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Vishwas Yadav[a], Pardeep Gahlot[a], Rajeev Rathi[b], Gunjan Yadav[c], Anil Kumar[d] and Mahender Singh Kaswan[b]

[a]Department of Mechanical Engineering, University Institute of Engineering & Technology Maharshi Dayanand University, Rohtak, Haryana, India; [b]School of Mechanical Engineering, Lovely Professional University, Phagwara, Punjab, India; [c]Mechanical Engineering Department, Swarnim Startup and Innovation University, Gandhinagar, Gujarat, India; [d]Operations, Supply Chain and Business Analytics, Senior Lecturer at London Metropolitan University, UK

ABSTRACT

Modern organisations are in quest of initiatives that will facilitate them to be sustainable as well as provide a competitive advantage to remain a continuous stakeholder in the global market. Green Lean Six Sigma (GLSS) is an inclusive approach that not only improves environmental sustainability but also leads to improvement in the financial stability of the organisations. To implement the GLSS strategy, it is essential to integrate Green, Lean, and Six Sigma initiatives under the umbrella of GLSS. In this study, GLSS integration has been proposed based on intangible features like enablers, toolsets, etc. Management dedication, participation, and team effort have been recognised as the most remarkable enablers to implement GLSS in the manufacturing sector. Moreover, this study also proposes a five facet GLSS framework for the manufacturing sector to enhance organisational sustainability. The current work will facilitate managers and practitioners to execute a sustainable GLSS programme in manufacturing firms for increased operational excellence as well as environmental sustainability.

1. Introduction

Since the last few decades, increasing levels of greenhouse gases have led to unprecedented changes pertains to increased earth surface temperature, changed rain patterns, extinction of rare species and vulnerable human health (Environmental Protection Authority Report, 2020). Climate change due to the increased concentration of greenhouse gases (GHGs) is affecting human health and society, including changes in Lyme disease, West Nile virus, heat- and cold-related deaths and hospitalisations (Kaswan and Rathi 2020). In 2019, the annual GHGs Index was 1.45, which represents a 45% increase in radioactive forcing (a net warming influence) since 1990 (National Centers for Environmental Information, Global Climate report, 2020). Persistent increment in the concentration of GHGs can be attributed to fossil fuel–based energy methods, changed lifestyle, traditional methods of operations, etc. Industrial organisations consume natural resources in an uncontrolled way and release a substantial proportion of pollutants into the atmosphere (Sagnak and Kazancoglu 2016). Moreover, these organisations are not adopting proper waste disposal measures, which further add to environmental degradation. It has been found that industry contributes nearly one-fifth of the total global GHGs (IPCC 2014). Furthermore, increasing concern about sustainability changed quality perception, and demand for sustainable products forced manufacturing industries to adopt sustainable business practices (Sony and Naik 2020). So, it is imperative for industries especially manufacturing to curb their current level of emission. For this, industries have to changes their traditional business practices to sustainable ones. The manufacturing organisations have the inherent capability to adopt environmental-friendly approaches like Green Lean Six Sigma (GLSS) in their operations (Yacob, Wong, and Khor 2019).

1.1 Why green lean six sigma?

Green technology, Lean and Six Sigma are complementary, each approach has the potential to minimise the disadvantages of the others (Sony and Naik 2020). Lean is valued due to its ability to quantify waste, but it is not able to quantify environmental impacts and possible environmental hot spots (Sreedharan et al. 2018). So, at this juncture, green technology fills this gap and estimate the environmental impacts of generated waste. Green technology is employed in operations management to recommend approaches that are conscious of the environmental effects of production and operations (Deif 2011). The key objective of the green manufacturing concept is to reduce resource usage and pollution or to enhance the environmental performance of the organisation (Kaswan and Rathi 2021). Integrated Green Lean (GL) although able to recognise wastes and quantify ecological impacts but not often provide an actual method to reduce the wastes, and defects associated with the process (Garza-Reyes 2015). Six Sigma is a data-driven approach that fills this gap and provides

a concrete stepwise methodology to reduce waste (Sreedharan et al. 2020). Although Six Sigma reduces wastes through the reduction of defects, it cannot recognise different wastes and environmental impacts (Hussain et al. 2019). Since the last few decades, various strategies have been evolved (Garza-Reyes et al. 2018; Bhat, Gijo, and Jnanesh 2016) to manufacture high specification products, but an individual strategy is not capable to communicate all the points collectively associated with sustainability (Pandey, Garg, and Luthra 2018). So, it is imperative to integrate three unique methodologies under the umbrella of Green Lean Six Sigma (GLSS).

The Integrated GLSS approach aids organisations considerably to cut their energy use (Kaswan and Rathi 2019). Inclusive implementation of GLSS must be gradual, meaning that industries must estimate their strengths and weaknesses, determine priorities, and choose targets for successful implementation (Gholami et al. 2021). Three different dimensions of sustainability such as environmental, economic, and social are vital factors to be considered by any organisation (Ershadi, Taghizadeh, and Molana 2021). GLSS supplements organisations pursuits towards sustainability through, reduce of wastes, environmental footprints and defects. As GLSS is a novel prospect of sustainability, so it is imperative to comprehend different features that foster its integration, so that an inclusive understanding of this approach can be developed. GLSS is a project-based approach, and it has been found that nearly 40% of the projects have failed due to a lack of understanding of GLSS features and implementation framework (Gandhi, Thanki, and Thakkar 2021). In the literature, the study pertains to a framework of GLSS in construction, Jute industry exists (Banawi and Bilec 2014). But no study exists in the literature that provides a dedicated framework of GLSS with a toolset for manufacturing industries. This study provides integral measures and framework of GLSS pertains to the manufacturing industry. The integration among has been established through theoretical constructs and the framework has been supplemented with different toolsets at each stage of realisation of the GLSS project.

1.2 Research questions

Based on the above discussion, this study has proposed the following research questions:

RQ1. What are measures that foster integration among Green, Lean, and Six Sigma?

RQ2. How a dedicated framework of GLSS pertains to manufacturing is realised in a stepwise manner?

RQ3. What will be the implications of a proposed framework for managers and practitioners?

The rest of the article is organised as follows. Section 2 discusses the background for the research and provides a summary of the most significant studies reviewed so far. Section 3 deals with the adopted method for integration and framework of GLSS. Section 4 reports results and discussion and section 5 presents implications driven from the present work. The final section of the paper enumerates the conclusion and future research agenda.

2. Literature review

The literature review comprises three sub-sections. The first sub-section outlines the literature search methodology. The second one present's literature related to GLSS and the final sub-section depicts identified grey areas of research.

2.1 Article selection scheme and study flow

To select pertinent research articles, authors have used the systematic literature review (SLR) technique. It is a technique that validates a rigorous and translucent, process to literature review (Kaswan and Rathi 2021). It comprises a sequence of phases to ensure that significant precision and lucidity can be assured in the process of literature review (Tranfield, Denyer, and Smart 2003). Figure 1 depicts a systematic literature search methodology. SLR comprises of the following five successive phases: (1) Scope formulation, (2) Locating studies, (3) Study selection and Evaluation, (4) Analysis and Synthesis and (5) Reporting and using of results. SLR phases are as follows:

In the first phase, the scope of the study is decided; here, the study has been conducted with the viewpoint of identification of integral measures and exploration of frameworks. The pertinent research articles were searched using prominent databases in a subsequent phase of SLR. Authors have included research articles from the span of 1990 to 2020. In the study selection and evaluation phase, Context-Intervention-Mechanism-Outcome (CIMO) (Rousseau 2012) was employed to decide the inclusion/exclusion aspects of research strings. So, (lean eco-efficiency), (environmental lean), (lean green six sigma) and (lean eco-sustainability) are used as search strings. This methodical research and selection strategy is essential to procure inclusiveness of the literature review. A point of obstruction was reached when the same manuscript occurs continuously. To avoid this problem, search strings criteria were incorporated in 'Manual Check' concept for all the manuscripts depending on the abstracts of the article. This resulted in eradicating those articles that surely did not convey the concept of GLSS. Other search strings like sustainable lean and sustainability lean were also be evaluated. Search results comprised peer-reviewed manuscripts, published in proceedings of international conferences and academic journals.

In the analysis and synthesis phase, many techniques that comprise thematic synthesis, meta-ethnography, ground theory, etc. are used (Garza-Reyes, 2015). Out of these methods, thematic synthesis is regarded as the most suitable technique for the synthesis of the outcomes from SLR. Thematic synthesis includes the methodical coding of data and causing of expressive and systematic themes (Reddy et al. 2021). Reporting phase of SLR reveals that GLSS has acquired significant interest and acceptance within the community of research since 2012 as 84% (52 articles) of the publications liberated in the span from 1990 to 2020 have been made. This indicates that the GLSS concept is a comparatively new and emerging research area. The trend of GLSS publications may be predicted to continue expanding in the upcoming years.

Based on the SLR, authors selected articles and further investigated the same to find out pertinent gaps in the literature. To answer first research question, which pertains to
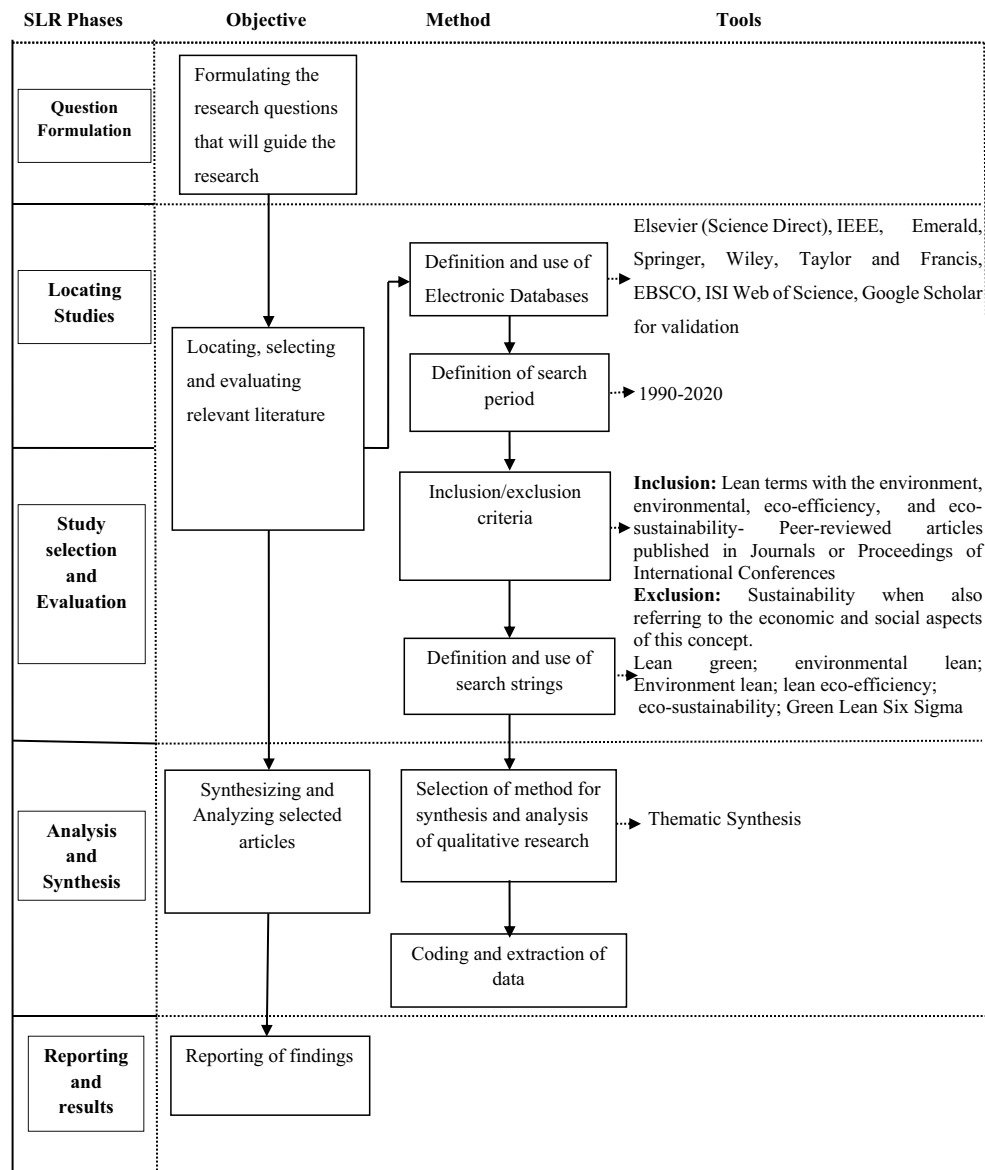
SLR Phases	Objective	Method	Tools

Question Formulation → Formulating the research questions that will guide the research

Locating Studies / **Study selection and Evaluation** → Locating, selecting and evaluating relevant literature →

- Definition and use of Electronic Databases → Elsevier (Science Direct), IEEE, Emerald, Springer, Wiley, Taylor and Francis, EBSCO, ISI Web of Science, Google Scholar for validation
- Definition of search period → 1990-2020
- Inclusion/exclusion criteria → **Inclusion:** Lean terms with the environment, environmental, eco-efficiency, and eco-sustainability- Peer-reviewed articles published in Journals or Proceedings of International Conferences
  Exclusion: Sustainability when also referring to the economic and social aspects of this concept.
- Definition and use of search strings → Lean green; environmental lean; Environment lean; lean eco-efficiency; eco-sustainability; Green Lean Six Sigma

Analysis and Synthesis → Synthesizing and Analyzing selected articles →
- Selection of method for synthesis and analysis of qualitative research → Thematic Synthesis
- Coding and extraction of data

Reporting and results → Reporting of findings

Figure 1. Systematic literature review methodology (adapted from Garza-Reyes, 2015).

integral measures of GLSS, authors identified enablers from literature and formulated theoretical elements (enablers, barriers, tools, etc.)-based model to facilitate the integration of Green technology, Lean and Six Sigma under the head of GLSS. To answer the second research question, authors formulated a five-facet GLSS implementation framework coupled with GLSS tools based on the insight gained from the previous studies. Finally, based on the proposed framework and integral model, theoretical implications and practical implications for potential research and practitioners have been driven.

2.2 Literature pertains to GLSS

Sustainable concerns have progressively acquired significance in the communities and economic discussions over the previous centuries (Chugani et al. 2017). Moreover, in recent years, there is an increasing pressure to enhance the quality, effectiveness and efficiency of products and services (Siegel et al. 2019). Manufacturing sectors contribute nearly one-

fifth of carbon emission and it can be mainly attributed to conventional energy methods (Kaswan and Rathi 2021). The Paris agreement acknowledges key requirements to increase collective methods to change the climate effect through the incorporation of sustainable manufacturing operations. So, to remain competitive at the global platform, industrial organisations have to incorporate sustainable operations in their business practices. Green technology is generally employed in operations management to adopt approaches that are conscious of the environmental effects of production and operations (Deif 2011). It is used to enhance environmental performance but it is not able to identify waste and defects associated with process or system (Sony and Naik 2020). Therefore, the answer to this question comes from Lean Six Sigma (LSS), which make the organisation competitive through the reduction of wastes and defects. LSS are two distinct process enhancement approaches (Lean and Six Sigma) that focus on yielding end product profits (Antony 2012; Sreedharan et al., 2018). Lean philosophy makes the
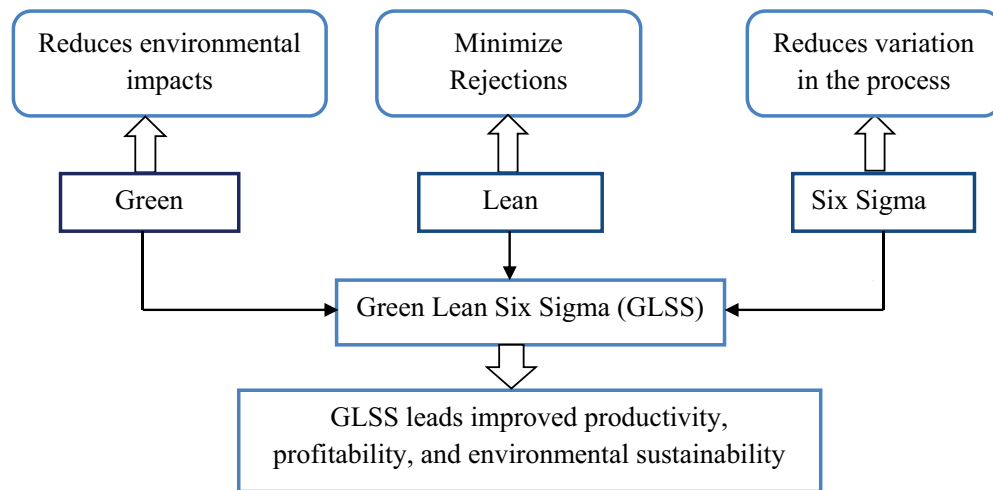
Figure 2. Integrated model of GLSS.

process streamlined and reduces different non-value-added activities (Persis et al. 2020). Six Sigma concept initiates value through compatible process output by recognising and minimising variations in the processes. Effective implementation of LSS approach will facilitate manufacturing sectors to minimise the variation in the process and manufacturing lead time (Albliwi et al. 2014). But LSS strategy is not able to estimate the ecological impacts of the process undertaken. The answer to this question is given by the incorporation of Green technology measures like life cycle assessment. So, it can be deduced from the above discussion that an individual approach is not able to address the modern challenges faced by industries related to sustainability aspects. So answer to this question comes through the integration of Green technology, Lean and Six Sigma under the umbrella of Green Lean Six Sigma. GLSS is a sustainable development approach that mitigates environmental impacts, wastes and defects from the process under consideration (Ershadi, Taghizadeh, and Molana 2021). Figure 2 depicts a simplified model of GLSS.

So, it is imperative to integrate Green technology with LSS pursuits to ensure the sustainability of manufacturing industries. In the literature, no study that prompts integration of Green technology, Lean manufacturing and Six Sigma based on theoretical measures has been reported for the manufacturing sector. Furthermore, as GLSS is a novel prospect of manufacturing, and it has been found that nearly 40% of projects pertain to GLSS have been failed due to a lack of GLSS know-how and framework (Kaswan and Rathi 2020). Although the study pertains to a framework of GLSS in construction, industries have been found in the academic literature (Banawi and Bilec 2014; Zamri et al. 2013). But there is no evidence of a systematic framework of GLSS framework pertains to manufacturing enterprises. Table 1 depicts major research pertains to GLSS that forms the basis for the identification of potential gaps in the research.

2.3 Research gaps

The literature advocates that LSS execution leads to constructive outcomes on the ecological and financial performance of the organisations (Ben Ruben, Vinodh, and Asokan 2017). However, the inclusion and implementation of Green technology with LSS are not deprived of challenges. Lack of finance for clean technologies, poor organisation support system, and unavailability of integral measures along with tools, further hinder effective execution of sustainability-oriented projects. In the literature, few studies exist regarding the framework of GLSS, but they are limited to the construction, jute and mining industries (Zamri et al. 2013; Hussain et al. 2019). There is no evidence of the GLSS framework that can exclusively be applied to the manufacturing industry along with the required toolset at each phase of execution. Moreover, there is no dedicated framework that guides industrial managers and practitioners to execute GLSS along with knowledge of different green metrics and associated toolsets. Furthermore, the study pertains to the integration of Lean with Green technology and Lean with Six Sigma exists but literature lack enough evidence related to the integration of Green technology, Lean and Six Sigma based on commonalities features. So, inclination towards sustainability practices, lack of dedicated execution method, and lack of knowledge base on green technologies measures, provides motivation and avenue for this research work.

3. Methods

In this research work to integrate Green technology, Lean and Six Sigma under the umbrella of Green Lean Six Sigma (GLSS) authors have used theoretical constructs found in the academic literature. For this, author's used enablers or success factors, tools, frameworks modern challenges to the manufacturing as commonalities features to foster integration. To make

Table 1. Major research work pertains to GLSS.

Sr. No.	Author	Year	Description
1	Zamari et al.	2013	Presented a model to analyse the correlation between GLSS and managerial innovation for automobile sectors. The major limitation associated with this study was that the GLSS framework and integration are not presented.
2	Banwai and Bilec	2014	Proposed a framework that integrates GLSS for enhancing the quality and environmental effects in the construction sector. The limitation of this framework was that it did not include manufacturing industries and takes more time for the implementation process.
3	Garza-Reyes	2015	The proposed integration of the green concept with Six Sigma initiative. The drawback was that it has a scarcity of application computation tools in distinct phases.
4	Cherrafi et al.	2016	Carried out the comprehensive review on LSS and sustainability perceptions and explored the prospect of combining GLSS into one approach for dispensing functional excellence. The main drawback of this review was that it is not valid for the manufacturing domain.
5	Sagnak and Kozancoglu	2016	Recommended Six Sigma integration to prevail over the drawbacks of green lean strategy. The proposed framework included measurement system analysis and gauge control-based methodology to assess variation of the process. The limitation of this framework was that it did not propose for GLSS implementation.
6	Cheraffi et al.	2017	Proposed a framework that efficiently assists the industries during the five-stage and sixteen-step process to successfully combine and execute GLSS to enhance environmental sustainability. The drawback of the framework was that empathetic operations may be complicated to execute the GLSS methodology.
7	Sreedharan and Raju	2018	Proposed a GLSS model in the public sector to explore the systematic aspects and hurdles in this sector. This framework lacks the comprehension and evaluation of many green lean wastes.
8	Pandey et al.	2019	Proposed GLSS approach to identify and rank performance improvement enablers in a business organisation. The drawback of this study was that enablers identified only for a specific sector and did not propose a framework.
9	Kaswan and Rathi	2019	Identified GLSS implementation enablers utilising Interpretive Structural Modelling. This model was evolved depends on the judgement of industrial personnel. This model is not certified with the help of other techniques.
10	Hussian et al.	2019	GLSS performance improvement barriers were recognised in the Pakistan construction industry. Modelling and outline were not presented.
11	Kaswan and Rathi	2020	Proposed execution model and framework of GLSS applicable to all industries. But, the application model for the realisation of GLSS in manufacturing at different stages of DMAIC methodology has not been reported.

manufacturing industries more sustainable, authors have proposed a five-step framework of GLSS and embedded different tools of Lean manufacturing, Green technology and Six Sigma. Subsequent sub-sections depict integration measures of GLSS and developed framework that will boost sustainability pursuits of manufacturing organisations.

3.1 Integration perspective of green lean six sigma

GLSS has emerged as a compatible strategy to ensure sustainable development due to its capability to improve productivity and reduces ecological effects (Sony and Naik 2020). Green Lean Six Sigma are three different strategies, but these are collaborative as, these mutually emphasise on mitigation of wastes and optimum resource utilisation (Kumar, Kumar, and Haleem 2015). Therefore, the general ideology and toolsets of these individual strategies can be combined under the umbrella of GLSS. Integration of GLSS can be perceived as the latest prospect to manufacturing sectors for enhancement in sustainable performance. It has been observed that industries that have incorporated GLSS have attained greater performance than those executed independent strategies (Kaswan and Rathi 2020). In the previous studies, there is no evidence of an ordered and congenital practice for the integration of GLSS. For this, the current study presents a conceptual integration model of GLSS based on factual aspects (Enablers, toolset, etc.). Figure 3 illustrates the integration model of GLSS. In this model at the input side are different challenge pertains to the modern manufacturing industries. Operational excellence techniques (Lean, Six Sigma, Lean Six Sigma) have been devised over time horizons to undertake these challenges to ensure organisational competitiveness. As new challenges pertain to social, environmental, uncertain information, and volatile demand comes to fore, organisation have to embed different strategies to realise the advantage of each approach (Ershadi et al. 2020). So, associated challenges with industries foster the integration of different approaches under a single aspect. Furthermore, enablers are the measures that make an organisation ready for the execution of a novel approach and ensure its success. The enablers perform as crucial input which encourages the combination of GLSS, whereas the performances in trade-off supply as output.

It has been found that most of the enablers of the individual approach of Lean, Six Sigma, and Green technology are similar (Cherrafi et al. 2017). In the previous studies, pertains to GLSS, top management support, organisation readiness and effective training have been identified as the most prominent enablers to execute GLSS (Kaswan and Rathi 2020). The same enablers that have been reported in the studies pertain to the individual approach (Aboelmaged, 2011). Therefore, enablers foster the integration of individual Green, Lean, and Six Sigma approaches under the canopy of GLSS. Different tools of Green technology, Lean, and Six Sigma are used concurrently (depicted in framework) and supplement organisational sustainability. For instance, green technology tool, life cycle assessment (LCA), is used to identify potential hot spots, where high emission occurs due to faulty process metrics. LCA provides a solution that leads to saving in a material by altering process parameters and using eco-friendly measures. This will lead to the saving of material and result in the reduction of waste of overprocessing and overproduction that is related to Lean manufacturing. Therefore, the tools of each approach supplement the function aspect from other individual approaches. GLSS tools/techniques will facilitate the organisations to address the challenges on the shop floor and managerial levels. Table 2 depicts production challenges and GLSS tools/techniques associated to overcome the same. This model exhibits the
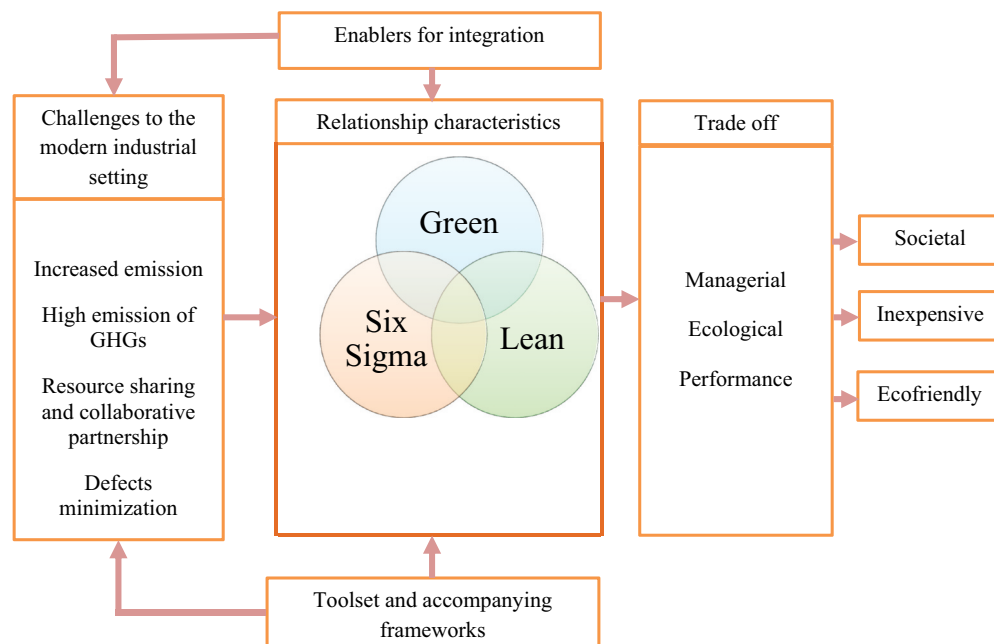
Figure 3. Integration of green lean and six sigma.

Table 2. Production challenges and GLSS tools.

Production Challenge/Problem	GLSS tool/Technique that can help
Batch Tracing	Kanban
Inventory and Equipment	VSM, Poka-yoke, SIPOC
High Emission of GHGs	LCA, VSM
Over Production	Kanban, Capacity Analysis
Defects Minimisation	Poka-yoke, LCA
Training to industrial Personnel	Kaizen, Standardisation
Imperfect by-product	Autonomation
Resource sharing and collaborative partnership	Standardisation
Perspective Plan	Policy Deployment, Hypothesis testing
Quality Control	Automation, Poka-yoke, JIT
Levelled exploitation	Heijunka
Automated Purchase	Kaizen
Materials controlling	5S
Estimating and understanding the relationship between variables	Regression Analysis

theoretical relationship linking these three synergetic strategies. The tools and related GLSS framework work as the assisting mechanism to support GLSS implementation and integration.

3.2. Proposed green lean six sigma framework

The manufacturing sector has employed Lean and Six Sigma strategies in their processes to minimise wastes and process variations. But, due to increasing concerns about sustainability and rigorous policies of the government, organisations have to shift operations dynamics towards eco-friendly methods. So, there is a great need for the inclusion of Green concepts in the LSS that leads to the development of an advanced strategy: GLSS. But to implement this comprehensive GLSS strategy, there is a requirement for a generic framework that dispenses step-by-step directions to attain sustainability. The proposed framework in this study includes a GLSS strategy into DMAIC methodology to attain both functional and environmental benefits (Figure 4). The objective of each step is

to monitor and reduce harmful impacts on the environment. The proposed framework of GLSS is executed through the following steps:

Step 1: Selection of suitable sustainability-centred project

The purpose of this step is to choose a suitable project that depends on emission level, the voice of business and customers. GLSS is a project-based strategy and implemented in a step-by-step manner by encompassing every compartment or unit separately (Sony and Naik 2020). The project is categorised as a specific part that is chosen for the commencement of this approach. The GLSS implementation requires significant expenditure and systemic modification in the firm. Therefore, it is essential to choose a suitable project of GLSS that reveals the substantial scope for improvement in sustainability.

For this, an inclusive study of different departments of the industry is carried out. The explicit study of whole industry dispenses wastes, imperfections and related ecological emission levels prevails to distinct sections of manufacturing sectors. The models are prepared for rejection level, imperfections and distinct emissions after many segments. The prioritisation of independent models is accomplished in the succeeding stage to choose a project that reveals substantial capability for enhancement in environmental performance. Also, a high-level SIPOC (Supplier Input Process Output Customer) is to be elevated to dispense transparency on customers, suppliers and input materials required. Tools like Eco QFD and critical to quality (CTQ) are used here to transform sustainably directed customer demand in technical and ecological aspects. Based on the customer demands, simultaneously with business and ecological aspects, a proper project is selected. After recognition of an appropriate project, a charter is developed depending on the scope, program and team of the recognised project. It dispenses a description of roles and responsibilities, objectives of the project, outlines major stakeholders incorporated, and defines a complete control plan of the project.

Table 3. Toolset for GLSS realisation in a manufacturing environment.

GLSS tools	Step 1 Selection of suitable sustainability centred project	Step 2 Estimation for mapping of the current state of the project	Step 3 Find out the prominent reason for emission and inefficiencies	Step 4 Select and implement the best solution	Step 5 Sustain with an adopted solution and make it mistake-proof
EVSM		√			
LCA		√		√	
Project charter	√				
VOC	√				
VOB	√				
Pareto chart			√		
Cause and Effect diagram			√		
BWM				√	
GRA	√			√	
Pugh matrix				√	
5 whys			√		
7'S				√	
3'R				√	
SOP					√
Solution matrix				√	
DOE				√	
OCAP					√
Brainstorming			√	√	
Performance improvement tool					√

Step 2: Estimation for mapping of the current state of the project

The purpose of this phase is to estimate the present state of the system or project undertaken. Now the performance of the adopted project has been estimated on various indices of GLSS. Based on collected data, sigma level, standard deviation" and C_{pk} of the project are evaluated with help of statistical tools. Further, assessment of carbon dioxide consumption, green energy coefficient, material consumption, etc. tools like life cycle assessment (LCA) environmental value stream mapping (EVSM) are used. To estimate the present stage of wastes, EVSM is treated as a beneficial tool of the lean concept. It dispenses an estimation of 'cycle' time and material consumption covering distinct phases and furnishes effective utilisation of time and funds. EVSM also estimates water, power and material consumption and environmental effects in conjunction with conventional value stream specifications like cycle time, changeover time, uptime, and lead time for all projects. Elaborating an Environmental Current State Map assists in predicting authentic manufacturing circumstances and dispenses awareness about resource consumption from point of view of the environment. Moreover, mapping is also employed in this step to gather details concerning the project to point out crucial input and output variables. Furthermore, LCA has been employed in the assessment process to estimate the ecological effects of every sub-process in distinct ecological influence classes. The integrated LCA and EVSM aid in the analysis of several green and lean measures that dispenses identification of possible hot spots for further improvements.

Step 3: Find out the prominent reason for emission and inefficiencies

The purpose of this step is to identify the major causes associated with wastes, emissions and imperfections in the adopted project. In this phase, firstly, value-added, and non-value-added actions have been recognised from the opinions of both customer and business. After this, the process cycle efficiency is directed to equate outstanding standards to detect how much enhancement is required. At the same time, a project is investigated to recognise the bottlenecks points and restraints in an adopted project. After investigation of the project under concern, the causes for emissions, defects and variations are identified. Here tools, like brainstorming, cause and effect diagram (C&E), five why analysis, life cycle impact assessment, failure mode effect analysis (FMEA), etc. are used. The project team here may use brainstorming sessions to recognise possible reasons for the development of these defects. Life cycle impact assessment has been carried out in this stage to measure the possible ecological effects of every process to identify possible sources for high emission levels. Once the potential causes have been investigated, then the study is constricted to find few pre-eminent causes. Tools like Pareto chart, principal component analysis (PCA), hypothesis, brainstorming and regression analysis are also been employed to unearth crucial root causes. Thus, these steps lead to the identification of main reasons for inefficiencies that require to addressed to improve sustainability measures of the project undertaken.

Step 4: Select and implement the best solution

After identifying major reasons for rejections and inefficiencies, then inherent solutions are suggested, explored and the best solution is implemented to handle pre-eminent causes. Here, assured cause and effect relationships are employed to detect a broad range of possible solutions. The solutions dispensed at the present juncture can be refused derived fuel (RDF), upcycling, anaerobic digestion (AD), and recirculation of water. In this phase, high innovation is required from the personnel of the organisation. Relevant training to the
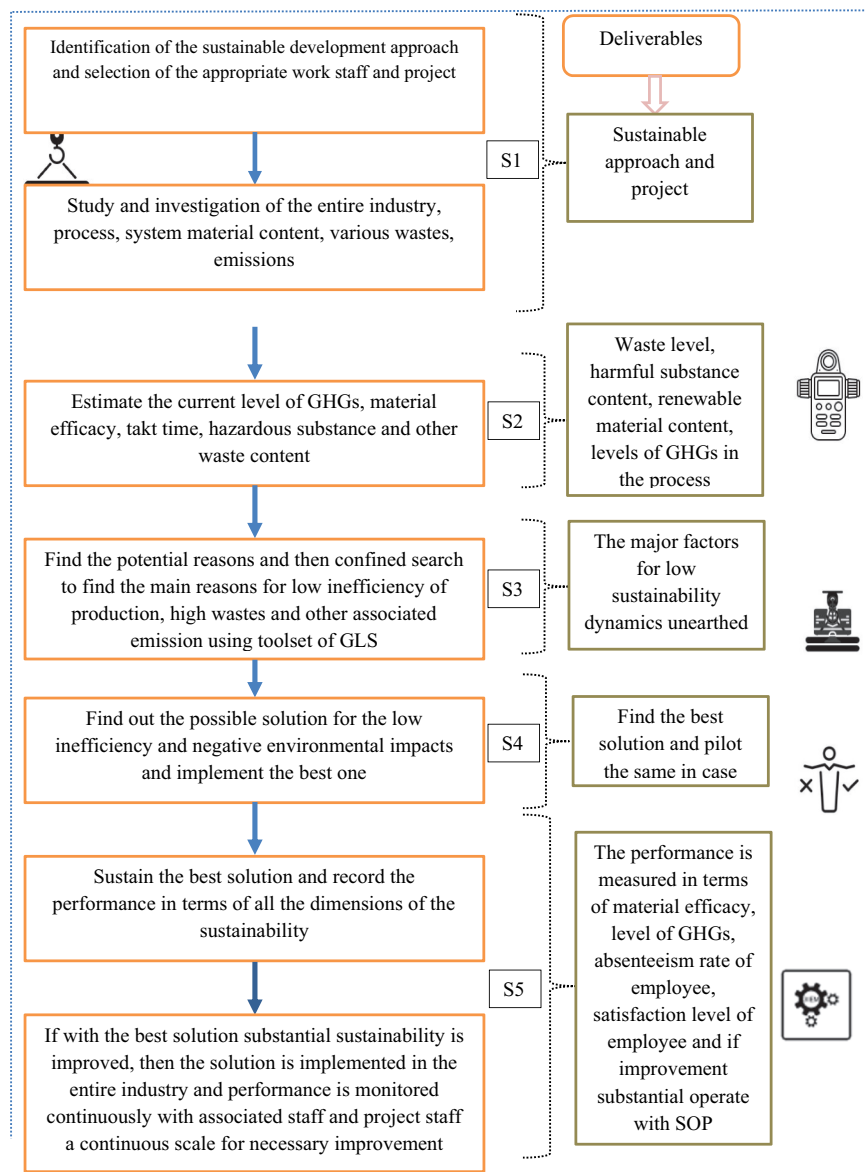
Figure 4. Green lean six sigma framework pertain to manufacturing.

industrial personnel and employees engaged in accomplishing the enhancement activities must be furnished to corroborate the effective execution of the GLSS framework. The feasible solutions are elaborated, standards are established, and elucidations are assessed to find out the best solution. Every origin of particulars like the customer, project sponsors, stakeholders and employed are utilised to propel assessment measures. CTQs, the business concerned, regulatory norms, are the crucial criteria that are used at this stage. Tools like solution matrix, Pugh matrix, Kaizen, and design of experiments (DOE), LCA, etc. are being employed to assess the best possible solutions against criteria.

DOE is carried out in this phase to identify the incredible settings for a merger of factors. Kaizen activities were suggested to improve those activities that do not outline any value based on rejection assortment. These were devised such that both functional and ecological requirements are fulfilled and all-inclusive efficiency gets improved. The Pugh matrix decides robustness and

deficiencies of possible solutions so that robustness can be sustained and weakness can be removed. Here, the professionals should be open to adopt or integrate solutions for the determination of the pre-eminent solutions. After choosing the best potential solution, the existing VSM is rephrased to exhibit what practice will seem after changes are devised. The chosen best solution is implemented in the concerned project as a pilot project.

Step 5: Sustain with an adopted solution and make it mistake-proof

The purpose of this step is to sustain or control the best solution if significant enhancement is noticed in the project. This phase confirms that the benefits attained after executing enhancement measures are preserved after the accomplishment of the project. The outcomes acquired after executing enhancements measures must be conveyed to every employee who was engaged in the project. Moreover, a flowchart is prepared to distinctly express the responsibility and jobs of

each person to sustain the improvements. Performance actions must be outlined to assess the performance of the project after enhancements. The outlined typical initiatives which enhance functional and ecological efficiencies are certified with the help of an appropriate control plan. Appropriate training is planned for persons included in the practice to handle modifications made and assist the best solution. Tools like standard operating procedures (SOP), visual management, and Poke Yoke are used to sustain project success. Here, the process is re-explored with the help of EVSM and LCA' to detect the level of rejection and emission metrics. Moreover, control chart, data metrics and control charts are also used to re-evaluate sigma level, C_{pk}, water, power and raw material consumption. If re-evaluated performance specifications are better than in the measuring phase, then adopted solution is retained. Once the success of the pilot solution is sustained, the same can be implemented throughout the industry for improvement in the sustainability of the industry to a greater extent. Therefore, inclusive execution of GLSS provides impetus to sustainability improvement pursuits of the manufacturing industry and enhances competitive advantage at the global platform through the production of sustainable products.

4. Results and discussion

Green Lean strategy has been broadly employed in manufacturing sectors; corresponding, limited work has been done pertains to the execution of GLSS (Hussain et al. 2019; Kumar et al. 2016). It is in its development stage, and manufacturing sectors are resistant to validate this strategy because of cultural differences and repulsion of practical shifts in the work process (Kumar et al. 2016). Once the integration of GLSS has been validated, one can simply communicate the distinct performances of the latest technologies. Enablers are the readiness bases for the manufacturing sectors to execute a novel approach (Laureani and Antony 2012). The industrial managers have taken into the consideration the changeover methods that assist in the effective execution of the new approach (Näslund, 2013). Table 4 represents the enablers for the adoption of GLSS. It is observed that management dedication and participation, team effort and organisational willingness are the key enablers for the effective execution of this strategy. The management dedication, knowledge base of GLSS tools, and assimilation of real-time dataset leads to the sublime success of the GLSS program. The authors have proposed theoretical integration of GLSS that motivates executives to embrace GLSS philosophy in their respective organisations. The study also reveals that the accomplishment of the project in distinct organisations will lead to an improved sigma level of organisation through the reduction in defects. The proposed framework will boost the organisation Green Lean initiative, consequently leads to improved environmental performance in business operations. Moreover, successful execution of the said framework will result in the reduction of material consumption, water usage, and energy utilisation that will enhance environmental efficiency. Besides, parameters that pertain to Lean like, cycle time, lead time, and work in process will significantly reduce through the adoption of the proposed GLSS framework.

The GLSS toolsets also boost the integration and execution of the GLSS strategy. GLSS tools explore hot spots, eliminate rejections, and assists in the best exploitation of resources (Kaswan and Rathi 2021a). Table 3 depcits GLSS toolser for manufacturing industry. The SIPOC chart and EVSM have been found as the most broadly employed tools. Moreover, the most generally employed tools found to be: cause and effect diagram (C&E), process capability and reverse logistics. After the assessment of 18 research manuscripts relates to GLSS, it is observed that most of the research manuscripts used 'lean tools' to obtain lean and green goals. So, manufacturing sectors are inclined towards Lean tools to satisfy environmental measures. The importance of GLSS is enhancing continuously due to its pragmatic impacts on sustainability dynamics. The current work dispenses an integration of GLSS employed on conceptual points and proposed a comprehensive DMAIC-based framework. The developed framework performs as a pilot frame for GLSS execution in a single unit or division of the manufacturing industry. This framework can be expanded in the entire firm after its effective implementation of a pilot project. The proposed framework exhibits the integration of Green and Lean matrices at each step that has been excluded in the prior studies related to Green Lean. Green and Lean actions perform as potential areas for the selection of the project in the first step of the framework of GLSS. To estimate the present situation of the system, in the second step of GLSS execution tools such that EVSM, LCA are employed. The inherent measures for rejections are detected in the third step of 'framework with the help of tools such as LCA and traditional statistical tools. To find probable solutions in the subsequent step of framework' tools like life 'cycle interpretation, EVSM, 5S, Kaizen, etc. are employed. The adopted GLSS framework is sustained for a 'longer span if gains made are significant than the preceding situation of 'project 'under consideration. The proposed framework of GLSS will ensure organisation sustainability through optimum resource utilisation, reduction of wastes, defects, and mitigation of environmental emissions.

5. Implications

The present research work exhibits both theoretical and practical implications. The subsequent subsection depicts the theoretical and practical implications of this research work.

5.1 Theoretical implications

There is a need to scale up the worldwide response to mitigate GHGs emissions through the incorporation of sustainable business practices. GLSS approach mitigates environmental footprint by systematically identifying and mitigating possible hot spots that improves the performance of triple bottom line (social, economic, and environmental). This study develops a thorough knowledge for potential researchers and academia by providing deep insights into integral measures and frameworks. Measures of integration (enablers, barriers, tools, etc) foster the success rate of the GLSS project as they serve as basic know-how before the execution of any sustainability

Sr. No.	Enablers	Description	References
1	Management dedication and commitment	The participation, support, and vision of the management perform a crucial role in executing the GLSS approach in manufacturing sectors. Management dedication performs a crucial role in the firm's environmental retaliation adequate human, technological and economic resources for executing this strategy.	Bhuiyan and Baghel 2005; Yadav and Desai 2016
2	Allocation of Funds	Funds allocation commences with suitable planning which the manufacturing sectors ready for its objectives and visions for the future. Once the objectives are prepared, the manufacturing sectors require allocating sufficient funds.	Snee 2010
3	Quality of raw material	Quality of raw material is the basis to ensure topmost quality products. A topmost quality product assists the satisfaction of the customers. It will result in improved functional performances, profitability, and the production of high specification products.	
4	Team effort	To attain the objectives of GLSS, every employee of the firm must perform as a group.	Sreedharan et al. 2018; Ben Ruben, Vinodh, and Asokan 2017
5	Prudent interconnection with the retailers	Faithful retailers are necessary with the purpose that raw materials and other components have been provided for some time.	Siegel et al. 2019
6	Proficient training and education programmes	Proficient training and education programs are the most vital needs for executing the GLSS strategy in manufacturing sectors successfully. A rigorously planned training program induced the essential knowledge, skills, and approaches in its employees that are essential for accomplishing the task.	Ravi and Shankar 2005
7	Relating GLSS to business approach	Relating the GLSS concept to business approaches assist the firms to attain prudent business objectives through the utilisation of policy decisions by the management care.	Antony, Gijo, and Childe 2012
8	Culture with effectual correspondence	Change in the culture is crucial for the progress of the manufacturing sectors. The workers associating with any firm should have the liberty of sharing their views to arise with inventive solutions to provide benefits to the organisations.	Hu et al. 2008; Zu, Robbins, and Fredendall 2010
9	Effective Scheduling	Waiting time is a vital problem in manufacturing operations. An effective scheduling system assists in minimising time guiding to curb cost surges, time-preserving, and better performance of the manufacturing sectors.	Maleyeff, Arnheiter, and Venkateswaran (2012)
10	Organizational know-how	Each worker of an organisation must be self-assured with the whole system such that the individual can lay down his or her perceptive attempts for the progress of the organisation.	Kaswan and Rathi 2021
11	Organizational willingness	The business must be in a situation to initiate GLSS in their processes as it needs again transition.	Cherrafi et al. 2017
12	Selection of appropriate tools	Tool selection and technical expertise is key to the execution of the GLSS program	Sony and Naik 2020; Sreedharan et al., 2020
13	Collection of data and performance measures	Collection of data and performance measures is essential for the achievement of the GLSS initiative as 'they dispense support for comparisons.	Habidin and Yusof 2012; Yadav, Seth, and Desai 2018
14	Incorporation beyond the phases of a 'product development 'cycle'	Concurrent engineering conception and incorporation at several phases of product development is necessary to instigate genuine products.	Luthra et al. 2011; Kaswan and Rathi 2020
15	Involvement of suppliers	The involvement of suppliers with the manufacturer is vital for the execution of the GLSS concept. Suppliers are the origin of renovation in the firm. Better involvement of suppliers results in the best quality products.	Kushwaha 2010; Luthra et al. 2011
16	Use of appropriate technology	Advanced technology facilitates organisations to improve the quality of products and enhances the overall environmental performance. It helps the organisation to improve communication, proper utilisation of resources, and minimising paperwork which would result in significant functional performances.	Ravi and Shankar 2005
17	Effective visual system	Visual control helps the organisations to identify those areas where improvements are required to be undertaken.	Shen and Tam 2002
18	Manufacturing facilities with good quality	An accurate, precise, and good quality manufacturing facility assists in the production of high quality and cost-effective products.	Antony, Gijo, and Childe 2012
19	Customer engagement	The customer engagement approach assists the organisations to consummate the business with minimum overheads on human resources. It also minimises the need for middlemen.	Albliwi et al. 2014
20	Green design actions	Green design implies eco-design which targets mitigating the environmental effects yielded by-product at several phases of product chain commencing from taking out of materials to the utilisation of the product.	Vinodh et al., 2011; Yadav et al. 2017

improvement project. Enablers are the promptness measures that make an organisation ready to execute a novel approach. Barriers knowledge base enables researchers to find out the avenues that mitigate the intensity of barriers. Systematic phase-wise toolset provided in this study augment researchers and academicians to adjudge which tool to be implemented at different stages of execution of the GLSS project. The proposed GLSS framework will methodologically facilitate researchers to implement GLSS in manufacturing industries. This will enrich insights on assessment of different metrics, reasons for inefficiencies,

identification and implementation of sustainable solutions during the execution of projects related to GLSS and sustainability.

5.2 Practical implications

The proposed framework of GLSS will methodologically facilitate manufacturing industries to implement sustainability improvement initiatives. The developed framework is designed in such a way that each phase contributes to the reduction of wastes and emissions, leads to enhancement in

revenue, making this initiative a worthwhile proposition in the long run. Moreover, this work also furnishes guidelines to industrial personnel for managing the GLSS approach conductive, to secure more flexible, vigorous and methodical processes. The implementation of the GLSS strategy facilitates industrial organisations to achieve organisational and environmental benefits. Further, this study encourages industrial managers and practitioners to recognise possible hot spots that require immediate attention to increase organisational sustainability. This study facilitates the entrepreneurs and ecologists to start sustainable industrial practices like GLSS that leads to reduced ecological damage by promoting: reduce, reuse, recycle, recover and residual management (5'R). Altogether, humanity will be promoted from this study in terms of mitigated emissions and other non-value-added activities through the sequential execution of a sustainable GLSS approach.

6. Conclusions

GLSS has been perceived as a comprehensive strategy that mitigates harmful environmental impacts and provides top-quality environmentally sound products. The purpose of this approach is to enhance metrics like quality, profitability, customer satisfaction, process efficiency and responsiveness. In this research work, GLSS integration has been proposed centred on intangible features like enablers, toolsets, etc. The enablers encourage the integration of the GLSS strategy and related tools and execution techniques to augment GLSS integration. Management commitment and team efforts have been recognised as the most remarkable enablers to execute GLSS strategy in manufacturing industries. The components and the elements of this framework have been presented in such a way that it would fetch high specification eco-friendly products more conveniently when applied in the manufacturing organisations. The proposed GLSS framework dispenses a prospect for the manufacturing enterprises to set up the best practices for defect minimisation and mitigation of environmental impacts.

6.1 Limitations and future scope

Despite several contributions, the present study has a few limitations. Firstly, the proposed GLSS implementation framework takes considerable time during implementation as different tools evolved at different stages of execution. Therefore, the generalisation of outcomes should be taken into consideration just after further studies in distinct manufacturing units. Secondly, limitations associated with this research work is that framework of GLSS has not been tested practically. This drawback imparts motivation for future research directions to implement GLSS in various manufacturing industries. The developed framework must be tested in multi-cultural environments to prospect the contingent and societal impacts on the developed framework. In offing, the proposed framework can be extended by incorporating more sustainability drivers and other associated tools of social sustainability. Further study can also expand GLSS applicability for sustainability

improvement by integrating aspects of industry 4.0 and circular economy.

Notes on contributors

Vishwas Yadav is pursuing Ph.D. 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 specialization in Industrial and Production from National Institute of Technology, Kurukshetra. He completed his bachelor's in Mechanical Engineering from UIET, Maharishi Dayanand University, Rohtak. He has a teaching experience more than 6 years. He is adept in optimization and decision making techniques like: ISM, GRA, AHP, BWM, Decision-Making Trial and Evaluation Laboratory.

Dr. 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. He is adept in optimization and decision making techniques like: Design of Experiments, Taguchi Method, Experimental Analysis, Response surface methodology.

Dr. Rajeev Rathi is working as an Associate Professor in the School of Mechanical Engineering Lovely Professional University, Punjab, 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 optimization and decision making techniques like: ISM, Preference Ranking Organization 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.

Dr. Gunjan Yadav is currently working as Associate Professor and Head in Mechanical Engineering Department at Swarnim Startup & Innovation University (SSIU), Gandhinagar (India). He is having more than 12 years of Teaching, Training, Consultancy, Research experience. He has had his education and training in Mechanical and Industrial Engineering at B.E. and M.E. He has completed his Ph.D. from Sardar Vallabhbhai National Institute of Technology (SVNIT), Surat. He has obtained MHRD sponsored funding of ▢ 1.5 Lacs to pursue International Projects. He is serving as reviewer to renowned International Journals such as Journal of Cleaner Production (Elsevier), Production Planning and Control (Taylor & Francis), Transportation Research: Part A (Elsevier), International Journal of Production Research (Taylor & Francis) and many more. Presently his h-index is 15 and i-10 index is 17. He has contributed 60+ research papers at National/International level at various journals (SCI/Scopus indexed), seminars and conferences. He is presently guiding 12 M.Tech and 3 Ph.D. students. He has chaired sessions at International/National conferences and delivered invited talks in various NITs and government funded institutions. He is presently associated with various societies which include Institution of Engineers (India), Indian Institution of Industrial Engineering (IIIE), Indian Society of Technical Education (ISTE), Operation Research Society of India (ORSI). He regularly conducts training programs and guides research scholars on areas such as Sustainable Manufacturing, Lean Six Sigma, QMS, GT, Renewable

Energy Management, Quality and Productivity Improvement etc. He has been in association with organization of several conferences and open as well as in-house training programs. He can be contacted at gunjanyadav86@gmail.com

Dr. Anil Kumar is a Senior Lecturer (Associate Professor) at Guildhall School of Business and Law, London Metropolitan University (LMU), London, U.K. For the last ten years, he has been associated with teaching and research. Before joining LMU, he was Post-Doctoral Research Fellow in area of Decision Sciences at Centre for Supply Chain Improvement, University of Derby, United Kingdom (UK). He earned his Ph.D. in Management Science from ABV-Indian Institute of Information Technology and Management, Gwalior, India. He did his graduation in Mathematics (Hons) and MSc (Mathematics) from Kurukshetra University, India. He earned his Master of Business Administration (MBA) and qualified National Eligibility Test (NET), June 2011. He has contributed over 100+ research papers in international referred & national journals, and conferences at the international and national level. He has sound analytical capabilities to handle commercial consultancy projects and to deliver business improvement projects. He has skills and expertise of Advance Statistics Models, Multivariate Analysis, Multi-Criteria Decision Making, Fuzzy Theory, Fuzzy Optimisation, Fuzzy Multi-Criteria Decision Making, Grey Theory and Analysis, Machine Learning, Application of Soft-Computing, Econometrics Models etc. His areas of research are sustainability science, green/sustainable supply chain management, customer retention, green purchasing behaviour, sustainable procurement, sustainable development, circular economy, Industry 4.0, performance measurement, human capital in supply chain and operations; decision modelling for sustainable business, and integration of operation area with others areas.

Dr. Mahender Singh Kaswan is an Assistant Professor in the School of Mechanical Engineering Lovely Professional University, Punjab, India. He holds a Ph.D. in Mechanical Engineering from Lovely Professional University, Punjab, M.Tech. in Industrial and Production Engineering from National Institute of Technology Kurkshetra India, and B.E. in Mechanical Engineering from former Career Institute of Technology and Management, India (Manav Rachna International University). He has published a number of articles in leading international journals and conferences. His research interests include lean six sigma, green manufacturing, life cycle assessment, circular economy, industry 4.0, clean technologies measures, and Sustainable supply chain.

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