A framework for the systematic implementation of Green Lean Six Sigma to improve performance in the manufacturing industry

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Rajeev Rathi
National Institute of Technology, Kurukshetra

Mahender Singh Kaswan
Lovely Professional University

Vishwas Yadav
Maharshi Dayanand University

Gunjan Yadav
Prashanti Institute of Technology & Science

A framework for the systematic implementation of Green Lean Six Sigma to improve performance in the manufacturing industry

Vishwas Yadav, Pardeep Gahlot* and Raj Kumar Duhan

Department of Mechanical Engineering,
University Institute of Engineering and Technology,
Maharshi Dayanand University,
Rohtak, Haryana, India
Email: vishwas.rs.uiet@mdurohtak.ac.in
Email: pardeepgahlotuiet@gmail.com
Email: rajkumarjas@gmail.com
*Corresponding author

Mahender Singh Kaswan

School of Mechanical Engineering,
Lovely Professional University,
Phagwara, Punjab, India
Email: mahi622@rediffmail.com

Rajeev Rathi

Department of Mechanical Engineering,
National Institute of Technology,
Kurukshetra, India
Email: rathi.415@gmail.com

Gunjan Yadav

Department of Mechanical Engineering,
Swarrnim Startup and Innovation University,
Gandhinagar, India
Email: gunjanyadav86@gmail.com

Pawan Kumar and Varun Kumar

Lovely Professional University,
Phagwara, Punjab, India
Email: pawan.11522@lpu.co.in
Email: varun.kumar@hotmail.co.in

Abstract: Green Lean Six Sigma (GLSS) is an all-inclusive methodology that assists the optimal utilisation of resources, minimises waste, and imparts the pathway for sustainable development. This study proposes a novel five facet GLSS framework for the manufacturing industry to improve performance in terms of different sustainability dimensions. The framework has been designed based on three key dimensions: insights from literature, the experience of authors, and inputs from the case organisation members. The framework is validated in an Indian automotive component manufacturing organisation. From the effective implementation of the proposed GLSS framework, defects were minimised from 18,000 ppm to 7,000 ppm and environmental impacts were brought down from 44.70 Pt to 32.70 Pt. This study facilitates industrial managers and practitioners to adopt the GLSS approach to improve sustainability dynamics in the manufacturing industries.

Keywords: Lean; Six Sigma; green manufacturing; Green Lean Six Sigma; GLSS; framework; sustainability.

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Biographical notes: Vishwas Yadav is pursuing his PhD in Mechanical Engineering from University Institute of Engineering and Technology, Maharishi Dayanand University, Rohtak, Haryana, India. His areas of research are Green Lean Six Sigma, total productive maintenance, life cycle assessment, sustainability and green manufacturing. He completed his Master’s in Mechanical Engineering with specialisation in industrial and production from National Institute of Technology, Kurukshetra. He has a teaching experience more than six years. He is adept in optimisation and decision-making techniques like ISM, AHP, and BWM.

Pardeep Gahlot is working as an Assistant Professor in University Institute of Engineering and Technology, Maharishi Dayanand University, Rohtak, Haryana, India. He completed his PhD from University Institute of Engineering and Technology, Maharishi Dayanand University, Rohtak, Haryana, India. He has been associated with teaching over last 12 years. His areas of research are: production engineering, friction stir welding, engineering materials. He has presented many papers in national and international conferences and published articles in reputed journals.

Raj Kumar Duhan is working as an Assistant Professor in University Institute of Engineering and Technology, Maharishi Dayanand University, Rohtak, Haryana, India. He completed his PhD from University Institute of Engineering and Technology, Maharishi Dayanand University, Rohtak, Haryana, India. He has been associated with teaching over last 13 years. His areas of research are industrial engineering and manufacturing, automobile engineering, material science, composite materials. He has presented many papers in national and international conferences and published articles in various reputed journals.

Mahender Singh Kaswan is an Assistant Professor in the School of Mechanical Engineering Lovely Professional University, Punjab, India. He holds a PhD in Mechanical Engineering from Lovely Professional University, Punjab, MTech in Mechanical Engineering from National Institute of Technology Kurkshetra India. His research interests include Lean Six Sigma, life cycle assessment, Industry 4.0, and sustainable supply chain.

Rajeev Rathi is working as an Assistant Professor in the Department of Production and Industrial, National Institute of Technology, Kurkshetra, India. His areas of research are Six Sigma, Lean Six Sigma, Green Lean Six Sigma, LCA, sustainability and green manufacturing. As inspired researcher, he has presented many papers in national and international conferences and published articles in various reputed journals. He is adept in optimisation and decision-making techniques like ISM, preference ranking organisation method for enrichment of evaluations, best worst method, decision-making trial and evaluation laboratory. His research interests include Lean Six Sigma, green manufacturing, life cycle assessment, circular economy, Industry 4.0, clean technologies measures, and sustainable supply chain.

Gunjan Yadav is currently working as an Associate Professor and Head in Mechanical Engineering Department at Swarnim Startup and Innovation University (SSIU), Gandhinagar (India). He is having more than 12 years of teaching, training, consultancy, and research experience. He has had his education and training in mechanical and industrial engineering at BE and ME. He has completed his PhD from Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat. He has obtained MHRD-sponsored funding of 1.5 Lacs to pursue international projects.

Pawan Kumar completed his PhD in Machine Learning from the School of Computer Applications, Lovely Professional University, India. His research interests include machine learning, data analytics and performance optimisation. He is a life member of the Computer Society of India (CSI). Also, he is a life member of the Indian Science Congress Association (ISCA). He has qualified UGC-NET in computer science and applications. He has also qualified GATE in computer science and information technology. He has acted as a reviewer for several reputed journals including *Decision Support Systems* by Elsevier.

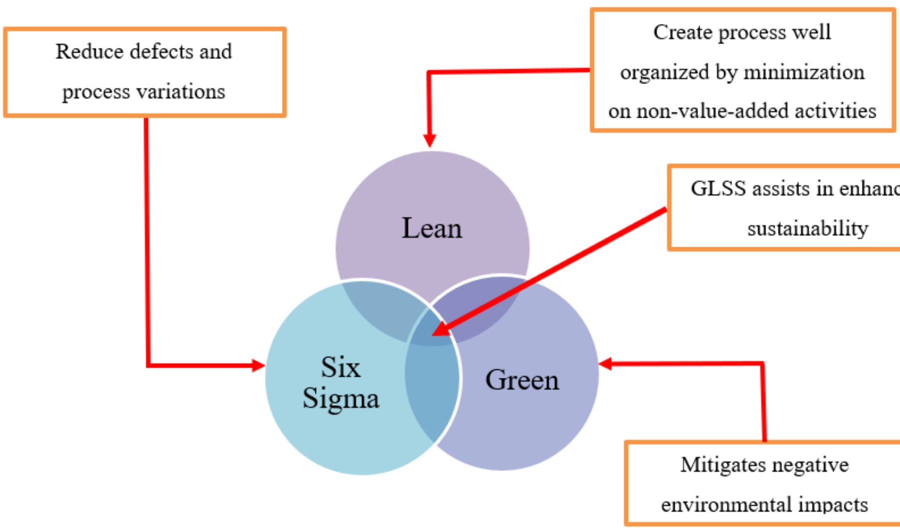
Varun Kumar is an Associate Professor in Lovely Professional University, Punjab, India. He holds a PhD in the Theory of Elasticity (Mathematical Physics) with a research experience of more than ten years. He has Master's degree in the Mathematics and has also qualified CSIR-NET. He has 15 years of university teaching to UG, PG and PhD students. He is a life member of the Indian Science Congress Association (ISCA).

1 Introduction

In an era of high competition to stay in the business, manufacturing organisations have to change their functional dynamics from traditional to eco-friendly. The human being-driven actions and quick industrial development have raised global surface temperatures to 1.5°C in several regions of the globe (Rathi et al., 2022a). Industrial organisations contribute to about 30% of greenhouse gas emissions (GHGs) (Kaswan and Rathi, 2021). This can be attributed to the conventional methods of operations adopted by manufacturing organisations (Kaswan et al., 2021). The enhanced level of GHGs will result in a surge of more than 20,000 deaths annually per °C (Jacobson, 2008). Thus, to persist competitive in the market and obey the environmental pacts the manufacturing sectors have to reduce their present level of emissions by implementing sustainable practices (Yadav and Gahlot, 2022). Therefore, the manufacturing sectors are expanding massive investment in research and development to evolve other ways of manufacturing high-specification eco-friendly products (Shokri and Li, 2020). In many manufacturing arenas, several methods have been proposed in the past such as green manufacturing, total quality management, value engineering, lean manufacturing, Six Sigma, Lean Six Sigma (LSS), Green Lean Six Sigma (GLSS) to attain functional excellence (Garza-Reyes et al., 2018).

GLSS strategy assists in the success of the organisation by methodical minimisation of wastes, GHGs, and process variation (Gupta et al., 2020). This approach discourses the contemporary problems of the organisation by the methodical implementation of related tools at distinct phases of the product attention (Kaswan and Rathi, 2020). Figure 1 illustrates the integration model of GLSS.

Figure 1 Integration model of GLSS (see online version for colours)



Source: Rathi et al. (2022b)

LSS leads to improvement in the performance related to economical dimensions of the sustainability but do not contribute considerably towards to ecological dimension (Rathi et al., 2022b). Further, LSS also not incorporate social aspects related to the sustainability that is also a pioneer aspect to remain competitive at the global platform (Mohan et al., 2022). Inclusion of green aspects fills this gaps and leads to the sustainable development of the manufacturing enterprises. In addition, there is a demand to incorporate societal facets into GLSS practices to focus on healthy work environment and exceptionally hard work practices. Furthermore, manufacturing sectors in developing countries seek to reduce operating prices and throttle overall in their ability to convert into durable goods. In literature no study related to GLSS that improve production rate environmental metrics and social metrics have been reported. For this research work tends to answer research question: How to construct a comprehensive framework to execute GLSS in the manufacturing environment and test the same for improvement in environmental, social and economical metrics? The proposed framework includes ecological aspects, life cycle assessment (LCA) procedures, social facets, and primary LSS tools in distinct phases. Every step of this framework comprises a set of specified activities that focus on reducing wastes and related environmental impacts. This framework assists the organisation in obtaining ecological benefits and operational improvement. The unique contribution of the article lies in proposing GLSS framework for a manufacturing industry to enhance performance dynamics. The proposed model was prepared based on three unique dimensions and has capability to improve manufacturing industry performance in terms of reduction of defects level, improve work space utilisation, and also provides measures to ascertain social sustainability.

2 Literature review

The green technology encourages manufacturing sectors to reduce their environmental impacts (Garza-Reyes, 2015). An abundance of literature has focused on the effects of green technologies like LCA, environmental management system (EMS), and design for environmental (DFE), on ecological performance (Al-Sheyadi et al., 2019). These techniques have pragmatic results in satisfying regulatory needs, and fulfilling customers' wants of environmentally-sound products (Prasad et al., 2016). This strategy aims to mitigate harmful ecological effects like hazardous wastes, air emissions, pollution, health prospect to human beings, and environment and power and resource conservation (Kaswan et al., 2022). The lean concept is employed to minimise waste in almost every section of the industry (Thakur and Mangla, 2019). Industries execute this strategy to generate value for consumers by reducing waste and lead time and enhancing process flow (Singh et al., 2021a, 2021b). These tools will facilitate organisations in attaining functional performance along with achieving environmental objectives (Erdil and Arani, 2019). Six Sigma concept is employed to minimise the defects up to 3.4 parts per million opportunities, and the word 'sigma' is utilised to express variations. The primary aim of this approach is to reduce variations and defect mitigation (Andersson et al., 2006). Even though minimising environmental waste is not the prime aim of this strategy, it can attain environmental performance like decreasing air emissions, electricity consumption, and wastewater (Chugani et al., 2017). However, Six Sigma does not directly address issues related to environmental and social sustainability (Rathi et al., 2022c).

An unrequired movement of raw material, work-in-process, and finished products are assessed as waste from both green and lean points of view regarding electricity consumption, gaseous emission, and excessive utilisation of resources (Prashar and Antony, 2018). The correlation between green and lean not only attains the environmental benefits but also minimises cost by waste reduction (Shokri and Li, 2020). Deployed on the common purpose of waste reduction, these have been integrated into a common approach (Campbell and Sigalov, 2022). Moreover, Lean and Six Sigma have been integrated into a joint strategy to achieve environmental benefits by minimising waste (Kaswan and Rathi, 2021). The substantial general features of LSS are waste reduction, continuous enhancement, and satisfaction to the customers (Yadav et al., 2020). The correlation between these three approaches of GLSS can be better realised by their intrinsic features of satisfaction of customers by waste minimisation and value addition (Ershadi et al., 2021). Every approach in GLSS overcomes the drawbacks of another system to impart value by recognising and eliminating wastes that positively impact the organisation's environmental performance (Yadav and Gahlot, 2022). In terms of the ecological impacts of these approaches, the green concept primarily emphasises environmental sustainability and resource conservation as of its key aspects (Gandhi et al., 2018). Lean preserves resources by minimising waste, so, is identified as an ‘eco-friendly technique’ (Yadav and Desai, 2017). Identically, Six Sigma describes defects as waste material, area employed, safety matters, and electricity utilised (Gedam et al., 2021).

Table 1 Major studies related to GLSS

Sr. no.	*Author*	*Year*	*Description*	*Limitations*
1	Zhang and Awasthi	2014	Presented a framework that integrates Six Sigma and sustainability. It completely describes imperative steps to attain exactly sustainable development.	The main drawback of this framework was that it did not emphasise economic growth.
2	Ng et al.	2015	Proposed a methodology for executing green and lean manufacturing employed on its metrics.	The major limitation associated with this study was that the tools and techniques that were utilised in this case observation; can not be used for other case research
3	Cherrafi et al.	2016	Proposed a framework that efficiently leads the industries by five-stages and 16-step processes to successfully combine and execute the GLSS strategy to enhance their environmental performance.	The key drawback associated with this model was that delicate operations could be elaborated to enhance by this method.
4	Ben Ruben et al.	2017	Presented an LSS framework with ecological considerations to simultaneously minimise all-inclusive defects and ecological effects to enhance the organisation’s functional and environmental performance. This framework is deployed on the DMAIC cycle of the Six Sigma strategy. The LSS framework is authenticated with the help of a case study that is carried out in an Indian automotive component manufacturing industry. The study reveals that internal defects were dropped down from 16,000 ppm to 6,000 ppm, and ecological effects were also minimised from 42 Pt to 32 Pt.	The major limitation of this study was that the LSS framework can be employed only for automotive component organisations and definite industrial sectors working with analogous industrial operations
5	Caiado et al.	2018	This manuscript presents a critical review of LSS approaches and underlines their significance to attain sustainable services. This article also provides a comprehensive GLSS framework seeking to assist practitioners to detect the way of standardising it in several types of services, by identifying nine critical factors for its execution.	The major drawback of this review was that LSS methodology was restricted only to service sectors.

Table 1 Major studies related to GLSS (continued)

Sr. no.	*Author*	*Year*	*Description*	*Limitations*
6	Talapatra and Gaine	2019	Presented and executed GLSS framework for jute industry to reduce defects, carbon footprints and energy utilisation.	The proposed framework completely emphasised jute industry and did not include societal aspects.
7	Kaswan and Rathi	2020	This manuscript is concerned with the integration and development of the GLSS framework. GLSS integration was presented dependent on conceptual factors, and the GLSS framework was presented dependent on DMAIC methodology. The developed framework imparts a way to implement the GLSS approach by a proper selection of the project.	The major drawback of the current study was that the framework of GLS has not been tested practically.
8	Yadav et al.	2021	This article is concerned with integrating and developing the GLSS framework in the manufacturing environment. Integration of the GLSS approach has been presented on intangible features like enablers, toolsets, etc. This article also presents a five facet GLSS framework for an industrial organisation to increase organisational sustainability.	The major drawback associated with this study was that the GLSS framework had not been authenticated with the help of a case study.
9	Kaswan and Rathi	2021	The purpose of this manuscript is to critically review the GLSS strategy simultaneously with readiness measures, failure factors, integration, and implementation of the framework. This study also presents a methodical GLSS framework with the related toolsets to encourage industrial managers and practitioners to execute this sustainable strategy..	The limitation of this study was that the GLSS framework had not been probed practically
10	Rathi et al.	2022b	Develop framework for GLSS for capacity waste reduction in the fastening component industry	The key drawback associated with this study was that the framework formed from the literature and to consult with the industrial personnel. Furthermore no techniques and actions were dispensed to modify defects level, societal sustainability of considered industry.

Previous studies have emphasised theoretical frameworks, but these have required pragmatic validation and experimental substantiation. Ruben et al. (2018) presented 'framework' of LSS with ecological features but could not discourse on how proposed 'framework' can be accepted by small-scale establishments. Furthermore, presented GLSS framework did not take into consideration the social facets of sustainability.

Gholami et al. (2021) employed this approach to enhance the functionality and ecological facets nonetheless presented framework wants practical authenticity in utilising LSS tools and LCA toolsets. Thus, past studies claim the research for the GLSS framework is non-specific, employed in a distinct context, and includes all facets of sustainability. Furthermore, several projects have a high prospect of execution failure of LSS sustainable frameworks (Singh et al., 2021a, 2021b). Thus, contribute to production literature; this study contributes to the restricted body of knowledge in the fields of GLSS and sustainability by developing and executing an GLSS framework that industrial organisations can use to enhance performance dynamics. Table 1 depicts major research work pertaining to GLSS.

2.1 Research gaps

The literature shows that execution of 'LSS' assists to positive results on environmental and economic concert. But, incorporation and execution of Green approach with this concept are not divested of tasks. Scarcity of finance for environmentally sound technology projects, lack of support from top management, shortage of assets, inaccessibility of equipments and practices, and over-focus on profits, further avert powerful execution of sustainability-orientated initiatives. GLSS literature reveals that focuses has been limited to ecological and financial aspects of sustainability but that the social component was not noted. Furthermore, industrial sectors in emerging countries require to open the restrain their ability for minimising functional costs and providing high specification ecological products. In the literature, there is no evidence of a committed GLSS framework that assists in the mitigation of environmental impacts and increased capacity utilisation together with improved social facets. Therefore, the noted literature gaps have dispensed path for the current study.

3 Proposed framework for GLSS execution and adopted methodology

GLSS framework was evolved dependent on three design dimensions. The first design dimension comprised of action of perusing characteristics, the main cause for development, and appropriateness of several GLSS execution frameworks pointed up in last section. This secured merger of utmost recent and specific conceptual knowledge in developed GLSS framework.

Lastly, the third design dimension incorporated the consideration of appropriate inputs from the industry. The professionals dispensed valued feedback and criticism to improve pertinency and adulthood of framework of GLSS. Afterward, the developed framework was probed in an automotive component manufacturing industry.

The GLSS framework was developed to inscribe problems associated with ecological and quality actions of projects and enhance functional subtleties of industrial sectors. Every step of the attainment of the GLSS framework has several activities that minimise waste and related ecological impacts. The conceptual facets of the developed GLSS framework are discussed below:

Step 1 This step of developed framework is concerned with recognising and delineating the adopted project (Section 4.1). The scope of the project is considered to explore ecological, social, and quality implications. The requirements, preferences, and presumptions of the business and customers are clearly stated in terms of VOB and VOC to recognise the expectations from the product being manufactured. This has been recognised from VOB and VOC analysis that the firm needed high-level customer satisfaction, capacity usage, and worker engagement while customers want high specification eco-friendly products at a reasonable cost. In this step, the subsequent process of manufacturing, SIPOC diagram, and project charter dispenses a complete understanding of several aspects of the adopted GLSS project.

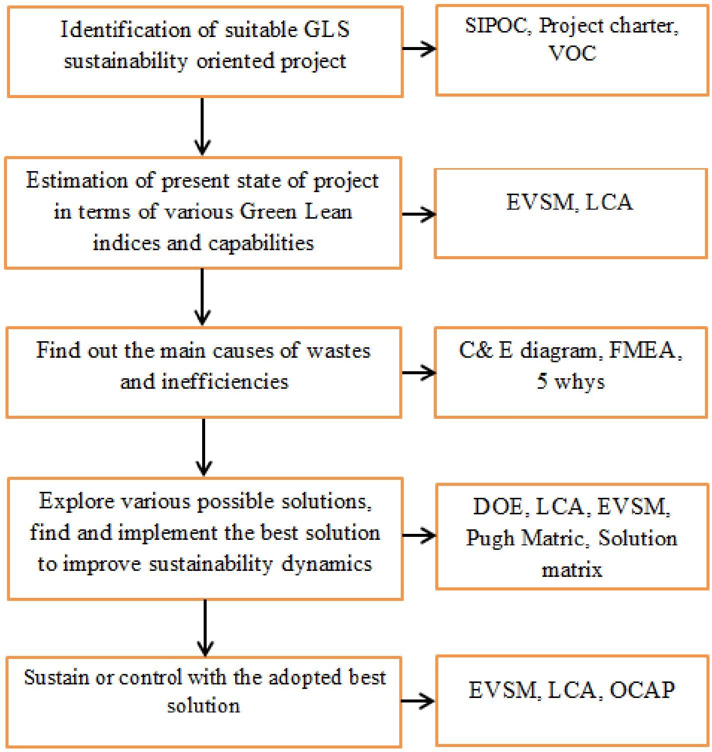
Step 2 In this step, data collection was carried out to represent present state of the system and data corresponding to defects and inefficiencies (Section 4.2). Moreover, EVSM analysis was employed to evaluate the current state of the project concerning lead time, raw material consumption, water consumption, etc. LCA was also utilised in this phase of the GLSS framework to estimate the current environmental impacts of the process. The data prevailing to rework was also gathered to find out shop's critical to rework problems.

Step 3 This phase focuses on recognising the root causes of waste and inspecting the problems and process inefficiencies (Section 4.3). Based on the measure phase, reasons for inefficient material handling, rework, low environmental performance, and enhancement in societal sustainability are recognised. Tools like brainstorming, C&E, 'FMEA and 5 why analysis are' deployed at this stage to determine probable reasons for defects. When the potential reasons are recognised, then the quest is dispersed to obtain crucial contributors for wastes and inefficiencies.

Step 4 In this phase, several solutions are recommended and the best solutions are recognised and implemented to mitigate root causes of waste and inefficiencies (Section 4.4). Each suggested solution has been executed in such a way that an appropriate recording can be done to compare with previous results. The training has been provided to employees and managers of the organisation from time to time for the effective execution of the GLSS approach. Tools such as DOE, Kaisen, and other process enhancement methods are deployed for planning the enhancement activities associated with productivity and quality.

Step 5 In this step of GLSS implementation, enhancements obtained are registered to sustain the improvement actions (Section 4.5). Now, the enhanced process is handed over to the process owner along with the whole procedure for sustaining the gains. This step confirms that gains attained from the enhancements made are sustained after the accomplishment of the GLSS project. In the beginning, it is imperative to document and regulate the process to represent a perfect image of the improvements made and how to maintain these improvements.

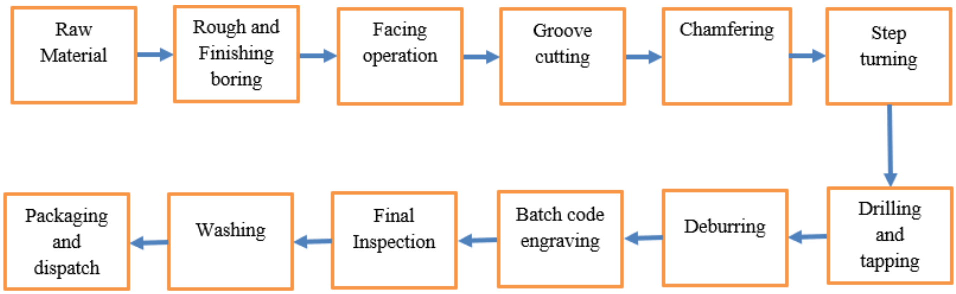
Figure 2 GLSS framework (see online version for colours)



4 Application and validation of the proposed GLSS framework

The work is carried out in a major automotive component manufacturing industry which is situated at Gurugram, Haryana (India). The considered organisation produces about 35 kinds of vehicle axle assembly components. The company is certified with ISO: 9001.2008 and QS 14001 certification. The automotive component banjo-type axle housing are selected to carry out the current study. A banjo-type axle housing comprises a hollow central member with a pair of hollow tubes extending outward. Such axle assemblies comprise several components that are adjusted to transmit power from one engine of the vehicle to the wheels thereof. The banjo-type axle housing is made up of mild steel and weighs about 45 kg as a finished product. The banjo-type axle housing required more quality and rework concerns as compared to other produced components. The concerned organisation was highly motivated to mitigate environmental impacts of this component. The manufacturing sequence of banjo-type axle housing is depicted in Figure 3. As can be seen in Figure 3, the manufacturing process begins with the flange rough and finishing boring operation.

Figure 3 Manufacturing sequence of banjo-type axle housing in the adopted organisation (see online version for colours)



4.1 Selection of sustainability-focused GLSS project

As previously indicated, the implementation of the GLSS project requires a well-committed team having several skills for manufacturing operations. In this current study, the team involved a specialist, a controller from the higher management, and five managerial members. In this step, the subsequent process of manufacturing, SIPOC diagram, and project charter dispenses a complete understanding of several aspects of the adopted GLSS project. A meeting was also arranged by the higher management of the industry to direct the workers about the requirement of the adopted project and its outputs. This assists in imparting appropriate consciousness and understanding about the project to the workers. The management of the selected firm outlined its concern for production waste, minimisation of emission for manufacturing of banjo-type axle housing, and evaluation of the social sustainability of the firm. The company produces 6,000 vehicle assembly components per month and about 72,000 components in a year. The total established capacity of business unit was 150,000 parts per annum. Based on significant data of the previous four years, it is observed that the firm was working at 56.8% of the total capacity that implying that there was about 48% of production waste. The company possessed a considerable level of ecological emission with 28.20 Pt, and there was no initiative to evaluate the social sustainability of the industry.

Crucial parameters for production waste were recognised in this subsection to consult with experts and industrial visits. Then radar chart is constructed to illustrate the percentage contribution of parameters in the production waste of the selected firm (Figure 5).

The radar chart outlines that inefficient material handling (39%), inefficient manpower movements and space usage (27%), ecological issues combined with social issues (18%), and rework (11%) were the significant contributing features for production waste of adopted organisation. The time utilised for material handling activities in several units was evaluated to recognise crucial units concerns to inefficient material handling. Shop-wise material handling time was evaluated in this subsection to detect key shops responsible for poor material handling. The previous 24 months' data refers to the time taken to find items and equipment in several shops that were collected. A Pareto chart is plotted to find out the shops that were incredibly accountable for the production waste of the considered organisation. The horizontal axis of this chart illustrates several shops/sections in the industry. The times adapted in the material have been delineated by the several bars conforming to every shop/section of the concerned organisation.

Figure 4 High-level SIPOC diagram (see online version for colours)

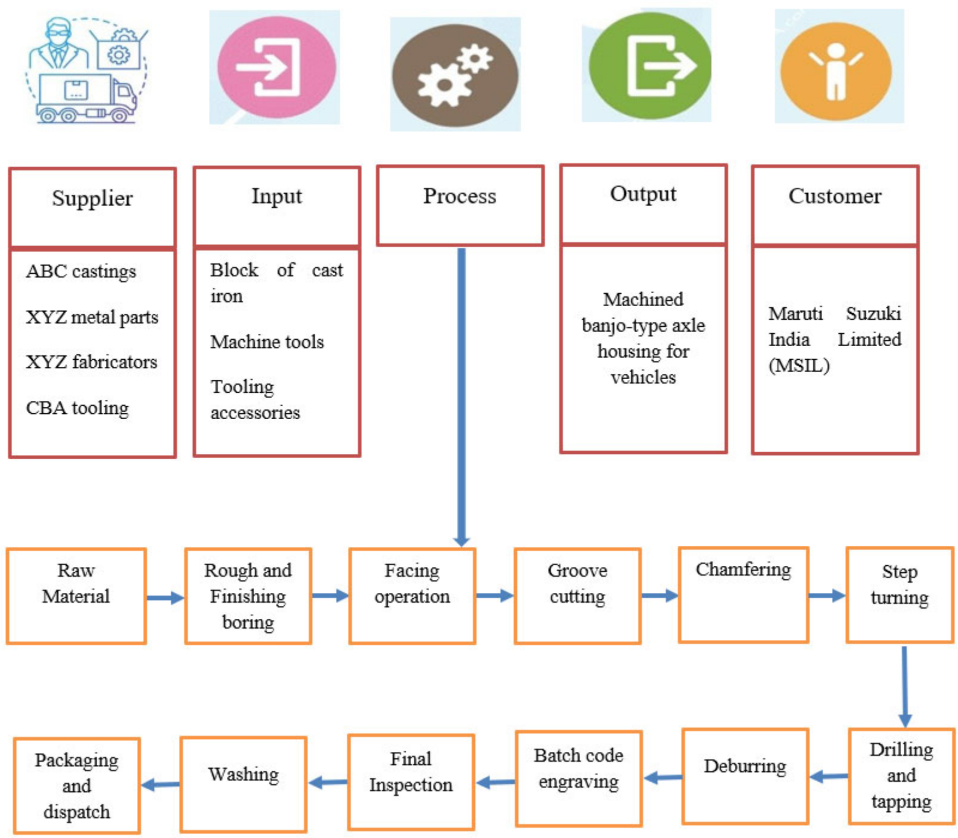


Figure 5 Crucial parameters for production waste (see online version for colours)

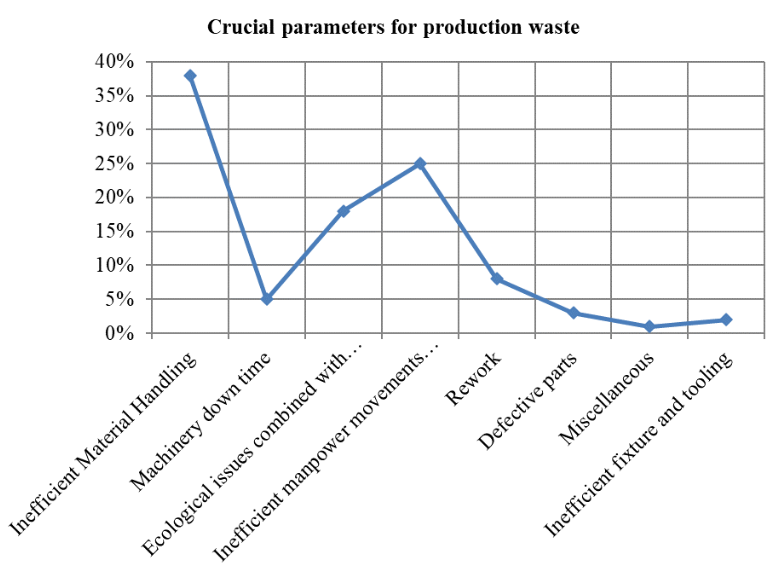
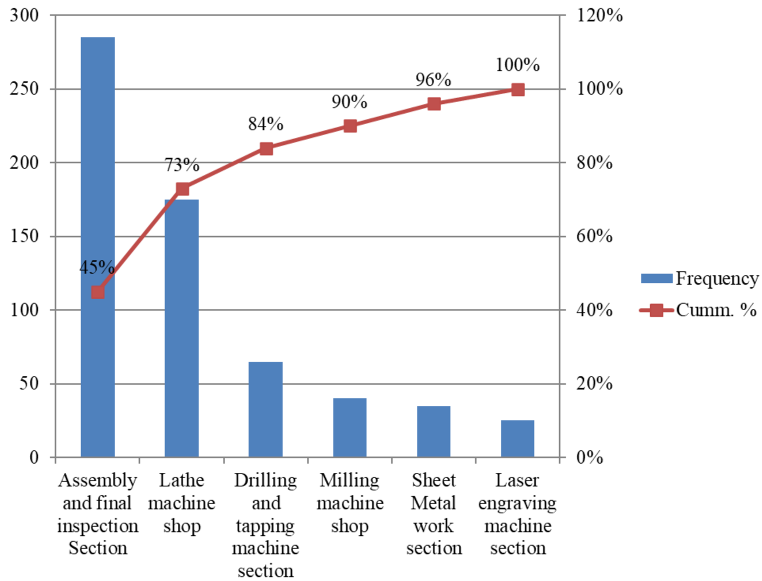


Figure 6 Pareto chart for poor material handling time for several shops/section (see online version for colours)



The Pareto chart indicates that the assembly and 'final inspection section and lathe shop are the key contributors to poor material handling and production waste of selected industry'.

4.2 Estimation for mapping of the current state of the project

An environmental current state mapping has been developed to impart higher insight into the current manufacturing operations. Environmental value stream mapping (EVSM) includes details concerning power consumption, water consumption, material consumption, environmental impacts, and conventional value stream criteria, such as cycle time, change over time, uptime, and lead time for every manufacturing process. Formulating an EVSM (Figure 7) assists in predicting the real manufacturing context and dispenses understandings on the resource consumption from the point of view of the environment, and leads to the development of critical process metrics (Table 2).

An open LCA (Figure 8) was carried out to compute current environmental impacts for the manufacturing process under consideration. The environmental impacts of process were estimated dependent on dataset of raw material, power, and water consumption. The environmental impacts were computed in Pt that indicates strength of impacts. These are assessed for entire process as well as independent processes. In EVSM, the estimated environmental impacts for each process are indicated in the boxes below water consumption line. The overall environmental impacts for present industrial processes considering the stakeholder were found to be 44.70 Pt. Stakeholders considered were cast iron, lubricating oil, water, electricity, groove cutting, chamfering process, drilling and tapping process, deburring and boring process.

Figure 7 Environmental current state value stream mapping (see online version for colours)

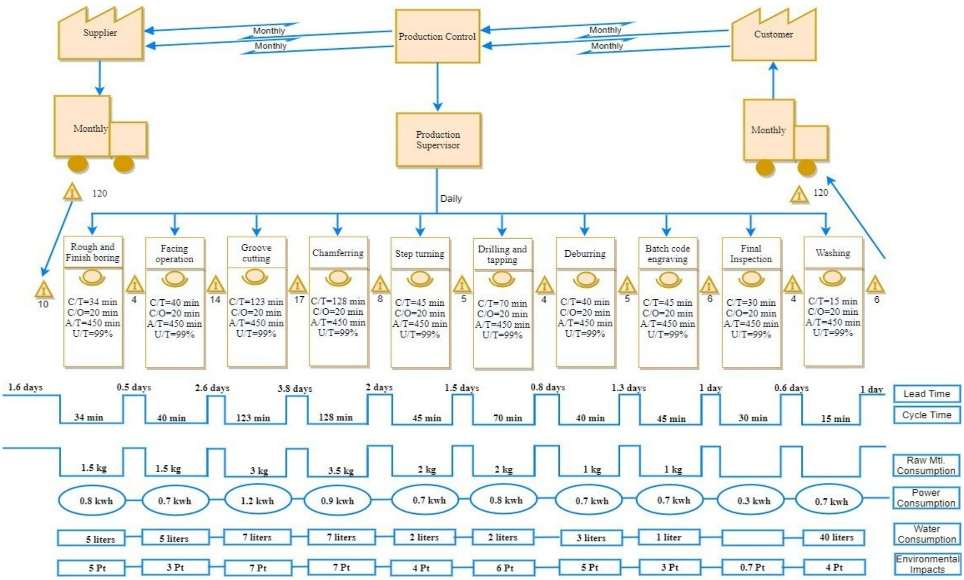
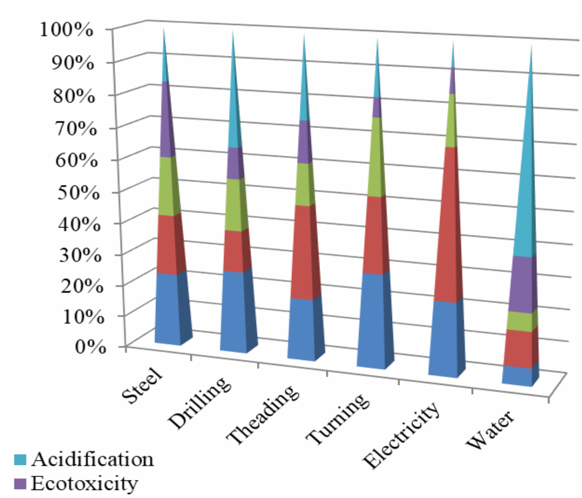


Table 2 Identified EVSM critical process metrics

Critical process metric	*Units*
Total cycle time	570 min
Process lead time	16.7 days
Raw material consumption	15.50 kg
Power consumption	7.5 kWh
Water consumption	72 litres
Environmental impacts	44.70 Pt

Figure 8 Current environmental impact using LCA (see online version for colours)



Further, for computing the current sigma level of the manufacturing process, a sample size of 1,000 units was taken into consideration. The number of defects detected was 18 units. For above-indicated number of defects, DPMO were calculated as 18,000 ppm. The current sigma level of the manufacturing process after matching the attained ppm value with the standard process sigma table was obtained as 3.65.

Figure 9 Shops/section-wise number of parts needed rework (see online version for colours)

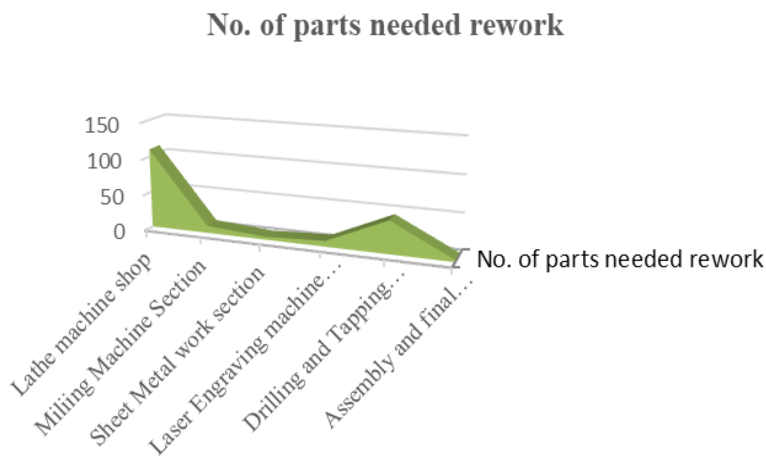
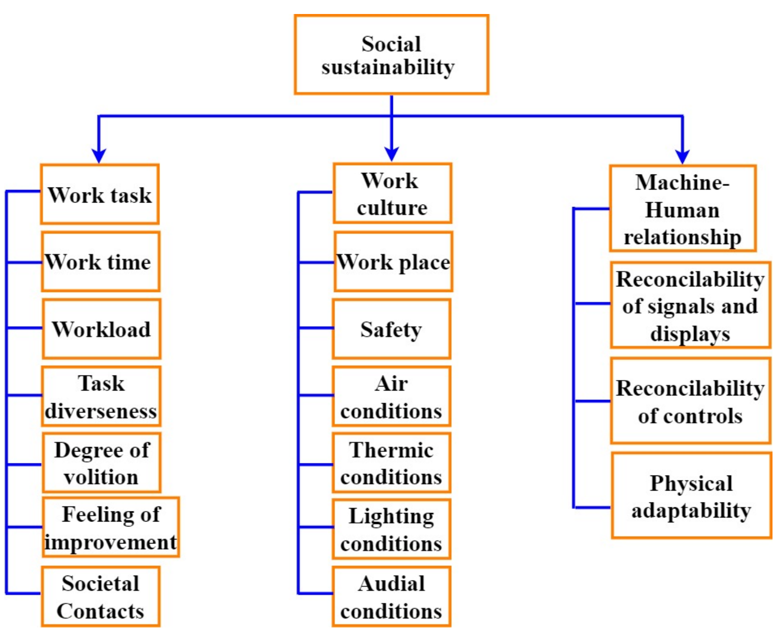


Figure 10 The suggested indicators for social sustainability assessment (see online version for colours)



An intensive analysis of distinct shops/sections of concerned organisation had been done by the project team to gather monthly data associated with the number of parts needing rework in distinct shops of industry. Figure 9 illustrates a plot of the section wise number of parts that needed rework. It is clear from Figure 9 that there are mainly two shops/sections that is a lathe machine shop and a drilling and tapping machine section that contributed to reworking in the considered organisation's processes.

To ascertain societal sustainability is crucial concern in worldwide supply chains to defend workers of the organisation from harassment and dispense a better work atmosphere (Venkatesh et al., 2020). Social sustainability estimations have been assumed to be a lesser consideration by industrial organisations, particularly in emerging economies such as India. In the current research work, a societal sustainability assessment model to evaluate the social sustainable performance has been presented (Figure 10).

Social sustainability has been divided into three categories: work task, work culture, and human-machine relationship. The work task aspect of the social sustainability assessment model includes work time, workload, task diverseness, degree of volition, the feeling of improvement, and societal contacts. The work culture aspect of the social sustainability assessment model includes workplace, safety, air conditions, thermic conditions, lighting conditions, and audial conditions. The machine-human relationship aspect of the social sustainability assessment model comprises reconcilability of signals and displays, reconcilability of controls, and physical adaptability.

In the current study, novel inventory societal performance data was collected by a questionnaire-based survey. The samples were obtained from workers, engineers, managers, and local government officers. It was observed that concerned organisations had marginal sustainability and contributes to society. There is a need to improve work task and machine-human relationship aspects of the social sustainability assessment model of considered organisation.

In this step, the gathered data, and the current state map of the project are used to recognise the weak sections where further analysis was needed. These identified areas are given below:

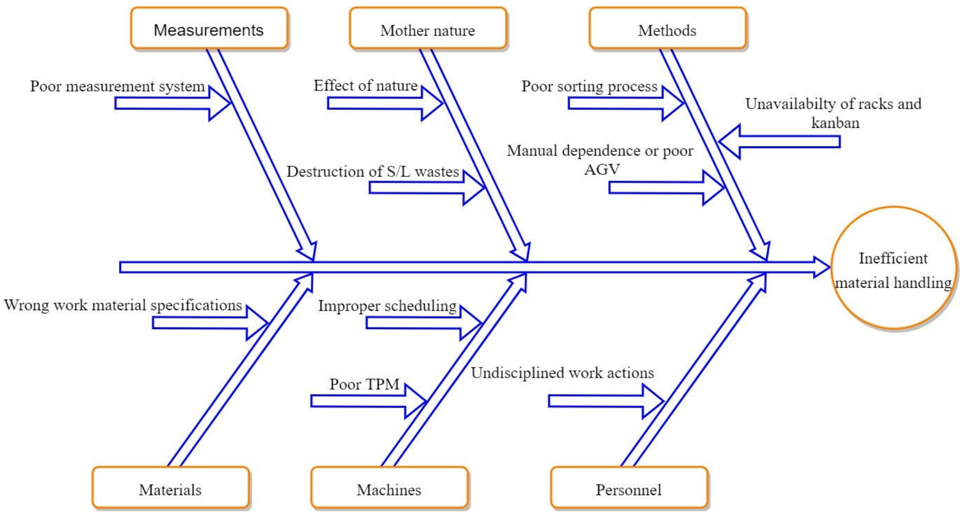
- inefficient material handling: Final assembly and inspection section
- inessential worker movement and space usage: the whole industry
- rework needed: Lathe machine section and drilling and tapping machine section
- environmental footprints: the whole industry
- societal sustainability: societal and confined community.

The priortised areas incorporating critical quality characteristics were further assessed to recognise possible causes in the succeeding steps.

4.3 Find out the prominent reason for waste and inefficiencies

The cause-and-effect diagram was instituted focused on inefficient material handling in final inspection and assembly section in selected industry (refer to Figure 11). Personnel, machines, methods, materials, mother nature, and measurements are the key categories that were taken into consideration for further investigation of potential causes. The brainstorming sessions were also organised with the low, middle, and top managers of concerned organisation.

Figure 11 Cause and effect diagram of inefficient material handling in the assembly section (see online version for colours)



It has been found that there are ten factors that were greatly accountable for inefficient material handling in the considered organisation (Table 3). Further, grey relational analysis (GRA) was employed to find critical causes/factors among the identified factors. Table 4 illustrates the ranks of causes/factors accountable for inefficient or poor material handling. It was observed 'by GRA analysis that unavailability of racks and Kanban system and poor sorting process' were most crucial causes/factors accountable for poor or inefficient material handling and thus actions were required to overcome these.

Table 3 Causes/factors accountable for poor or inefficient material handling

Sr. no.	*Factors accountable for poor or inefficient material handling*	*Labels*
1	Poor sorting process	W1
2	Destruction of S/L wastes	W2
3	Effect of nature	W3
4	Wrong work material specifications	W4
5	Poor TPM	W5
6	Improper scheduling	W6
7	Unavailability of racks and Kanban system	W7
8	Poor measurement system	W8
9	Manual dependence or poor AGV	W9
10	Undisciplined work actions	W10

Table 4 Prioritisation of poor or inefficient material handling factors/causes by GRA

Label	*CR1*	*CR2*	*CR3*	*CR4*	*GRG*	*Rank*
W1	0.982	0.621	0.991	1	0.898	2
W2	0.543	0.432	0.421	1	0.599	5
W3	0.343	0.352	0.664	0.374	0.433	9
W4	0.383	0.524	0.534	0.623	0.516	8
W5	0.374	0.519	0.687	0.512	0.523	7
W6	0.549	0.412	0.424	0.991	0.594	6
W7	0.799	1	0.991	0.872	0.915	1
W8	0.472	0.362	0.343	0.442	0.404	10
W9	0.642	0.762	0.991	0.567	0.74	3
W10	0.372	0.612	1	0.434	0.604	4

Five why was also used for analysis for rework, inessential worker movement, and space usage. This tool dispenses methodical analysis for obtaining root causes of the problem and aims only on the regarding reasons. In the current study, team members of the project discuss with section heads, section supervisors, workers, and machine operators for computing the root causes of rework and inessential worker movement and space usage. Figure 12 depicts the prime root cause for rework issues.

Figure 12 Five why analysis for rework (see online version for colours)

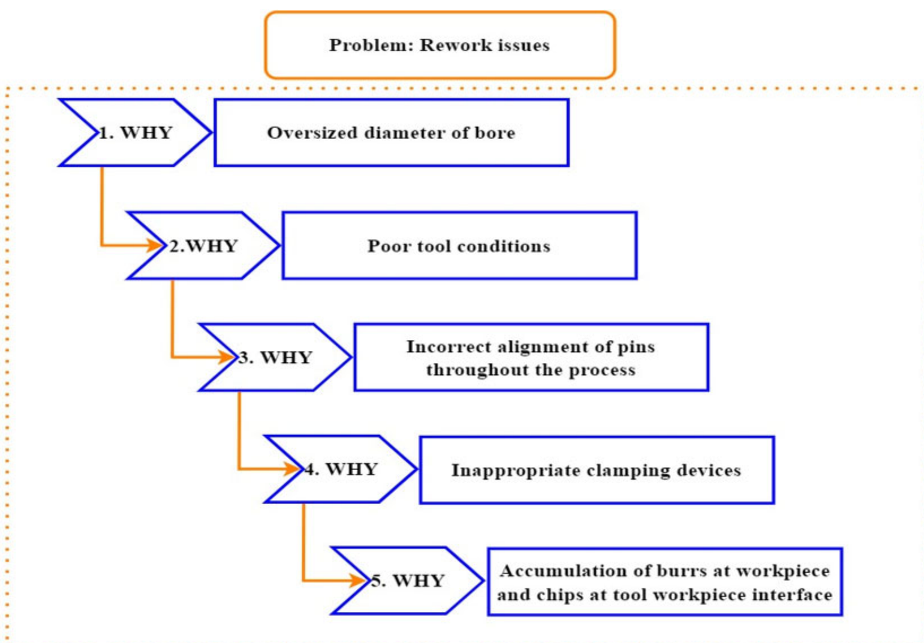


Figure 13 Five why analysis for inessential worker movements and space usage (see online version for colours)

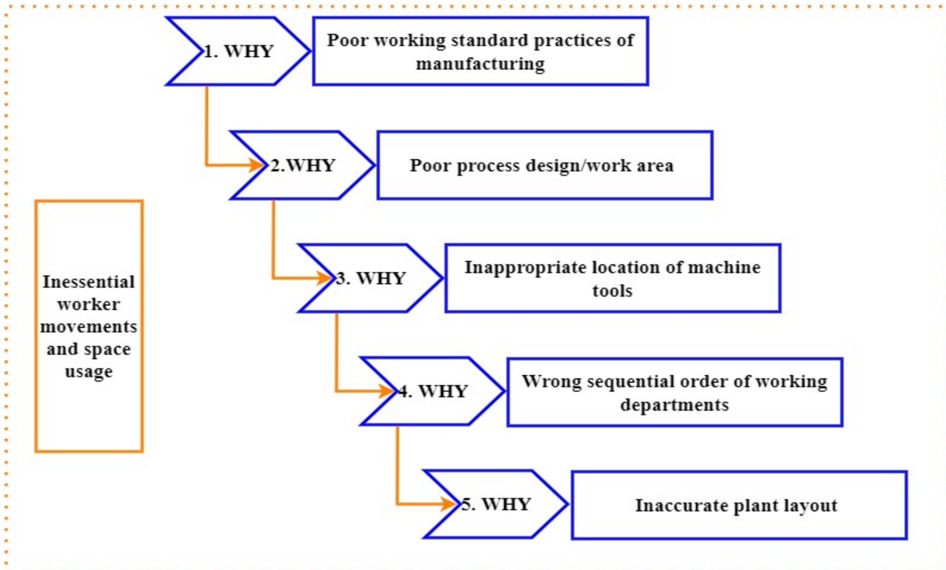


Table 5 Identified prominent reasons for waste and inefficiencies

Sr. no.	*Encountered problem*	*Key areas*	*Prominent reasons for waste and inefficiencies*
1	Inefficient material handling	Final assembly and inspection section	Unavailability of racks and Kanban system, poor sorting process, manual dependence, or poor AGV
2	Inessential worker movement and space usage	whole industry	Inaccurate plant layout
3	Rework needed	Lathe machine section and drilling and tapping machine section	Accumulation of burrs at workpiece and chips at tool-workpiece interface
4	Excessive water, power, and raw material (consumption)	Overall plant	Poor tool conditions, inaccurate machining parameters, lack availability of appropriate cleaning and recirculation system
5	Societal performance	Societal and confined community	Locality investment, new employment in the whole plant, majority of deployment from the local region

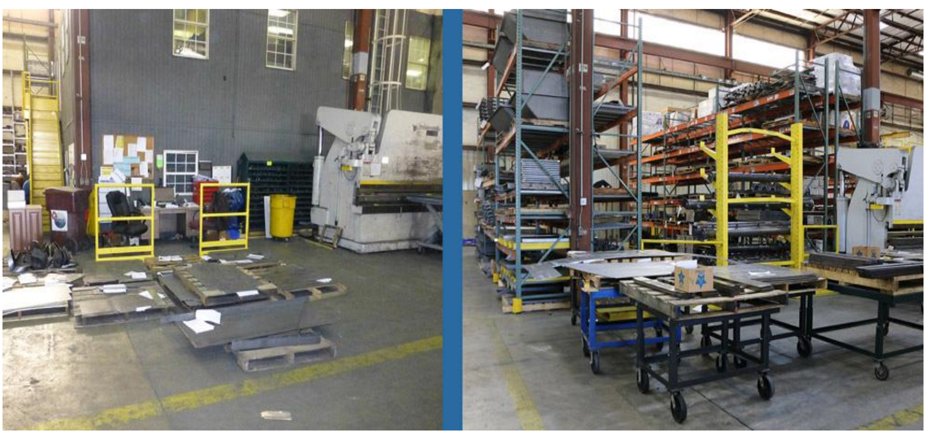
The team of the project also carried out a five why analysis for inessential worker movement and space usage. It was observed from the analysis (Figure 13) inaccurate plant layout resulted in inessential worker movement and space usage.

Furthermore, the team of the project crucially inspected several departments of the concerned organisation and organised distinct brainstorming sessions with industrial managers and employees, and recognised that key sources for low ecological performance were water, power, and material consumption. This was recognised that for enhanced societal sustainability, considered organisation must work out on humanity and resident communal facets. With the help of the cause and effect diagram and five why analysis, the list of prominent reasons for waste and inefficiencies at the selected organisation is shown in Table 5. In the next step of the GLSS framework, several actions were executed to enhance the sustainability dynamics of the considered industry.

4.4 Select and implement the best solution

After executing enhancement activities, pilot tests are carried out to register the concert of the improved design, and cost-benefit study is accomplished to assess the complete investments initiated from the project.

Figure 14 Final assembly and inspection section before and after the implementation of 7S technique (see online version for colours)



(a) (b)

A brainstorming sessions was conducted with experts dispense suggestions on how to employ 5S techniques for minimising the inefficient material handling in final assembly and inspection section of considered organisation. In the current study, the 7S tool, (5S + Sustainability + Safety) was adopted to enhance the sustainability dynamics of the company. 7S techniques were also used to create a sorted out, safe, clean, accident-free, and eco-friendly workplace in the concerned organisation. Here 7S stands for Seri, Seiton, Seso, Seiketsu, SeJizoku kanosei, and SeiAnzen which implies sort, simplify, shine, standardise, sustain, sustainability, and safety, respectively. In the Seri step, all the parts and equipment were sorted out as per their operating frequency. After sorting, the replanning of all the parts and equipment was done to streamline the flow of material. The structure of the final assembly and inspection section before and after the implementation of the 7S technique is shown in Figure 14. This technique assists in the daily saving of about 145 minutes in finding the parts/components to assemble one product. Furthermore, the workplace was cleaned appropriately to create a healthy working environment and reduce air pollution. The assumed work actions were standardised to make a compatible means of executing tasks accomplished daily, incorporating sort, set in order, and shine. Standardise compel methods and process more pragmatical and rigorous to create right things, the right way and right time. The visual process control system was also incorporated to encourage employees and other members of the organisation to retain things at assigned places. The work standards were decided such as regular checking of the first aid kits and reforming the environmental rules and regulations for sustainability.

To certify sustainability and safety in the adopted industry, separately from the 5S technique, probes for mitigation of accidents, also enclosing the areas of machine tools liable to high-temperature chips were accomplished.

Kaizen activities

To minimise various non-value-added activities in the considered organisation, several kaizen activities were suggested and executed. These activities have been mapped out in a manner that can improve the productivity and ecological sustainability of an organisation. These were also mapped out to minimise work issues, setup time, and improve the social sustainability of the considered organisation.

Enhancements concerned with the cutting of raw material and lathe section

Initially, overhead crane systems were used to transport the raw materials bars to a devoted slicing system in the lathe machine shop of considered organisation. The raw material bar was inserted in the devoted fixture and positioned on cutting machine to be cut into small pieces after dispensing appropriate clamping and location. The clamping and setting work takes more time as the size of bar size changes. Therefore, there is great requirement to impart quick change over and minimisation of set up time. For this purpose, exploration and practicability of three possible techniques were carried out. Table 6 outlines the analysis of techniques for set up time minimisation.

Table 6 Exploration of set up techniques

Technique	*Explanation*	*Adopted feasibility*
Modularisation of equipment	Create changes in prevailing fixtures to encounter operational needs	Time minimised for setting up but demands quick moderation
Modification in equipment	Accomplish redesigning of fixtures and substituted existing one with an improved one	This assists in huge reduction in set up time by reshaping and enhancements in the prevailing fixture
Advance part preparedness	Fortified with a batch devoted fixture to minimise changeover time	This could be employed for the short time period when handling and total manufacturing cost is high

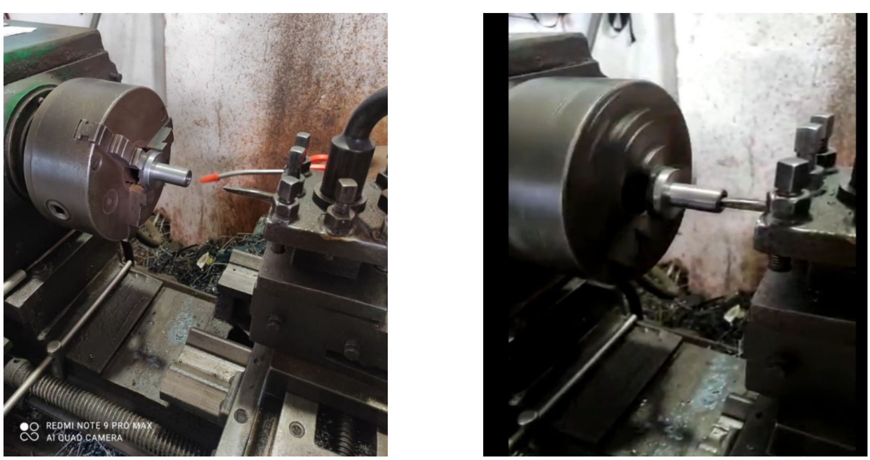
Enhancements prevailing to rework issues

In the previous step, this has been recognised that the accumulation of burrs at the workpiece and chips at the tool-workpiece interface was a crucial aspect behind the rework concerning problems in the section of the lathe machine. To assist, in appropriate tool conditioning the carbide tool has been substituted and locators have been imparted and pins positioned accurately to minimise the disarticulation of parts. The pressurised air guns have been included to reduce the chips and burrs from the W/P and interface areas. This will assist in improvement in tool life and minimisation of rework problems. Figure 15 shows lathe machine tools before and after the assimilation of an air pressure gun to eradicate burrs at the tool-workpiece interface.

Enhancements to improve social dynamics

Obtaining brilliance in ecological, health, protection, employment, and community engagement should be a part of the value conception plan to sustain the world market. This has been observed from the LCA technique that the considered company was straggling in the constraints of community and employment investment. However, the selected organisation shows a societal sustainability level but to improve the existing one, to a better level, the company must include measures to improve community and employment investment facets. As powerful community performance in lengthy turn forces stakeholder value conception, concerned organisations ought to capitalise more inside the community closer to the non-profit sectors. Enlarging community investment in conjunction with the measurement of final results finished will cause approach enrichment, enhanced social resource engagement, culture constructing, and enterprise technology for the selected company. The selected company ought to include actions for training, education, and skill development as a part of commercial societal responsibility. Such types of actions will improve the manufacturing sector to recruit probable talents from the local community that only improve social sustainability but also assist in enhanced efficiency of the organisation.

Figure 15 Lathe machine tool before and after assimilation of air pressure gun (see online version for colours)



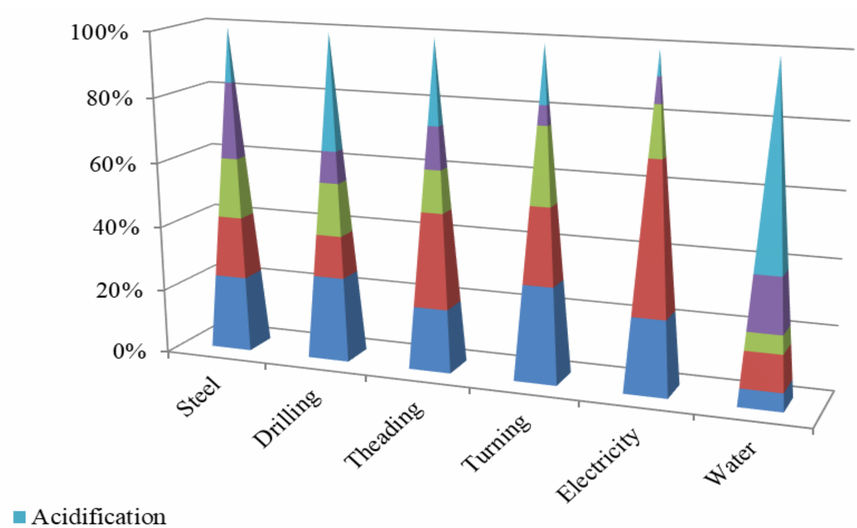
(a) (b)

Table 7 Proposed actions for minimising the overall environmental effects

Aspects	*Executed actions*	*Proposed actions*
Raw material consumption	Excessive scrap was minimised by changing machining parameters The weight of input raw material was minimised by altering the product features	Utilisation of different materials with lesser environmental impacts as related to cast iron
Water consumption	The washing machine is situated with a closed-loop circulating water system to minimise coolant consumption The surface of the water tank was bordered through a smooth material to circumvent loss from the condensation	Adopt normal methods of cleaning with usage of steam to diminish coolant consumption
Power consumption	Experiments and investigations were carried out milling, deburring, and turning machines tools to minimise power consumption by optimising the features of feed rate, spindle speed and authorising electrical units Energy storage and recovery stoppage elements were mounted in the machine tools to attain energy efficacy	Electrical power management system (EPMS) has been incorporated to recognise and modify energy waste

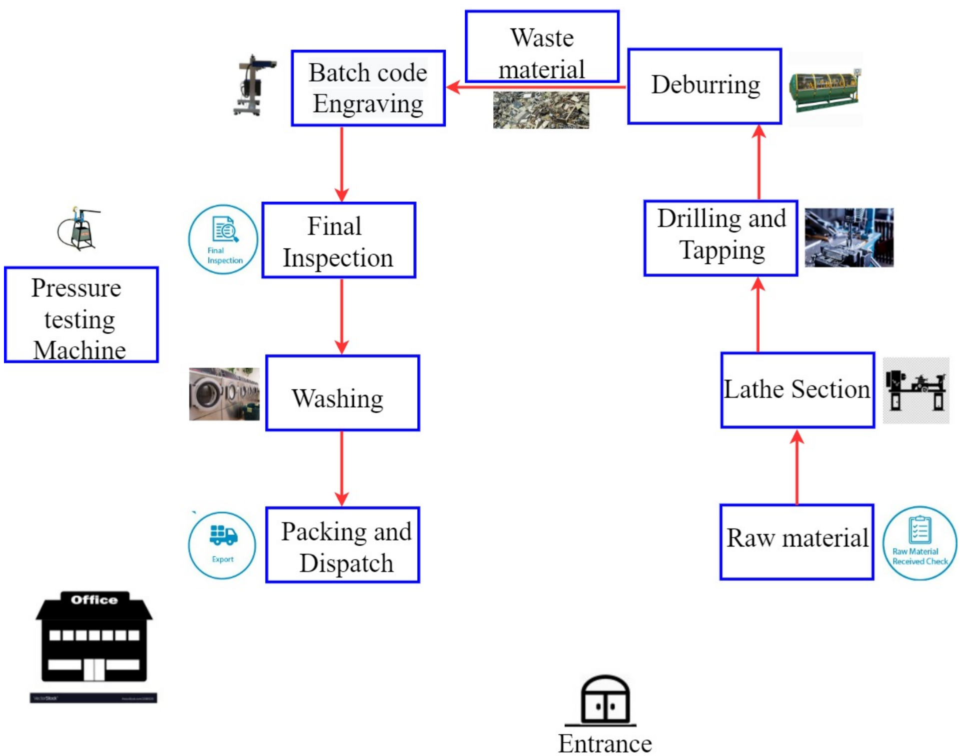
The mitigation in overall environmental effect has been attained by a corresponding reduction in the usage of raw material, consumption of lubricant, and power utilisation. The enhancement activities were recommended and applied for each factor. Table 7 illustrates the executed activities and proposed actions for each ecological factor to improve the environmental sustainability of the industry.

Figure 16 Lifecycle assessment after inclusion of environmental impacts mitigation measures (see online version for colours)



After the incorporation of power-saving actions, power consumption reduces from 7.5 kWh to 6.1 kWh. The saving in the overall power consumption of the organisation leads to reduction in the overall cost of product. The water consumption was also minimised from 72 litre to 60 litre because of the amalgamation of the proper water circulation system and uncomplicated coating for water tank. In perspective of material sustainability, several analyses and tests were carried out for vehicle assembly parts to get the proper design. The raw material consumption was brought down from 15.50 kg to 12.50 kg through understanding with improved specifications for the product. After the incorporation of the execution methods, the overall environmental impacts were again assessed by LCA technique and it obtained to be 32.70 Pt which was 44.70 Pt earlier. Figure 16 illustrates the LCA after the inclusion of the environmental impact removal aspects. Furthermore, the possibility still occurs for the mitigation in the environmental impacts by the utilisation of substitute material and minimisation of material consumption.

Figure 17 Plant layout before analysis (see online version for colours)

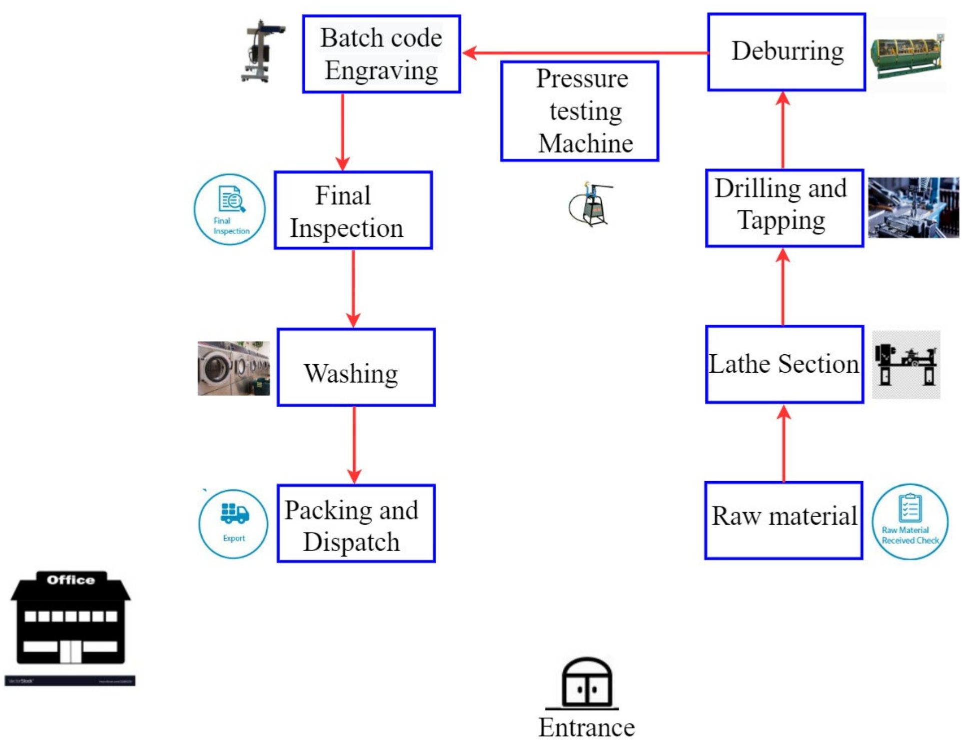


Moreover, to determine the main cause of critical factor that is inessential worker movements, a brainstorming session was conducted among selected experts. The result of the brainstorming session reveals that improper plant layout is the main cause of inessential worker movements within the plant. The current plant layout was outlined and analysed those methods were not accurately aligned and caused in the inessential movement of workers and materials. The faculty plant layout also assists in enhanced electricity consumption for jib crane operation and other related material handling equipment. To improve the existing layout, primarily movements of workers were traced with the existing layout to find out materials, tools, etc. Thus, the movements of the semi-finished products, raw material, and material handling equipment are also tracked. Figure 17 illustrates the plant layout before analysis. It has been observed by the methodical study of the plant that in the existing plant needed floor space was not efficiently planned. The possible solutions for execution were investigated and further steps were instigated to improve the prevailing plant layout.

It has been recognised that in the existing layout there was no appropriate space for the storage of tools or accessories and as a part of the same workers have to move every time to find out the needed tools. That is why an appropriate toolset box was unified on each machine tool to save time to find out the tools. This has assisted in saving time for workers and increased their overall efficiency. Furthermore, the pressure testing machine that was firstly positioned near the office, moved nearby to the deburring section that was initially occupied with waste material. The resulting movement of the machine tool assists in the attainment of the U-shaped layout of the plant.

Furthermore, efficient floor space usage was attained by the removal of the waste material and repositioning of the machine tools in the plant. The existing developed layout assisted in the attainment of the smooth workflow of material and employees, and subsequently supports a minimisation in waiting and electricity consumption for material handling equipment. Figure 18 depicts the plant layout after analysis.

Figure 18 Plant layout after analysis (see online version for colours)



4.5 Sustain with an adopted solution and make it mistake-proof

After several enhancement activities in the previous step of the GLSS framework, different ‘activities’ and data were registered form ‘next’ six months to inspect whether enhancements activities sustain for a longer duration. Distinct measures relate to wastes, environmental, and defects were evaluated again to inspect for any deviation from enhancement step. The improvements attained from implementation of GLSS project are imparted to all the associates included in this project and flowchart is created for the role and responsibilities of each member to sustain enhancements. Table 8 illustrates the Out of Control Action Plan (OCAP) to decide roles and responsibilities to maintain improvements for a long duration. The performance metrics in terms of observation, collection of data, and registering are planned to trace the performance of the system after the execution plan.

Based on the exploration of the current state of VSM, enhancement activities were mapped out and executed to enhance the distinct process measures of the considered organisation. After effective implementation of the recommended activities, future state of VSM was created. It is imperative to dispense appropriate training and education to the workers included in the GLSS project to support improvements made and sustain assumed best practices. The tools like Poka Yoke, visual management, out-of-control action plan, and total productive maintenance have been employed in the present study to dispense pictorial assistance and to control major input-output variables relates to functional and ecological practices.

Table 8 Out of control action plan

Sr. no.	*Control element*	*Control process*	*Responsibility*	*Response plan*
1	Conveyor system	Visual audit	Machine operator	Certify mistake-proofing and inspect appropriate maintenance of crane bearings
2	Location of pressure gun	Visual audit	Machine operator	Instruct machinist for appropriate pressure gun location setting at the tool-workpiece interface
3	Location of drill in the drill and tapping section	Visual audit	Machine operator	Certify appropriate location of drill and assumption by standard operating procedures
4	Hydraulic motor	Metric	Maintenance section	The gap occurs in the sleeve part of the motor are protected in such a way that hydraulic obstruction does not exist
5	Coolant system	Visual audit	Machine operator	Instruct machinist for appropriate supply and outflow of the coolant

5 Results and discussion

On effective implementation of the GLSS approach by the proposed framework, the concerned industry was able to enhance its functional performance and ecological sustainability. Enhancements were perceived in the manufacturing process and ecological specifications by implementation of adopted GLSS framework. The enhancements perceived stated to lean measures like cycle time and process lead time. The efficient execution of method 7S, Kanban, formation of proper plant layout, and Kaizen activities resulted in a minimisation of the cycle time from 570 minutes to 440 minutes (22.80%). Moreover, process lead time was also reduced from 16.7 days to 13.1 days (21.55%), which assists in a substantial saving in postponement of the final product. The applied enhancement activities fetched enhancement in the environmental measures of raw material consumption, water consumption, power consumption, and overall environmental impacts. Raw material consumption, power consumption, and water consumption were minimised by 19.35%, 18.66%, and 16.66% respectively. As there is a decrease in the principal resource consumption, a minimisation in overall environmental impacts was also detected. The environmental impacts were minimised from 44.70 Pt to 32.70 Pt con 26.84% enhancement.

Furthermore, the methodical application of several enhancement methods carried significant enhancements in prevailing capacity utilisation of plant by 19.80%. The sigma level of the considered industry was enhanced significantly by a minimisation in number of parts rejected. Sigma level was enhanced from 3.65 to 4.08 (for a sample size of 1,000 parts the number of parts found defective was 7 and it is correspondence to the DMPO 7.000 that was previously 18.000). Table 9 represents the process parameters before and after the execution of the GLSS project in the considered industry.

Table 9 Process parameters before and after the implementation of GLSS project

Process parameters	*Before implementation*	*After implementation*	*Percentage improvement (%)*
Cycle time	570 min	440 min	22.80
Lead time	16.7 days	13.1 days	21.55
Raw material consumption	15.50 kg	12.50 kg	19.35
Power consumption	7.5 kWh	6.1 kWh	18.66
Water consumption	72 litre	60 litre	16.66
Sigma level	3.65	4.08	11.78
Production waste	48.30 %	38.80 %	19.66
Environmental impact	44.70 Pt	32.70 Pt	26.84

Table 10 Financial gains from GLSS project implementation

Particulars	*Before GLSS implementation*	*After GLSS implementation*
Total number of products produced/month	13.000	15.060
Number of parts rework/months	185	35
Rework cost/ piece	$4	$4
Total rework cost	$17.760	$3.360
Total earnings obtained	$325.000	$373.000
Possible financial savings because of GLSS project implementation	$48.000	

Moreover, enhancement metrics resulted in the minimisation of rework parts from 185/month to 35/month. This assists in a saving of $ 1,210/month from the rework associated problems in the considered industry. The inclusive implementation of GLSS project caused in a monetary improvement for industry in terms of saving a net value of $ 48,000/year (3,672,967 Indian rupees). Table 10 depicts monetary gains from implemented GLSS project in selected industry.

The considered organisation attained substantial benefits in terms of functional parameters, environmental metrics by the effective implementation of the GLSS project. This proves the competence of the presented GLSS framework to alleviate the current challenges of the industrial sectors.

5.1 Managerial implications

The GLSS framework which is assumed in the present study will encourage the industrial sectors to execute the GLSS approach within the organisation in a pragmatic way. The suggested GLSS framework activities enumerated under each step have been outlined in such a way that it assists to the methodical step-by-step procedure to address both functional and ecological issues. During the execution of the GLSS framework, the organisations should be focused on the existing culture of the organisation towards environmental measures. The organisations may utilise the EVSM to draw the whole process in the quantified value sustainably. A training session about GLSS execution is also needed for employees and supervisors so that they can engage in GLSS execution with full eagerness and attention. The current study's unique contribution lies in supporting industrial sectors to compute several functional, environmental, and societal measures and dispense ways to enhance and sustain the same for improved organisation competitiveness.

6 Conclusions

Approaches to enhance environmental performance must be associated with the conventional industrial initiatives to enhance measures like process efficacy, satisfaction of customers, and receptiveness. GLSS, environmental aspects, and societal contemplations have been combined with an intent to reduce waste, resource consumption, cultivate worker health and well-being. The contribution of the current study lies in two-fold, first, the GLSS framework has been suggested to direct in conducting the activities of implementation of this program. The presented framework dispenses a prospect to the industrial sectors to enhance ecological wastes, improved capacity usage, handling of items, along with enhancement in social subtleties by the deployment of tools like LCA, EVSM, Kaizen, etc. Second, this work exhibits the empirical benefits of using the projected GLSS by its effective execution framework in an industrial environment by methodical insertion of green technology, Lean and Six Sigma tools.

Effective implementation of the suggested framework has assisted to a minimisation in defects, level of rework, and environmental wastes, together with enhancement in functional and financial gain. The efficient execution of method 7S, Kanban, formation of proper plant layout, and Kaizen activities resulted in a minimisation of the cycle time from 570 minutes to 440 minutes (22.80%). The environmental impacts were minimised from 44.70 Pt to 32.70 Pt contributing 26.84% enhancement. Sigma level was enhanced from 3.65 to 4.08 (for a sample size of 1,000 parts the number of parts found defective was 7 and it is correspondence to the DMPO 7,000 that was previously 18,000). The GLSS project fetches a financial savings of $ 48,000 by the effective implementation of this framework. The current research work allows the organisation to understand its present level of environmental effects and aids it in detecting further means of minimising CO_2 emissions by the integration of more green technology measures. This framework also had a constructive impact on the societal significance as enhancements were perceived relating to the health of human (as an outcome of minimised ecological effects) and shopfloor safety (after the deportment of the 7S).

Limitations and future scope

Despite several contributions, the study has its limitations. This GLSS framework can be employed only in automotive manufacturing sectors, and definite industrial sectors employing with analogous industrial operations. In the present study, the suggested framework has been tested through only in a single automotive manufacturing organisation. In future research, proposed framework can be expanded to another industrial organisation wherever the necessity to implement the GLSS approach is insistent. Future research can also focus on improving the current steps and by incorporating additional tools and techniques into every phase concerning producing reliable outcomes by the application of the proposed framework in several enlightened environments.

In another future research direction, the framework can be improved to encompass its scope for allowing additional sustainability drivers during the GLSS execution and more unconventional tools and techniques can be appended to framework for furthermore improvement.

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