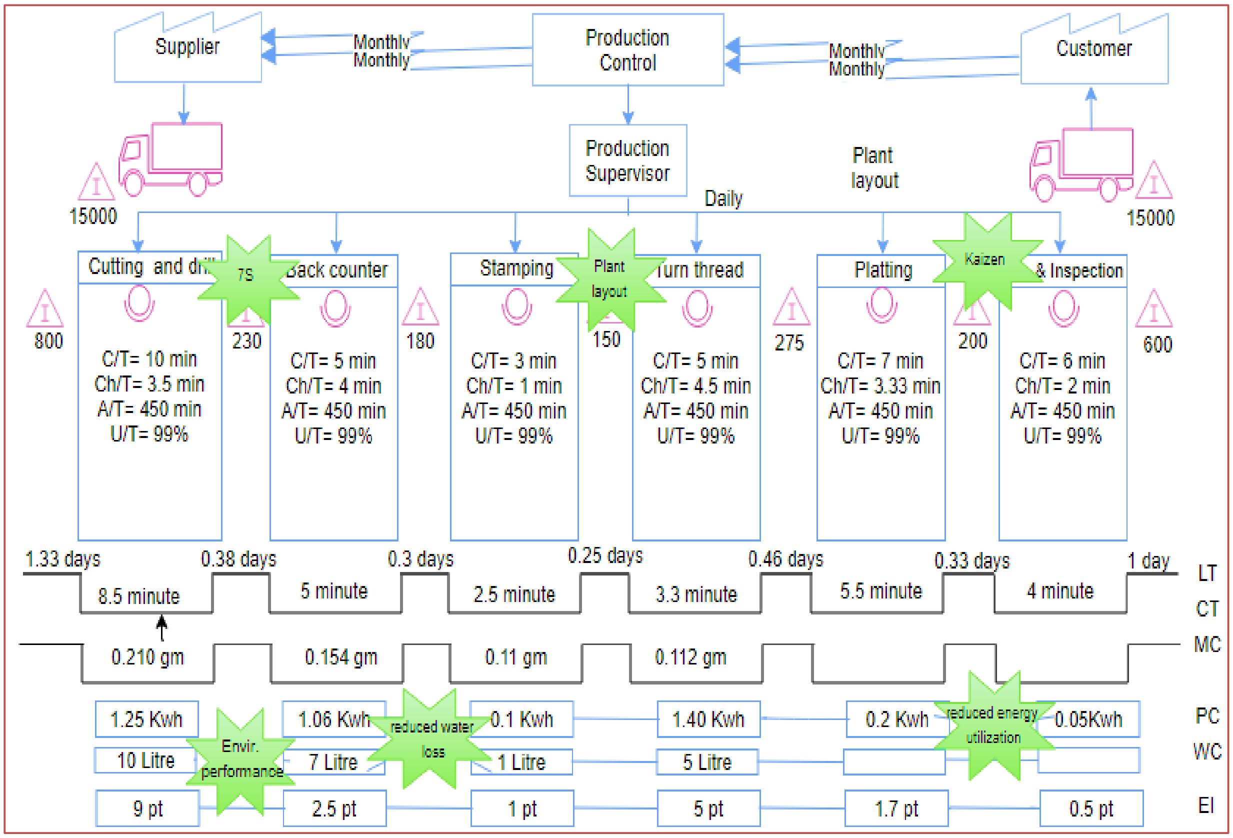

Figure 15: Future state value stream mapping

6. Results and Discussion

Through the successful execution of the GLSS program through the adopted framework, the said company improved its operational performance and environmental sustainability. Improvements were observed in process and environmental parameters through the deployment of the proposed GLSS framework. The improvements observed referred to lean metrics such as cycle time and lead time. The systematic implementation of process Kaizen, 7S, creation of effective plant layout, and Kanban resulted in a reduction of cycle time from 36.5 minutes to 28.3 minutes (22.47%). Furthermore, lead time was also improved by 19%, which led to a considerable saving in the delay of the end product. The applied improvement actions brought a considerable improvement in environmental metrics, particularly on raw material consumption, coolant use, energy utilization and hence overall environmental impact. Raw material consumption, energy utilization, and coolant consumption were reduced by 17.81%, 17.31% and 25.81% respectively. The cumulative effect of reduction in environmental metrics resulted in the reduction of environmental impact by 26.40%. Moreover, the systematic application of different improvement methods brought considerable improvements in the existing capacity utilization of the plant by 18.16%. The sigma level of company was improved from 3.62 to 4.01 through a reduction in the number of components rejected. Table 10 summarizes the process metrics and the corresponding improvements before and after the deployment of the proposed GLSS framework.

Table 10: Process metrics before and after execution of the GLSS project

Process metric	**Before execution**	**After execution**	**Improvements (%) term**
Cycle time	36.5 minutes	28.3 minutes	22.47%
Lead time	5 days	4.05 days	19%
Environmental footprint	26.75	19.7Pt	26.40%
Material consumption/piece	0.713gm	0.586gm	17.81%
Energy utilization	4.91 Kwh	4.06 Kwh	17.31%
Coolant consumption	31 Litre	23 Litre	25.81%
Sigma level	3.62	4.01	10.77%
Capacity waste	46.30%	37.80%	18.16%

On other hand, improvement actions resulted in reduction of rework parts from 2172/year to 407/year. This contributed to a saving of $14,129/year from rework related issues. The comprehensive execution of the GLSS project resulted in a financial gain for the company in terms of savings worth $43,000/year. Table 11 shows the financial gains from the executed GLSS project.

Table 11: Monetary benefits from GLSS execution

Metrics	**Before GLSS execution**	**After GLSS execution**
Total number of components produced/month	15000	17057
No. of parts rework/year	2172	407
Rework cost/ piece	$4	$4
Total rework cost	$17,376	$3,256
Total revenue earned	$315,000	$358,000
Potential monetary saving due to GLSS project execution	$43,000	

The proposed framework can be used as a pilot framework for realization of GLSS in a single section or department of an organization. Moreover, the framework can be extended within an entire organization after its successful execution as a pilot project. The framework provides insights to industrial managers and practitioners to identify sustainability-oriented GLSS projects that exhibit the most potential for improvement in all aspects of sustainability. The proposed framework brings together different tools of Six Sigma, Lean, and Green technology to identify and assess different metrics related to wastes, defects, emissions and the social dimension of sustainability. The framework was developed for manufacturing companies and incorporates aspects of sustainability that have not been considered in previous studies. Ruben et al. (2017) developed a framework of LSS with environmental facets, but did not consider how the framework could be adopted by smaller organizations; moreover, the LSS framework did not consider societal aspects of sustainability. In the existing framework, stepwise methods to identify major reasons for various wastes and inefficacies have been found using C&E and 5 why analyses. The systematic identification of the prominent causes for wastes, emissions, and other inefficiencies will make industrial professions adept in search for continuous improvement plans in the future. Once the leading causes for wastes, environmental issues, societal issues, rework and ineffective material handling are determined, potential solutions are proposed, tested and the best solutions implemented. This step of the proposed framework makes companies arrange an interactive session with people from all levels of organization to unearth different notions and solutions for problems and propose solutions to adopt. Moreover, the GLSS proposed framework can contribute to making manufacturing organizations more capable to remove different non-value-added activities through incorporation of different Lean activities to remove operational issues such as rework, setup time, etc. The framework incorporates the application of LCA and SLCA to identify potential areas for improvement in the environmental and social dimensions of sustainability. Gohlami et al. (2021) used GLSS to improve operational as well as environmental measures but the developed framework lacks practical validity in terms of the use of Lean, Six Sigma, and Green technology tools. The systematic application and adoption of LCA and SLCA lead to the identification of different areas for improvement. The present study suggested different improvement areas to address environmental sustainability problems. These suggested areas and actions can be considered by manufacturing companies and managers in their respective organizations to make the manufacturing industry more responsive towards corporate social responsibility (CSR).

To validate the proposed framework, a fastening component manufacturing organization was considered. As being an implementation framework, it takes considerable time for its deployment and analysis of various metrics. The framework is generic, and hence it could be applied to various automotive component manufacturing and automotive organizations with similar cultures and operating conditions. However, to make it suitable for other manufacturing organizations, consideration of case studies in different industrial settings concerning size and type is needed. The elements and components of the framework have been designed in such a way that it would produce deliverables more effectively when applied to automotive industries. Moreover, the proposed framework with some modification in its existing steps and with inclusion of other tools can be considered suitable to adapt its application in other industrial sectors such as hospitality and healthcare, where similar operations exist.

6.1 Theoretical and practical implications

There is immense need to scale up the global response to estimate and improve social and environmental sustainability. GLSS leads to improved organizational efficacy through the reduction of wastes, emissions, and other non-value-added activities. This research provides both theoretical and practical implications towards a resilient manufacturing industry and society. Practitioners may use results to develop a thorough knowledge of the GLSS approach. The study facilitates potential researchers for systematic application of GLSS tools at different stages of GLSS project. The proposed framework will facilitate effective utilization of available resources and materials for improved environmental sustainability. Moreover, the framework provides an impetus to industrial managers to reconsider, source, and incorporate sustainability through the adoption of GLSS. Researchers can utilize the insights gained from this work to strengthen their knowledge to assess and improve sustainability dynamics. Moreover, the study provides a theoretical knowledge base by uncovering 'hidden' GLSS aspects. This work will benefit policymakers by facilitating the formulation of better and more effective policies that support the manufacturing sector in its sustainable development journey. Moreover, society will be promoted from the present work as GLSS successful execution leads to lesser rework, waste, and reduction in the current level of emission of the organization. Therefore, GLSS implementation not only leads to better health of industry personnel but also society.

7. Conclusions

Pursuits to improve social and environmental dynamics must be aligned with operational strategies to improve metrics such as process efficacy, quality, and financial gain. GLSS has been integrated with environmental and social aspects to reduce waste and consumption of resources as well as cultivate employee well-being. To achieve this, a generic framework with a step by step procedure is necessary to guide companies in implementing GLSS. The term 'generic' implies that the proposed framework could be applied to manufacturing organizations with similar cultures and operating conditions. The features and constituents of the framework have been modelled in such a way that it would bring the deliverables more effectively when applied to manufacturing companies. Successful execution of the proposed framework led to a reduction in the level of rework, defects, capacity waste, and environmental wastes in the said organization, together with an improvement in operational and monetary metrics. The framework also had a positive effect on social consequences (due to reduced environmental impact), as improvements were observed concerning human health and workplace safety.

To identify environmental improvements, data related to raw material usage, water usage and energy usage were collected and EVSM and LCA analyses were performed. The study also used a systematic SLCA model to estimate social sustainability and explore areas for further improvement. The study also contributes to the knowledge base of social sustainability assessment and provides actions to improve community investment through social metrics. Thus, this study contributes to attaining sustainable business practices by providing ways to harmonize among social, economic and environmental actions through the systematic development and adoption of a sustainability-focused integrated GLSS framework.

Despite several contributions, the present study has its limitations. The main limitation is the framework was tested in a single manufacturing organization. Future research work should focus on the wider application of the framework in different industrial organizations. Further, the framework has only been studied in the manufacturing sector; future researches should evaluate applicability of the framework in service industries. Future research could also consider methods to integrate mechanisms and models within the existing framework for increased employee utilization, customer engagement and community investment pursuits to yield and quantify improvements. Finally, researchers and practitioners could explore incorporating additional methods and tools into the framework for improved workforce management, and better process control/monitoring of health and safety of employees.

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