Exploration and Investigation of Green Lean Six Sigma Adoption Barriers for Manufacturing Sustainability

Abstract

The increased awareness about effect of operations on sustainability dynamics and governmental pressure to cut emission rates has forced industries to adopt sustainable approaches like Green Lean Six Sigma (GLSS). Despite increasing interest in GLSS, very limited research has focused on its implementation and no research has investigated barriers that hinder GLSS execution. This study investigates GLSS implementation barriers, their relationship, and removal of same in manufacturing sector. In this research, 18 GLSS barriers have been recognized through literature review and formulated into logical groups using principal component analysis. This study pioneers with decision making trial and evaluation laboratory (DEMATEL) with intuitionistic fuzzy set to prioritize barriers and handle the important and causal relationship among the same. The results of the study were validated through intuitionistic fuzzy best worst method (IF-BWM). The results reveal that management-related barriers are the top-ranked followed by environmental and organization barriers with BWM weights 0.5283, 0.1704, and 0.1035 respectively. This provides impetus to policymakers for induction of GLSS in business organization to make harmony between economic development and environmental sustainability.

Keywords: Green Lean Six Sigma; Manufacturing sector; DEMATEL; Best worst method; Sustainability.

1. Introduction

Green Lean Six Sigma (GLSS) is a sustainable development approach that leads to improved process performance through the reduction of wastes, variations, and environmental emissions [1]. The term “Lean Six Sigma” (LSS) was used at the end of the last century to depict an approach that delivers high operational performance through application of different statistical and quality tools [2] [3]. The successful execution of LSS make an organization enable to reduce its defect level, wastes, and helps to stay competitive in global market [4] [5]. In the recent scenario, increased customer focus towards sustainable products has forced the industries to cut current level of emissions [6] [7]. Although LSS leads to improved organizational performance and profitability, it is not able to address environmental issues. But if LSS is integrated with Green technology, then integrated approach called GLSS, will lead to reduced negative environmental impacts. GLSS leads to improvement in material efficiency, promotes 3'R (reduce, reuse, and recycle), and makes the process more streamlined [8].

Although Green, Lean, and Six Sigma are three different approaches but can be integrated under the ambit of a single entity [9]. GLSS is an inclusive approach that meets modern demand of customers and leads to increased sustainability through systematic application of GLSS tools[10]. In the first step of GLSS execution, a project that shows the maximum potential for sustainability is selected based on customer and business requirements. Project in GLSS is a particular segment or shop of the industry, where GLSS has to be implemented initially. Existing state of the selected project is estimated in second step of GLSS execution. Here, present state of project is measured using tools like life cycle assessment (LCA), environmental value stream mapping (EVSM), etc. The third step of GLSS is related to find out the main causes of the various wastes and inefficiencies in the project. A thorough investigation of selected project is done to find reasons for a high level of environmental emissions, variation in process, high rejection rate, etc are found out. The tools like cause and effect diagram, 5 why analysis, etc. are used to explore the possible reasons for the inefficiencies. In the fourth step of the implementation, various possible solutions for improvement in sustainability are proposed, evaluated and the best solution is implemented. The detailed exploration of possible solutions by GLSS tools leads to identification of the best solution. The best solution is now implemented as a preliminary solution, activities to be done are documented, and personnel is educated in different aspects of the best-identified solution.

The changeover for traditional approach of doing business to GLSS is a substantial task as many GLSS programs have failed during their inception stage [11]. This can be attributed due to lack of knowledge base on Green Lean metrics, GLSS tools, causes of waste and emission, GLSS adoption barriers, etc. [8]. The barriers are constraints or path-breakers that, if get rid of from a system or process, leads to smooth execution of a program [12]. So, there is an immense need to relook GLSS adoption barriers in manufacturing environment. The article presents a study on identification and investigation of GLSS barriers in manufacturing sector. Eighteen barriers to GLSS adoption have been identified through a detailed literature survey and further categorized into six logical groups using principal component analysis (PCA) using responses from experts (industrial personnel and academicians).

There exist interrelationship among grouped GLSS barriers, and it must be exhibited to decide which barriers affect other barriers. For this, IF-DEMATEL method has been used to bifurcate grouped barriers into cause and effects barriers. Moreover, due to limited finance and time constraints, organizations can only focus on critical GLSS barriers. So, the prioritization of the barriers has been done using IF-DEMATEL, and ranks of the barriers were further validated using intuitionistic fuzzy best worst method (IF-BWM). The present work considers case of a manufacturing industry for investigation of GLSS barriers. The research questions addressed in the present study are:

- What are the barriers to the adoption of GLSS for the manufacturing industries?
- What type of contextual relationship exists among the barriers and which barriers should be removed at the initial stage for successful execution of the GLSS program?
- How practitioners and industrial managers can remove GLSS adoption barriers through a systematic understanding of the GLSS concepts?

2. Literature Review

GLSS strategy aims to improve sustainability dynamics of industry through systematic reduction of wastes, inefficiencies, and associated environmental impacts. The development of GLSS can trace back to evolution of the Toyota production system (TPS) [13]. The Lean approach enhances organizational efficacy through reduction of wastes, but not able to address climate issues [12]. This shortcoming of Lean can be addressed by integration of Green technology within Lean. The integrated Green Lean (GL) approach has been one of answers for industrial organizations to make them environmentally sustainable [14]. The integration of GL seems natural based on the common motto of waste reduction [15]. But increased product rejection due to process variation leads to more rework and wastes that adversely affects organizational sustainability [16]. The integrated GL approach is not able to address this issue of production system. This demands integration of GL approach with Six Sigma that reduces defects [17]. Each approach has its unique capabilities and associated drawbacks, but each approach supplements another to cope with challenges [17]. The similarities between Lean production, Six Sigma, and Green technologies based on the insights gains from Ruben et al. [18] and Garza- Reyes [13] are represented in table 1.

Table 1: Similarities among Lean production, Green technology, and Six Sigma

S. No.	Characteristic	Lean view	Green View	Six Sigma View
1	Focus	Improve industry performance through the reduction of wastages	Increase the utilization efficiency of energy to improve ecological efficiency	Improve performance through reduction in defective parts
2	Competitiveness and profitability	Make the organization more profitable through the reduction of various non-value added activities	Strong orientation towards competitiveness through minimization of environmental impacts	Increased competition through the delivery of high quality of products and lesser rework
3	Waste	Mainly focus on waste reduction to reduce cost	Focus on environmental waste reduction	Defects reduction leads to lesser rework
4	Customers	Cost reduction; strong customer focus through the elimination of non-value-added activities	Aim to get customer pride through production of eco-friendly and lesser input of organizational resources.	Aims to achieve customer satisfaction through reduction of defects

So, the inherent characteristics and capabilities of the Green technology, Lean manufacturing, and Six Sigma lead to the development of Green Lean Six Sigma (GLSS). It has found applications in public enterprises, automotive, and construction industry for improvement in the existing process [19]. Banawi and Bilec [19] proposed a model to integrate Green technology, Lean, and Six Sigma to improve environmental efficiency of the construction industry. Cherraffi et al. [15] proposed a model to integrate GLSS for superior sustainability. Ruben et al. [18] proposed environmental associated LSS framework for manufacturing enterprise. Kumar et al. [20] found GLSS barriers in product development process and model same using interpretive structural modeling (ISM). Kaswan and Rathi [21][7] found enablers of GLSS and proposed framework of GLSS. Sony and Naik [1] provided a GLSS framework for the coal mine industry and find that integrated model leads to reduction in current level of graphite and dust.

GLSS found very few applications in the manufacturing sector because of its novelty and cultural difference; the organizations have faced various challenges or barriers to implement GLSS[22]. Barriers are specified as managerial and technical challenges that defer an organization to get desired targets [23]. Table 2 depicts the prominent studies pertains to barriers and enablers of LSS, Six Sigma, and GLSS. The GLSS barriers exhibit contextual relationship and it is imperative to understand the relationships among the barriers [20]. Based on the nature of barriers, they can be classified into different logical groups. Parmar and Desai [24] classified 20 enablers of sustainable Lean Six Sigma (SLSS) into different groups based on expert opinions. Aboelmaged [23] classified 47 barriers of Six Sigma into groups of the knowledge base, support, sustainability, resource, customer focus, complexity, and alignment barriers using principal component analysis. Any business organization needs to identify key challenges or barriers within a particular time frame to take competitive advantages over competitors [23]. Once failure factors have been identified, and contextual relation established then improvements measures are undertaken to overcome these barriers. To develop contextual relationship among factors different methods have been adopted like ISM, Structural Equation Modeling, Decision Making Trial and Evaluation Laboratory (DEMATEL), etc.

DEMATEL, an approach to solve the complex decision-making problems was developed by Gabus and Fontela in 1973 [25]. The DEMATEL method clarifies the interrelation among the selected criteria through visual depiction of the causal diagram [26]. It has been applied in various life problems like supplier selection [27] etc. DEMATEL requires decision-makers to provide assessment against criteria using assessment scales. Sometimes crisp value does not truly reflect human thinking, so to circumvent this disadvantage fuzzy DEMATEL was introduced, where DM's preferences were measured against fuzzy membership degree [26]. The decision making becomes quite difficult in an uncertain or fuzzy ambiance. To reduce the vagueness in the human perceptions the favorites are represented as fuzzy numbers rather than binary or classical logic [28]. The fuzzy sets don't consider the degree of hesitancy in human judgment. To overcome this, Atanassov [29] developed intuitionistic fuzzy set (IFS) an alternative to represent the membership degree, and hesitancy degree. The IFNs is a generalization of fuzzy set defines the membership and non-membership of a given member by an exact value between 0 and 1. The IFS help DMs to denote their preferences accurately by considering the disagreement degree [30]. The main benefits of the IFS are as follows: [31] [32]

- IFS enable the practitioners to model unidentified information using a degree of hesitation. So in real-life problems, where DMs are not sure for their preferences, IFS would be more comparable than the normal fuzzy set to get the opinions.
- IFS is special kind of type 2 fuzzy set that have three degree of grades called membership, non-membership, and hesitancy, whereas all other fuzzy numbers give one grade of membership in the interval [0,1].

Based on the literature available it has found that the application of GLSS has not explored extensively due to its novelty and cultural difference, and resistive nature to adopt a new approach. To bridge the gaps in the literature, the present study deals with the exploration, establishing the contextual relationship, prioritizing of GLSS adoption barriers.

Table 2: Prominent studies pertains to GLSS, Six Sigma, and LSS's barriers and enablers

S. No.	Authors	Factor	Findings and Methodology	Sector
1	Gamal Aboelmaged [23]	Barriers	Explored barriers to Six Sigma implementation based on questionnaire base study and reveled that soft impediments are the most crucial barriers to Six Sigma implementation	General
2	Raghunath and Jayathirtha [33]	Barriers	Explored barriers of Six Sigma implementation for SMEs and found that lack of management commitment is the most critical barriers in the execution of this methodology	General
3	Albliwi et al. [34]	Barriers	Identified failure factors of LSS from the comprehensive literature study and It has found that lack of management obligation and participation, lack of communication, lack of training, as failure factors among different industrial settings.	
4	Mittal et al. [35]	Barriers	Identified barriers of the GL manufacturing system through a two-way assessment process and found that reluctance to production disruption as one of the prominent barrier.	Manufact uring
5	Kumar et al. [20]	Barriers	Modeled barriers of GLSS in the product development process using ISM-MICAC and deduced that lack of management commitment as one of the most prominent barrier.	General
6	Pandey et al. [36]	Enabler s	Identified enablers of GLSS for business sector and derived into five segmental groups of eighteen enablers and further prioritized the same using analytical hierarchy process (AHP).	General
7	Shamsi and Alam [37]	Barriers	Explored barriers of LSS in the IT sector and found short term involvement in LSS projects, difficulty in data collection, and projection section as the most significant barriers.	IT
8	Yadav et al.[38]	Barriers	Authors used techno-managerial study for identification and fuzzy AHP-modified TOPSIS for prioritization of LSS barriers and provided solutions to overcome adoption challenges	General
9	Kaswan and Rathi [21]	Enabler s	Modeled enablers of GLSS using ISM-MICAC and found that Effective data assimilation and GL metrics identification is one key enabler for GLSS adoption.	General
10	Hussain et al. [10]	Barriers	Found that unstable political government and support as key challenges to adopt GLSS in the construction sector of Pakistan	Construct ion
11	Kaswan and Rathi [39]	Enabler s	Identified and prioritized the enablers of GLSS using BWM method found that organization readiness for GL is the most dominating factor for GLSS execution.	Manufact uring
12	Singh et al.[40]	Barriers	Used DEMATEL approach to establish relationship and prioritize barriers to integrated GL approach and found that Lack of management support and lack of employee training as key barriers to adoption GL.	General

Research Gaps

Based on the comprehensive review it has found that very few studies exist in the literature pertains to the integrated GLSS approach and all such studies highlighted that successful execution of this approach not only makes the organization's productivity better but leads to a reduction in carbon footprint. Although the study pertains to enablers or success factors, and barriers pertain to construction sector exists. The study pertains to barriers in the product develop process that exhibits hierarchical structure of barriers exists in the literature. But no work related to exploration, establishing the contextual relationship among GLSS barriers for understanding intrigue nature of barriers exists in the literature. Moreover, no study of GLSS barriers provides prioritization of barriers that facilitate the industrial managers to systematically remove the most critical barriers from the implementation point of view. The previous study of barriers were only limited to the phase of product development mainly to the design and prototype point of view, but present study investigates barriers from the point of view for realization of product by covering different aspects from the sustainability. The said research gaps provide an impetus for the present study.

3. Research Methodology

The research methodology adopted in the present work consists of two distinct phases. Figure 1 demonstrates various phases of adopted research methodology. The various phases of the methodology are as follows:

Phase 1: Identification and grouping of GLSS barriers

Phase 1: In the first phase, a comprehensive literature survey was done to identify barriers of GLSS in manufacturing environment. This results in identification of 18 barriers of GLSS that hinders its implementation (Table 3). A well-defined questionnaire was prepared and to check internal reliability of questionnaire Cronbach's alpha test was performed. Alpha has been recognized as an important concept for assessment of questionnaire in medical and statistical sciences. It was developed by Lee Cronbach in 1951 and its values vary between 0 and 1 [41]. The value of the alpha is 0.83 that depicts the high reliability of the formulated questionnaire. The questionnaire was sent to the practitioners at the mid and high levels of management in the manufacturing industry, LSS personnel (LSS green belt and black belt, these LSS personnel comes from industrial and academic background (Industry/ Academia) as some of them belong to academia and other are actively engaged with LSS projects in industries), and academicians from academic institutions (106 respondents). Table 4 depicts the characteristics and demographic background of respondents. The potential experts were identified through the purposive sampling technique using the Linkedin profiles and personal contacts.

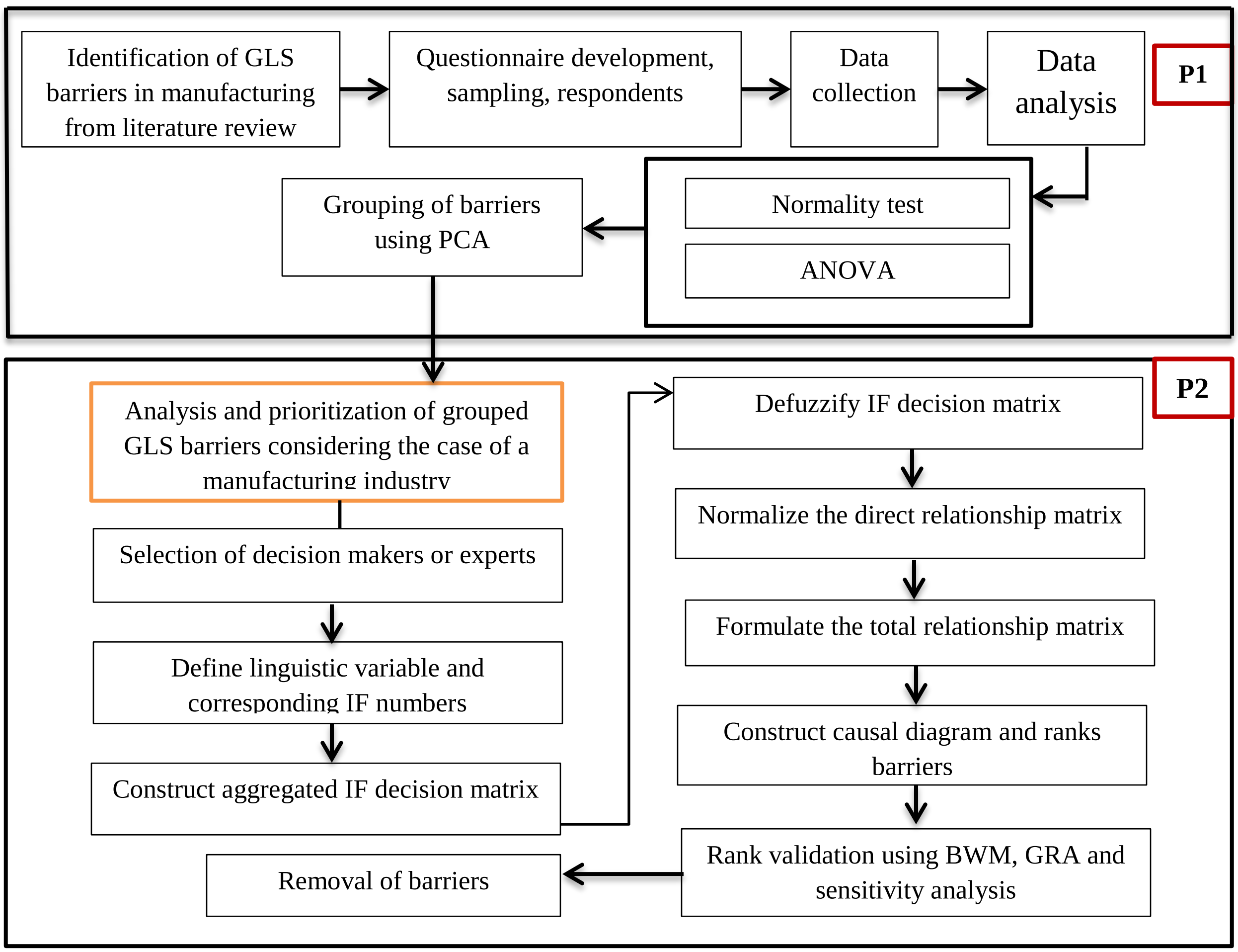

Table 3: Green Lean Six Sigma barriers

S. No.	Barriers	Description	Reference
1	Lack of understanding of different VOC	The selection of the GLSS project rests on the customer's view; many times, organizations have failed in the past to convert VOC into desired results.	[34]
2	Inappropriate GL areas identification	Successful GLSS projects demand identification of a particular shop/ section of the industry that has maximum effects on organizational sustainability.	[42]

3	Lack of CI thinking	The positive mindset with constant improvement thinking is key to the success of the GLSS project within an organization.	[42]
4	Resistance to change	Traditional practices are being adopted by industries operated for a very long time; managers have resistance to change it.	[43]
5	Inadequate regulatory framework	The deficient of the monitoring framework to direct the firms for high productivity and eco-friendly performance hinders the implementation of GLSS.	[35]
6	Lack of environmental knowledge	Comprehensive environmental knowledge, together with the understanding of the effect of various process parameters on ecology, is considered vital for GLSS success.	[44]
7	Wrong GLSS tool section	The success of GLSS highly depends on selection of proper tools during various phases of implementation; the wrong choice leads to failure of GLSS project.	[34]
8	Un-optimized transportation	The un-optimized transportation system leads to wastage of movement, money, and energy.	[45]
9	Lack of management support	Top management support is necessary for GLSS success as an absolute authority to release the orderlies with it.	[6]
10	The obliviousness of re-engineering	A complete understanding of various approaches of reengineering is quite essential for effective GLSS project implementation within a particular organization.	[42] [46]]
11	Unawareness of GLSS strategies	The GLSS execution demands a thorough understanding of its different plans and their associated pros and cons.	[20] [42]
12	Lack of synergy between CI and objectives	Coherence between objectives and CI is required for the GLSS project so that desired results can be achieved within a particular time frame.	[47] [34] [42]
13	Deficiency of experienced GLSS personnel	Experienced persons are well versed with the process of the organization; their skills play a focal role in indecisive time	[5] [38]
14	Lack of training	GLSS requires a comprehensive training of each employee and their full and timely participation.	[48]
15	Poor culture	GLSS implementation leads to a shift in the culture of the organization from the traditional to a sustainable one.	[48]
16	Economic constraints	GLSS implementation within organization will bring paradigm shifts in concerned industry, so investment is needed to incorporate these changes.	[48]
17	Lack of standardization procedures	Standardization brings a specialty in the system that leads to less rework and wastes.	[44]
18	Cultural fragmentation	GLSS implementation leads to the shift in the culture of the organization from the traditional one. The organizations' members, show resistance to change towards a sustainable culture.	[48]

Table 4: Characteristics and demographic background of respondents

S. No.	Work profile	Number of person	Percentage	Industry/Academia
1	Senior Manager	28	26.42	Industry
2	Manager	24	22.64	Industry
3	LSS Green belt	22	20.75	Industry/Academia
4	LSS Black belt	17	16.04	Industry/Academia
5	Professor	15	14.15	Academia

The dataset received from all respondents was checked for the normality using the Shapiro-Wilk test and Q-Q plot in the statistical package for social sciences version 20 (SPSS 20). The value “p” of the Shapiro-Wilk test ($p \geq 0.05$) and data points distributed along the line in the Q-Q plot designate that data is normally distributed [49]. The p-value was found as 0.087 all data distributed along line in Q-Q plot (Figure 2).

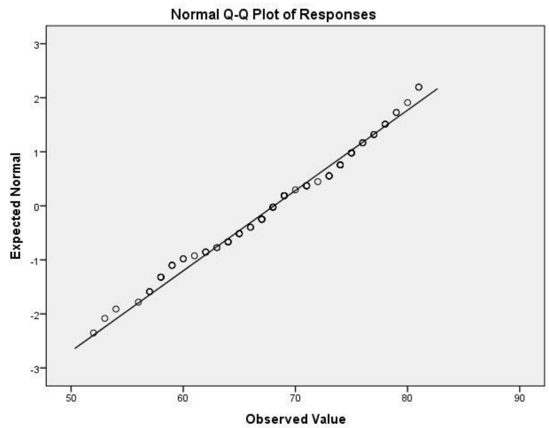

Figure 2: Q-Q plot

The analysis of variance (ANOVA) test was performed for the extracted factor to check whether sample means differ for different groups is significant or not [50]. The ANOVA test was performed with the null hypothesis (H_0) that there is no significant difference among the sample means of different groups. The p-value after conducting the ANOVA test was found to be 0.046, which is less than 0.05, which implies that H_0 is rejected and H_A prevails [51]. It is obvious from the ANOVA that there is significant difference among the different groups’ barriers as a whole. The Tukey post hoc test was conducted to depict which group of differ from other. From the multiple comparisons post hoc test the p value of environmental (ER) set of barriers against continuous improvement (CI) barriers was found to be 0.36, which states that there is significant difference of the sample means between ER and CI barriers. This infers the importance of removal of the ER barriers high as compared to the CI barriers. The p value training related (TR) barriers against knowledge (KB) barriers was found as 0.784, which depicts that there is no substantial difference among sample means for these two set of barriers. This implies that these set of barriers have nearly same significance of removal for the execution of the GLSS program. The Tukey post hoc test p value for management (MR) barriers against organizational barriers (OR) was found as 0.635, that depicts there is no substantial difference among sample means for these two set of barriers. The managerial functionality and top management support is essential for the organizational operations and decisions. This implies that these two set of barriers have not much difference in the priority list for removal of barriers.

The exploratory factor analysis's principal component analysis (PCA) was used to fit barriers into a manageable number of groups. PCA provides information about common hidden pattern that exists in a particular set of data [52]. Before the PCA analysis, Kaiser-Meyer- Olkin and Bartlett's test of sphericity were performed to help assess the factorability of the dataset and sample adequacy respectively. The value recommended for Kaiser-Meyer- Olkin should be greater than 0.5 and Bartlett's test of sphericity's $p \leq 0.05$ (Field, 2000). It has been found that in the KMO test value found to be 0.052 and Bartlett's test of sphericity was high at with chi-square 301.885 and p-value 0.000 Afterwards, the eigenvalue and percentage of variance approach of PCA were used to represent the GLSS barriers into different groups of same characteristics According to Field [53], groups with eigenvalues (> 1) are retained and those with small eigenvalues are ignored for further study. The extracted factors or group must account for at least 60% of the total variance for authenticity of the number of groups [23]. The PCA shows that six grouped GLSS barriers account for 60.687 % of total variance explained with average of item loading 0.657 (Table 5). Moreover, it obvious from the scree plot (figure 3) those barriers have to be grouped into six groups as with eigenvalue greater than one has to be retained.

Table 5: Principal component analysis for grouping of barriers

Grouped Barriers	Barriers	Factor loading	Interitem correlation	Rotation	Variance explained	Cumulative variance
Environmental barrier	Unawareness of various GLSS strategies (B11)	0.625	0.654	.680	10.853	10.853
	Lack of environmental knowledge (B6)	0.731	0.686	.667		
	Wrong GLSS tool section (B7)	0.618	0.314	.560		
	Inappropriate GL areas identification (B2)	0.513	0.562	.522		
	Deficiency of experienced GLSS personnel (B13)	0.726	0.649	.521		
Management related barriers	Lack of management support (B9)	0.631	0.529	.759	10.086	20.938
	Poor organizational culture (B15)	0.652	0.494	.689		
	Resistance to change (B4)	0.541	0.629	-.504		
Knowledge base barriers	Lack of understanding of different types of voice of customers (VOC) (B1)	0.634	0.583	.773	11.718	32.657
	Un-optimized transportation system (B8)	0.56	0.678	.691		
Training related barriers	Lack of training (B14)	0.713	0.664	.504	8.272	40.929
	Lack of standardization and standard scheduling procedures (B17)	0.639	0.582	.681		
	Inadequate regulatory framework (B5)	0.691	0.621	.599		
Organization related	Cultural fragmentation (B18)	0.711	0.715	.659	9.336	50.265
	Economic constraints (B16)	0.545	0.429	-.644		
	Lack of synergy between CI and strategic objectives of the organization (B12)	0.812	0.626	.573		
Continuous improvement barriers	Lack of continuous improvement (CI) thinking (B3)	0.821	0.492	.777	10.442	60.687
	The obliviousness of re-engineering (B10)	0.679	0.642	-.630		

GLSS is a project based approach and its success primarily lies with appropriate project selection [54]. The project selection demands experienced personnel in GLSS practice, tools, and proper knowledge of environmental aspects. The manufacturing organization to implement GLSS faces difficulty in terms of improper area identification, lack of experienced persons with knowledge of GLSS strategies and tools, intrigue nature of environmental sustainability.

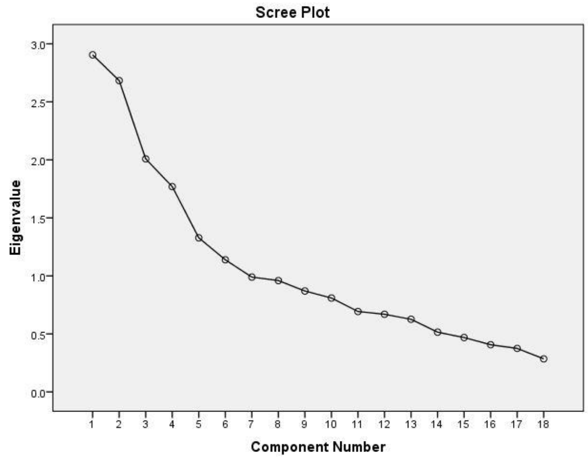

Figure 3: Scree plot

So, these all barriers discussed here if removed will lead to improved organization sustainability, hence they are clubbed under the head of the environmental barriers. The top management support is the most essential for realization of any new strategy within an organization [12]. Management serves as a motivating force for development of continuous learning culture, establishment of confidence among the organizations members for shifting resistive culture to continuous improvement culture. So, management lack of support, resistance to change, and poor organization culture has been put under the umbrella of management barriers. GLSS project selection is made based on different aspects of VOC and VOB. Knowledge of VOC, different facets of transportation system, and material handling is essential for effective GLSS execution. Therefore, the barriers pertains to, lack of understanding of VOC, unoptimized transportation have been put under the group of knowledge base barriers. The training of employee in different strategies of GLSS and toolset is essential to tap the full potential of this sustainable development approach [12]. Lack of training leads to inappropriate application of tools and GL areas selection that subsequently leads to potential failure of GSL project. The training in GLSS aspects makes organization members aware in different GLSS practices, regulatory frameworks, and standard operating procedure for improve organizational performance. So, barriers of training, lack of standardization, and regulatory framework have been put under the umbrella of training related barriers. The linking of organization objectives with GLSS, making everyone responsible for sustainability, and financial assistance are predominate factors for GSL success [55]. Organization look forward culture makes everyone responsible for the incorporation of sustainability measures, realization of the pursuits to ensure social and environmental sustainability to sustain in the global market. So, the barriers of lack of synergy of organization and GLSS objectives, cultural fragmentation, and economic constraints have been put under the group of organization barriers. The continuous improvement thinking generates opportunities of 3'R (reduce, reuse, and recycle) in organization that are essential for incorporation of sustainable development culture within an organization. So, the barriers of obviousness of re-engineering and lack of continuous improvement thinking have been put in the group of continuous improvement barriers.

Environmental barriers

The barriers that hinder environmental performance or sustainability improvement of organizations are termed as environmental barriers. This group of barriers encompasses five barriers: unawareness of various GLSS strategies, lack of environmental knowledge, wrong GLSS tool section, inappropriate lean and green areas identification, and deficiency of experienced GLSS personnel. This group of the barriers is termed as environmental barriers and it accounts for 10.853 % of the total variance. The comprehensive knowledge base of Green and Lean metrics and environmental aspects associated with the process is indispensable for the success of GLSS.

Management related barriers

The barriers which are related to lack of support and functionality of the management are termed as management barriers. This group of barriers include: lack of management support, poor organizational culture, and resistance to change and accounted for 10.086% of the total variance.

The management commitment, adaptation to clean technologies, and go forward culture is demanded for the incorporation of sustainability aspects in the organization.

Knowledge base barriers

The barriers that are related to the development of background to understand voice of customers (VOC), voice of business, and different aspects pertains to the transportation and material handling are termed as knowledge base barriers. This group includes barriers like, lack of understanding of different types of VOC and un-optimized transportation system.

Training related barriers

The barriers that restrain the sustainability of the organization due to lack of training or exercise on GLSS tools, standard practices, metrics, adoption methods are named as training related barriers. This set of barriers includes; lack of training, lack of standardization and standard scheduling procedures, and inadequate regulatory framework and it accounts for 8.272 of the total variance explained. The training of the organizational personnel in different aspects of GLSS implementation is needed to tap the full throttle of this sustainable approach.

Organizational related barriers

The barriers which are related to the lack of organizational functionality on part of developing the cultural of mutual learning, generation of finance for incorporation of clean technologies, and embedment of green culture in the organization objectives are termed as organizational barriers. This set of barriers accounts for 9.336% of the total variance explained and represents barriers of cultural differences, economic constraints, and synergetic differences among continuous improvement methods and strategic objectives of the organization.

Continuous improvement barriers

The barriers that restrict the organizational capability to adopt continuous learning, improvement and adoption of re-engineering methods are named as continuous improvement barriers. This grouped barrier accounts for 10.442% of the total variance and is loaded with barriers of continuous improvement thinking and adoption of sustainable recycling approaches.

Phase 2: Classification and Prioritization of GLSS barriers

The second phase of the methodology is related to classification of grouped barriers into cause and effect barriers using IF- DEMATEL along with the prioritization of the grouped barriers. Moreover, the results of the study were primarily validated using IF-BWM and then IF-GRA. The steps associated with IF-DEMATEL execution are:

Step 1: Linguistic data collection from the decision makers (DMs)

In the decision-making problem of the multi-criteria, responses from a group of the DMs are mainly focused on the opinion of the DMs regarding rating of identified criteria. The DMs here are: a LSS black belt, general manager, and senior manager from the case organization. Master Black belt has previously managed LSS projects within the firm and completed them successfully. General Manager encompasses rich knowledge and expertise in LSS and manufacturing operations. Senior Manager has a vast experience in managing shop floor improvement operations. The DMs are requested to provide linguistic assessment by rating criteria, here grouped barriers using the five linguistic scales ranging from 'no influence' to very 'high influence using table 6 (filled linguistic response have been attached in appendix). In the IF-DEMATEL method, a set of proper linguistic variables and their corresponding IFS are required to compare each grouped barrier with another. The IFS in a finite set X can be written as

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \in X|\}$$

Here, $\mu_A(x), v_A(x)$: $X \rightarrow [0, 1]$ are defines as membership and non-membership function such that

$$0 \leq \mu_A(x) + v_A(x) \leq 1 \qquad (1)$$

The third member of the IFS, $\pi_A(x)$ called a hesitation degree and denotes that whether *x* belongs to *A* or not.

$$\pi_A(x) = 1 - \mu_A(x) - v_A(x) \qquad (2)$$

If $\pi_A(x)$ is small the knowledge about x is more certain and if it is large than knowledge about x is more uncertain. Linguistic variables and corresponding IFS were adopted from Boran et al.. (2009) (Table 6). For example, here for the linguistic variable 'No influence', $\mu_A(x)$ = 0.1, $v_A(x)$ =0.8, and $\pi_A(x) = 0.1$

Table 6: Linguistic variables and corresponding IFS Boran et al. [56]

S. No.	Linguistic Variable	Linguistic Preference Scale	IFS
1	No influence	NI	0.1,0.8, 0.1
2	Very low influence	VL	0.25,0.6,0.15
3	Low influence	L	0.5, 0.4,0.1
4	High influence	HI	0.75, 0.2, 0.05
5	Very high influence	VH	0.9, 0.05,0.05

Step 2: Find the weights of DMs

The weights of the DMs are calculated in the 2nd step of IF-DEMATEL. Let *l* is number of DMs, and $D_k = [u_k, v_k, \pi_k]$ is defined as an intuitionistic fuzzy number (IFN) for weighting rating of kth DM. The weightage of the kth DM is calculated using equation (3)

$$(\lambda_k) = \frac{\left(u_k + \pi_k\left(\frac{u_k}{u_k+v_k}\right)\right)}{\sum_{k=1}^{l}\left(u_k + \pi_k\left(\frac{u_k}{u_k+v_k}\right)\right)} \quad ; \ \sum_{k=1}^{l}\lambda_k = 1 \qquad (3)$$

Step 3: Construct aggregated IF decision matrix

In this step, the aggregated IF decision matrix is made based on the responses of the DMs. Let $R^k = \left(r_{ij}^k\right)_{mxn}$ is the IF decision matrix of each DM, and $\sum_{k=1}^{l}\lambda_k = 1,\ \lambda_k \in [0,1]$. For this, the subsequent operator suggested by Xu [31] , named intuitionistic fuzzy weighted averaging (IFWA) operator is used. This subsequently generates the initial reachability matrix *A*

$$r_{ij} = IFWA_\lambda\left(r_{ij}^{(1)}, r_{ij}^{(2)}, ,,,,,,, r_{ij}^{(l)}\right)$$

$$r_{ij} = \left[1 - \prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-v_{ij}^{(k)}\right)^{\lambda_k}, \prod_{k=1}^{l}\left(1-\mu_{ij}^{(k)}\right)^{\lambda_k} - \prod_{k=1}^{l}\left(1-v_{ij}^{(k)}\right)^{\lambda_k}\right]$$

Here $r_{ij} = \left(u_{A_i}\left(x_j\right),\ v_{A_i}\left(x_j\right),\ \pi_{A_i}\left(x_j\right)\right)\ (i = 1,2,3, \ldots \ldots m; j = 1,2,3 \ldots \ldots n)$ (4)

The aggregated IF decision matrix is represented as:

$$R = \begin{bmatrix} u_{A_1}(x_1), v_{A_1}(x_1), \pi_{A_1}(x_1) & u_{A_1}(x_2), v_{A_1}(x_2), \pi_{A_1}(x_2) \ldots & u_{A_1}(x_n), v_{A_1}(x_n), \pi_{A_1}(x_n) \\ u_{A_2}(x_1), v_{A_2}(x_1), \pi_{A_2}(x_1) & u_{A_2}(x_2), v_{A_2}(x_2), \pi_{A_2}(x_2) \ldots & u_{A_2}(x_n), v_{A_2}(x_n), \pi_{A_2}(x_n) \\ \vdots & \vdots & \vdots \\ u_{A_m}(x_1), v_{A_m}(x_1), \pi_{A_m}(x_1) & u_{A_m}(x_2), v_{A_m}(x_2), \pi_{A_m}(x_2) \ldots & u_{A_m}(x_n), v_{A_m}(x_n), \pi_{A_m}(x_n) \end{bmatrix}$$

Step 4: Obtain crisp value of initial reachability matrix

Defuzzification is a method of converting fuzzy output into a crisp value. It is executed to get a crisp value of each grouped barrier corresponding to another. In this procedure, input is a cumulative set, and output is a single number. The equation proposed by Karaşan and Kahrama [28] is used to get crisp value and formulate initial direct relationship matrix for further processing of the DEMATEL method.

$$P = \frac{u_A(x)+v_A(x)+\pi_A(x)}{3} + \frac{u_A(x)+v_A(x)+\pi_A(x)}{\pi_A} \quad (5)$$

Here, P is crisp value of one grouped barrier against the other barrier. From the crisp values, initial reachability matrix A is formulated.

Step 5: Normalizing the direct relationship matrix

The normalized direct relationship matrix was obtained using equation (6).

$$Z = A/s \quad (6)$$

where $s = \frac{1}{max \sum_{j=1}^{m} a_{ij}}$ and a_{ij} are elements of initial reachability matrix A. In this step, row-wise summation of each element of direct relationship matrix is done. After that, each element of the direct relationship matrix is divided by maximum sum value among the row-wise sum to get the final normalized direct relationship matrix [57].

Step 6: Formulate total relationship matrix

In this step, the total relationship matrix (T) is computed by using equation (7) [58], where "I" represents the identity matrix. The said equation is solved in MATLAB.

$$T = Z(I - Z)^{-1} \quad (7)$$

Step 7: Compute D, R, D-R, and D+ R

The sum of rows and columns of the total relationship matrix (T) is computed in this step to construct (D+R) and (D-R) vectors [30].

Based on these vectors, GLSS barriers were ranked and cause and effect diagram was made. (D+R) is a horizontal axis vector that represents degree of relationship of each grouped barrier with another. The barrier, which represents the highest value of (D+R) is the most important. The (D+R) values of grouped barriers depict the ranks of the same. (D-R) is the vertical axis vector that exhibits the kind of relationship among the barriers. The grouped barriers with positive (D-R) is called cause group or dispatcher, whereas the barriers with negative (D-R) is called an effect group or receiver [59]. The ranks of the barriers found through the IF-DEMATEL were further validated using primarily with IF-BWM. BWM has been selected for ranking as it delivers highly reliable results due to its high consistency; fewer pairwise comparisons (2n – 3) as compared to another matrix-based multiple-criteria decision-making methods use n (n – 1)/2 comparisons [7]. The final weights derived from BWM are highly reliable as it provides more consistent comparisons compared to other MCDMs. While in most MCDM methods like DEMATEL, consistency ratio is a measure to check if the comparisons are reliable or not, in BWM consistency ratio is used to see the level of reliability as the output of BWM is always consistent [60].

4. Results

The present work considers the case of a manufacturing organization in India. The organization is in business run for more than 40 years, and its annual turnover is more than INR 5000 M. The foremost apprehension for concerned industry is negative environmental impacts from process of product generation. So, organization is planning to adopt an environmentally friendly approach in business process. The inclusion of GLSS within an organization is challenging as it deals with significant overhauls, and a lot of factors called barriers hinder its implementation. So, concerned organization has to identify barriers of GLSS together with logical relationship among the barriers. Moreover, organization cannot eliminate all barriers at one time, so it is essential to rank barriers to finding barriers which must be handled at inception of GLSS program. The entire research work was discussed with said industry to sensitize them about usefulness of present work. The execution steps of the IF- DEMATEL are as follow:

Step 1: Linguistic data collection from the DMs

In this step, the appropriate linguistic variables and their corresponding IFS were defined. The linguistic responses of three DMs of case industry, for one criterion against others have been presented in the appendix. The team was comprised of a LSS black belt, general manager, and senior manager.

Step 2: Find the weights of DMs

The linguistic variables defined with their corresponding IFNs in table 6 have been used to find weights of DMs. The IFS set for three DMs were considered for linguistic variable of the very important, important, and medium as [0.9, 0.05, 0.05], [0.75, 0.2, 0.05], and [0.5, 0.4, 0.1] respectively. The weights of the DMs have been found using equation (3)

$$\lambda_1 = \frac{\left(0.9+0.05\,\frac{0.9}{0.95}\right)}{\left(0.9+0.05\frac{0.9}{0.95}\right)+\left(0.75+0.05\frac{0.75}{0.95}\right)+\left(0.5+0.1\,\frac{0.5}{0.9}\right)} = 0.4133$$

The weights of other DMs: $\lambda_{2,}$ and λ_3 were found in the similar manner. The weights of three DMs have found to be as 0.4133, 0.3444, and 0.2423.

Step 3: Construct aggregated IF decision matrix

The DMs preferences are aggregated using the IFWA operator as shown in the equation (4) to formulate the initial reachability matrix *A.* For example, the computation of KB barriers affects barrier ER is shown as = [0.3105, 0.5515, 0.1378].

Table7: Aggregated IF decision matrix

Barrier	KB	ER	TR	OR	MR	CI
KB	0.1,0.8,0.1	0.310,0.551,.0137	0.5,0.4,0.1	0.439,0.448,0.112	0.413,0.468,0.117	0.786,0.163,0.05
ER	0.75,0.2,0.05	0.1,0.8,0.1	0.838,0.111,0.05	0.848,0.101,0.05	0.863,0.086,0.05	0.75,0.2,0.05
TR	0.310,0.5515,0.1378	0.434,0.448,0.112	0.1,0.8.,0.1	0.5,0.4,0.1	0.5,0.4,0.1	0.9,0.05,0.05
OR	0.786,0.1636,0.05	0.310,0.551,0.137	0.9,0.05,0.05	0.1,0.8.,0.1	0.786,0.163,0.05	0.848,0.101,0.05
MR	0.838,0.111,0.05	0.7863,0.1636,0.05	0.801,0.148,0.05	0.838,0.111,0.05	0.1,0.8,0.1	0.439,0.448,0.112
CI	0.5,0.4.0.1	0.413,0.468,0.117	0.336,0.531,0.132	0.353,0.517	0.5,0.4,0.1	0.1,0.8,0.1

Step 4: Obtain the crisp value of the initial reachability matrix

The aggregated IF decision matric values for each barrier against another was converted into their corresponding crisp value using equation (5) that also serves as an initial reachability matrix for DEMATEL. Table 8 depicts the initial reachability matrix.

Table 8: Initial reachability matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	10.3333	7.5858	9.3000	8.2154	7.8643	8.3333
ER	8.3333	10.3333	8.3333	83333	.3333	2.3333
TR	7.5858	8.2527	10.3333	9.3333	9.3333	8.3333
OR	2.3333	6.5858	8.3333	10.3333	8.3333	2.3333
MR	8.3333	2.3333	4.3333	3.3333	10.3333	9.2527
CI	9.3333	7.8643	6.8646	8.0652	10.3333	10.3333

Step 5: Normalizing the direct relationship matrix

In this step, the row-wise summation of all elements of initial reachability matrix (A) was done, After that, all elements of matrix were divided by maximum value among entire row-wise sum to get normalized direct relationship matrix Z (Table 9)

Table 9: Normalized direct relationship matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	0.0948	0.0696	0.0853	0.0754	0.0721	0.1774
ER	0.1774	0.0948	0.1774	0.1774	0.1865	0.1865
TR	0.0696	0.0757	0.0948	0.0856	0.0856	0.1774
OR	0.1865	0.0604	0.1774	0.0948	0.1774	0.1865

MR	0.1774	0.1865	0.1774	0.1865	0.0948	0.0757
CI	0.0856	0.0721	0.0630	0.0740	0.0948	0.0948

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Step 6: Formulate total relationship matrix

The total relationship matrix has been formulated form normalized direct relationship matrix by solving function Z $(1\text{-}Z)^{-1}$ in MATLAB. Table 10 depicts total relationship matrix.

Table 10: Total relationship matrix

Barriers	KB	ER	TR	OR	MR	CI
KB	0.3371	0.2454	0.3195	0.2872	0.2917	0.4588
ER	0.621	0.4168	0.6095	0.5641	0.5828	0.6981
TR	0.324	0.2603	0.3413	0.3084	0.316	0.4699
OR	0.5602	0.3381	0.5414	0.4247	0.5098	0.6218
MR	0.5946	0.4802	0.5858	0.549	0.4734	0.5666
CI	0.3066	0.2322	0.2777	0.2675	0.292	0.3466

Step 7: Compute D, R, D-R, and D+ R

In this step, row-wise and column-wise sum of total relationship matrix has been done to get R and D matrix respectively. From D matrix and R matrix, D-R, and D+ R are calculated. (D+R) represents degree of relationship among the barriers, whereas (D-R) represents the kind of relationship among barriers (cause and effect). Table 12 depicts degree of relationship and type of relationship among barriers.

Table 11: Row wise and the column-wise sum of barriers

Barriers	KB	ER	TR	OR	MR	CI	D
KB	0.3371	0.2454	0.3195	0.2872	0.2917	0.4588	1.9397
ER	0.621	0.4168	0.6095	0.5641	0.5828	0.6981	3.4923
TR	0.324	0.2603	0.3413	0.3084	0.316	0.4699	2.0199
OR	0.5602	0.3381	0.5414	0.4247	0.5098	0.6218	2.996
MR	0.5946	0.4802	0.5858	0.549	0.4734	0.5666	3.2496
CI	0.3066	0.2322	0.2777	0.2675	0.292	0.3466	1.7226
R	2.7435	1.973	2.6752	2.4009	2.4657	3.1618	

Table 12: Degree and kind of relationship among barriers

Barriers	D	R	D+R	D-R
KB	1.9397	2.7435	4.6832	-0.8038
ER	3.4923	1.973	5.4653	1.5193
TR	2.0199	2.6752	4.6951	-0.6553
OR	2.996	2.4009	5.3969	0.5951
MR	3.2496	2.4657	5.7153	0.7839
CI	1.7226	3.1618	4.5844	-1.4392

The barrier MR and ER have been found as the most influential barrier among identified six barriers with (D+ R) values 5.7153 and 5.4653, respectively. The cause and effect diagram (figure 4) was constructed by mapping outcome of (D+R) and (D- R). In causal diagram, barriers above horizontal baseline belong to cause group, whereas barriers below horizontal baseline depict effect group of GLSS barriers. The (D+R) also represents ranks of grouped GLSS barriers. The barrier MR found top rank with (D+R) score 5.7154. The barriers ER and OR found the 2nd and 3rd rank with (D+R) scores 5.4653 and 5.3969, respectively. The barrier is considered to be cause group if (D-R) is positive, and in case of negative of (D-R), barrier attributes it to effect group. The barriers of cause group reveal a more influential impact (D) than influenced impact (R). The (D+ R) value represents relative significance of a barrier. The management-related barriers (MR) exhibit the highest (D+R) score and hence should be given the most priority in the removal of the barriers (Table 11).

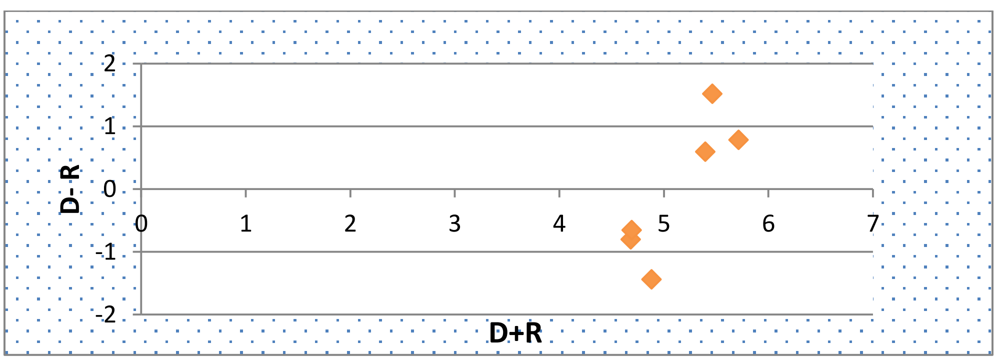

Figure 4: Causal diagram

The barriers continuous improvement (CI) has the lowest (D- R) score, - 1.4392, and hence obviously impacted by all other barriers. The results of study have been found compatible with Cherrafi et al. [63] where 'environmental barrier' was found as one of the most prominent barriers that hinder implementation of the Green Lean (GL) within an organization. Also, Aboelmaged [23] found that 'management barrier' is the most influential barriers for implementation of Six Sigma approach in industrial settings. The empirical research of Singh et al. [40]also signified that 'lack of management support' and 'lack of training' as the most critical barriers for GL implementation within industrial organization. Hence the findings of Singh et al. [40] support paper results which revealed that management-related and environmental-related barriers the first and second, most critical barriers for the GLSS execution.

The results of the IF-DEMATEL for the ranking of the GLSS barriers were validated using IF-BWM and IF-GRA (Steps in the appendix). The grey relational grade (GRG) is average of the value of the coefficients of grey relational. It is defined as a numerical measure of the relevancy between two methods or two sequences such as the reference and the comparability sequence [64]. The value of GRG between the two sequences is always between 0 and 1 [65]. Table 13 depicts ranks of the GLSS barriers found through the different multi-criterion decision making approaches.

Table 13: Comparative results of IF-DEMATEL against other MCDMs

Barriers	**Label**	**D+ R**	**IF-DEMATEL**	**Weights**	**IF-BWM**	**GRG**	**GRA**
Knowledge base barriers	KB	4.683	5	0.0579	5	0.5918	5
Environmental related	ER	5.465	2	0.2008	2	0.7528	2
Training related barriers	TR	4.695	4	0.0899	4	0.6296	4
Organizational related	OR	5.396	3	0.1102	3	0.7210	3
Management-related barriers	MR	5.715	1	0.4887	1	0.7653	1
Continuous improvement	CI	4.584	6	0.0529	6	0.5860	6

The management-related barriers have got the highest weight (0.5283); consequently, it is 1st ranked barrier of GLSS. Similarly, environmental-related barriers got 0.1704 weights, and it was observed at the 2nd position of IF-BWM ranking. The continuous improvement barriers got the final rank in the IF-BWM ranking of GLSS barriers in the manufacturing sector with 0.0581 weights. It has found that ranks of GLSS grouped barriers are similar to as observed by the IF-DEMATEL. So, it can be deduced from the comparative analysis with different MCDMs methods that ranks of barriers are highly consistent, and results found are reliable.

4.1 Sensitivity analysis

Sensitivity analysis is an effective tool to check the robustness of results found through MCDM techniques [66]. In the present work to have more robustness in results found through IF-BWM or to check biasness, sensitivity analysis was performed. This analysis is executed by varying weights of top-ranked criterion and noting changes in weights of other criteria [67]. Table 14 depicts the changing weights of the other barriers while changing the weight of management barrier (MR) with an interval of 0.2.

Table 14: Weights of GLSS barriers using sensitivity analysis

Barriers	Normal	Preference weight value for selected barrier				
		0.1	**0.3**	**0.5**	**0.7**	**0.9**
KB	0.0653	0.081	0.073	0.0646	0.0214	0.0053
ER	0.1704	0.4851	0.2443	0.1871	0.1154	0.041
TR	0.0744	0.1124	0.1242	0.1123	0.0527	0.0209
OR	0.1035	0.1842	0.2151	0.1057	0.0986	0.0247
MR	0.5283	0.1	0.3	0.5	0.7	0.9
CI	0.0581	0.0373	0.0434	0.0303	0.0119	0.0081

It has been found that ranking of GLSS barriers did not change considerably during sensitivity analysis. Table 14 depicts the ranks of GLSS barriers during different run of sensitivity analysis. The variations in ranks of barriers are shown in figure 5. From table 14, it is obvious that by changing the weight of top-ranked weights of other barriers change considerably. It has been found that ranks of barriers did not change significantly during test. The outermost layer in figure 5 presents ranks of barrier 'KB' with changing weight of 'MR'. It is obvious from table 14 that other weights change together with weight change of barrier 'MR'. So, ranks of GLSS barriers did not change considerably which is a characteristic of a consistent system. So, it can be deduced that the results of the study are found to be consistent.

Table 15: Ranks of GLSS barriers using sensitivity analysis

Barriers	Normal	0.1	0.3	0.5	0.7	0.9
KB	5	5	5	5	5	5
ER	2	1	2	2	2	2
TR	4	3	4	3	4	4
OR	3	2	3	4	3	3
MR	1	4	1	1	1	1

CI	6	6	6	6	6	6

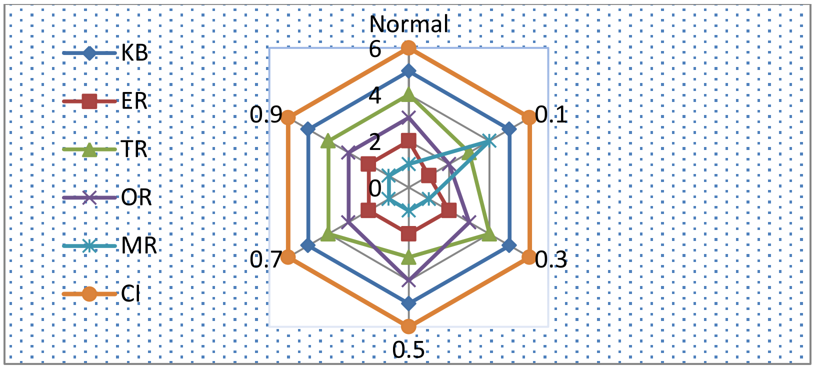

Figure 5: Sensitivity analysis of GLSS barriers

5. Discussion

Since last few decades, sustainability has received an increasing interest in both scholarly research and industrial circles [14]. Shareholders are conscious that without stewarding our natural resources human civilization is on the way towards an appalling breakdown. For this, Green Lean Six Sigma is proposed to have a strategic importance to help various industries, particularly manufacturing industries, to be more sustainable [68]. But, integration of Green, Lean, and Six Sigma and real-time execution of the same is not an easy task as many impending barriers arise during implementation of GLSS [69] [13]. So, without exploring and investigating these barriers organization cannot guarantee successful execution of GLSS in their business operations. Barriers affect execution of GLSS at different steps of its implementation in industry. As GLSS is a project based approach and its success primarily lies with identification of a suitable sustainability oriented project that tap maximum possibility to enhance organization sustainability[8]. Barriers like lack of environmental knowledge and training hampers selection of a suitable project. Further in second step of GLSS, as different metrics pertain to sustainability are estimated, so funds for tools and expertize in selection and application GLSS tool is required. Further, in next step, different causes for inefficacy are estimated using tools like C& E diagram, FMEA, 5 whys. For this, communication and cooperation between different sections of industry are demanded. Moreover, to improve efficacy of organization, solutions to tackle different wastes are found in next step of GLSS. In this step, expertize on GLSS know how, and management commitment towards to adopt best solution and funds for the same are needed. So, every step of GLSS execution program has some barriers that impede its execution. Figure 6 depicts simplified GLSS execution model.

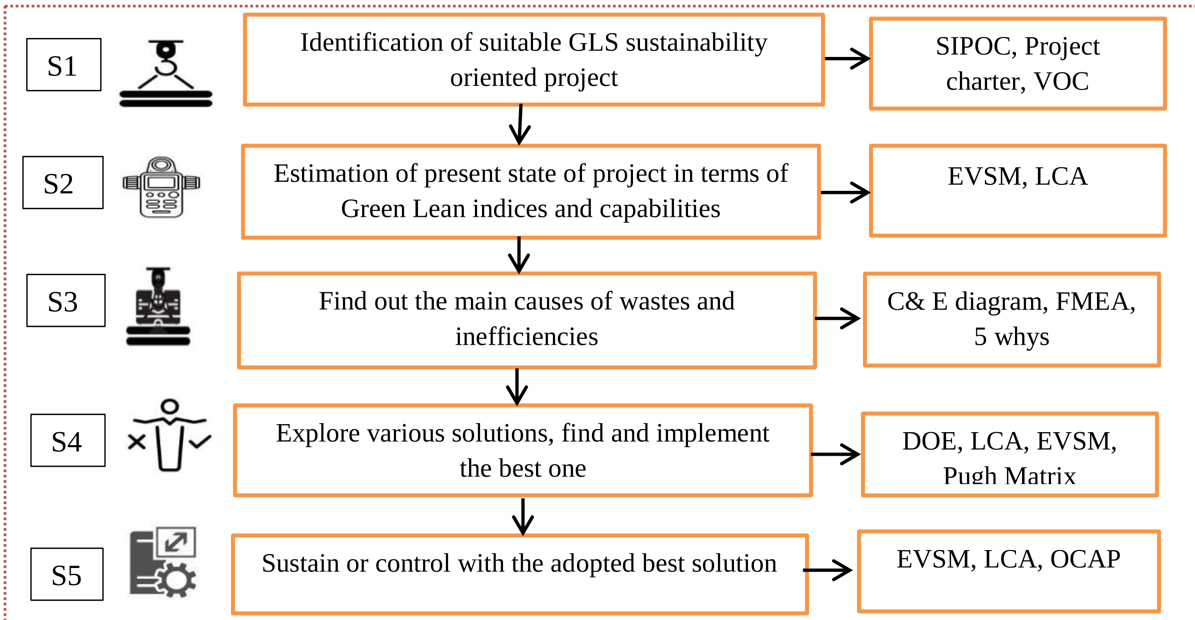

Figure 6: Green Lean Six Sigma implementation framework

In this study prominent barriers of GLSS have been identified through systematic literature review and further analyzed in consultation with industrial experts and through IF-DEMATEL approach to prioritize and understand underlining relationship among the barriers. The study aims at gaining and providing knowledge pertains to barriers that hinder GLSS execution as an initial step to achieve their elimination or reduce intensity so that implementation of GLSS becomes an easier practice. “Environmental related barriers” and “Management related barriers” have been found as key barriers in GLSS implementation. GLSS implementation demands considerable knowledge base on different aspects of environmental practices; tools pertain to GLSS, and appropriate project selection [54]. According to study conducted by Gadenne et al. [70] execution of environmental approach is influenced by existing and potential shareholder including management and government.

Top management support is the most essential for realization of any new strategy within an organization [20] [71]. Management serves as a motivating force for development of continuous learning culture, establishment of confidence among the organizations members for shifting resistive culture to continuous improvement culture [72]. The contribution, patronage, and vision of the management play a vital role in implementing the GLSS concept in the manufacturing sector [73]. The management's strategic efforts by linking the organizational objectives with eco-friendly approaches provide an ambiance of change and mitigate the fear of the adoption of new strategies [74]. Government campaign and advertising can help manufacturing industries to be more aware of the benefits associated with adoption of sustainability oriented approaches. It has been reported that despite having green attitude, level of execution of sustainable practices is low due to their little awareness about the potential cost saving that may arise from adoption of eco-friendly practices. This is in line with finding with previous studies that exhibited positive relationship among environmental knowledge and environmental practices (Peters and Turners, 2004). Also, it has been found that due to lack of stake holders support especially government and management; many industries are not motivated towards sustainability initiatives without external pressure [75]. Governmental supportive policies have exhibited positive impact in many developed nations. For instance, a pilot project to execute Green Lean approach was launched by Washington state department of ecology in collaboration with Washington manufacturing industries. This project greatly supported many manufacturing industries to improve sustainable performance through execution of sustainable Green Lean Approach [76]. In the organizational category “economic constraint” and “cultural barrier” exist. To execute GLSS sufficient and efficient fund allocation are important factors. Financial constraints and costs have been recognized as key barriers to execute any initiative [23]. So, findings of the present study are in line with common research findings widely reported in academic literature. Financial constraints include non-availability of bank loan to impetus organization to adopt sustainable practices due to poor polices and lack of regulations. The result of the study suggest that some of the crucial barriers that execute GLSS execution are related to human aspects, like training and management commitments. It is obvious that a skilled human capital is key element to generate a conductive environment that facilitates GLSS execution. Furthermore, research has demonstrated that lack of contribution human resources in Green Lean projects can decease opportunities to realize sustainable benefits [68]. This is in line with findings of Cherrafi et al. [14] who conducted an inclusive literature pertains to Green Lean and concluded that most of the research dealt with soft (human) rather than hard (technical) elements. Technical, behavioral, and managerial aspects are also challenging factors, which need to be removed such as “resistance to change”, “culture of fear to failure” and “lack of synergy between continuous improvement approach and organization objectives”. So, to assure success of GLSS execution it is imperative for manufacturing industries to identify critical barriers and also explore solutions to mitigate the intensity of the same.

Removal of barriers

In this section, a few general actions to mitigate barriers that hinder GLSS implementations are suggested. These removal measures will facilitate industrial managers to implement GLSS for superior operational and sustainable performance.

Barrier mitigation action 1:

‘Lack of environmental knowledge base’, ‘Inappropriate GL area identification’, ‘Wrong GLSS tool selection’, ‘lack of synergy between CI and strategic objectives of the organization’ can be overcome by the development of the green economy [77]. Figure 6 depicts the mission, strategy, and vision of the green economy that affects positively the GLSS implementation.

Barrier mitigation action 2: The barrier of ‘economic constraint’ can be overcome by setting up of financial institutions so that credit access make easier for industrial settings that want to implement the GLSS program. The supportive government fiscal policies will facilitate banks about probable risks involved in releasing funds to GLSS adopting organizations.

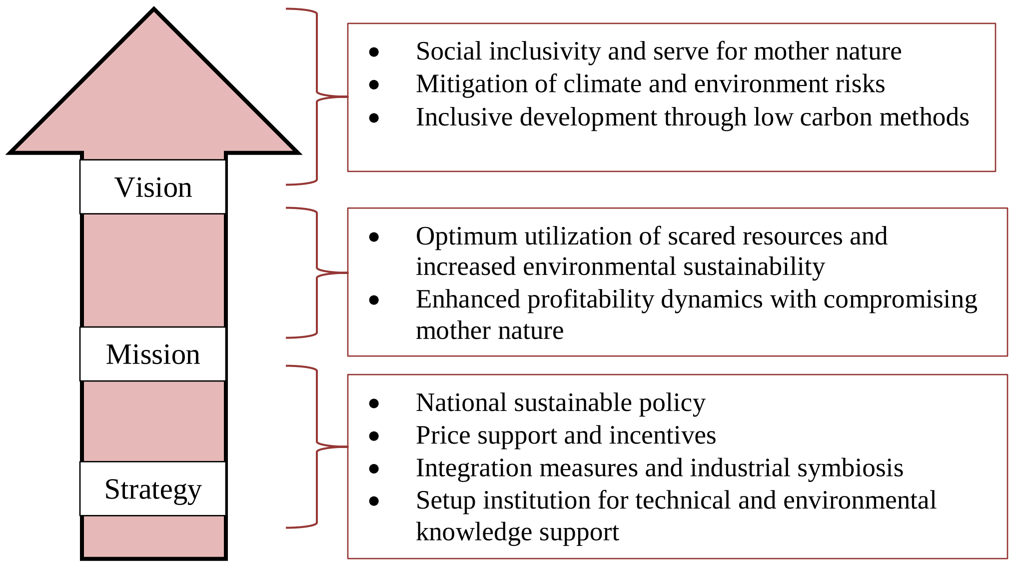

Figure 6: Green economy model to facilitate GLSS implementation

The industry can use different types of plans to enhance their internal competencies to execute GLSS. The organization should develop a memorandum of understanding with environmental centered organizations, academic and research institutes to get opportunities for , technical knowledge, and capacity enhancement through the training programs. This collaborative strategy will lead to a reduction in the organization's expenses that otherwise go in vain by providing training from the outer agencies. The agencies like the UN climate change learning partnership (UNCC: Learn) and US environmental protection agencies provide free resources for climate literacy, mitigation action for carbon footprint, and guide industrial organizations to become more sustainable through the adaptation of Lean and climate-resilient practices (unccelearn.org). This type of work will lead to the removal of resistive organization culture to new practices, barriers of training, lack of management supportive culture, and obliviousness of reengineering practices.

Barrier mitigation action 4: Barriers like ‘Inappropriate Lean and Green area identification’ can be overcome by appropriate implementation of visual/statistical control and performance monitor and measurement systems. This will enable the organizational managers to identify the problem in the existing system and process, quantify the performance of the existing best practices, and monitor the progress towards the goal set by the industry. The other barriers of GLSS can be overcome by making everyone in the organization responsible for the quality, deploying the right person in the right area, and adopting the culture of 3'R (reduce, reuse, and recycle) in daily practices.

6. Conclusion

GLSS has been recognized as an inclusive approach that mitigates environmental emissions and delivers eco-friendly products. To meet targets of regulations pacts and sustainable voice of customers, manufacturing organizations need to understand and analyze barriers in implementation of GLSS. Eighteen barriers pertain to GLSS have been found through the comprehensive literature survey and further formulated into six logical groups. The barriers have been categorized in cause and effect through IF-DEMATEL and also prioritized for systematic implementation of GLSS within manufacturing organization. The ranking of grouped GLSS barriers was further validated using BWM. The study depicts that cause barriers are: management-related, environmental-related, and organizational related. The cause barriers have a consequential effect on training, knowledgebase, and continuous improvement barriers. Further, through prioritization of the GLSS barriers, it can be concluded that top-ranked barriers like management related and environmental centered barriers should be tackled first for the incremental application of the GLSS program.

6.1 Practical Implications

The manufacturing organizations have to make rigorous pursuits for improvement in material and energy efficiency to remain sustainable in the market. The present research work will facilitate the practitioners and managers to implement GLSS through systematic understanding of intriguing nature of barriers and removal of same. The IF-DEMATEL analysis of GLSS barriers facilitates managers to focus on cause barriers that eventually lead to removal of effect barriers. The ranking of grouped barriers will facilitate industries to systematically wipe out obstacles which are more influential in adoption of this approach. GLSS execution measures facilitate practitioners to relook operations, sources, and possible hot spots for improvement in real industrial settings. This will facilitate practitioners to develop the possible solution measures for increased sustainability dynamics of industry. Moreover, study facilitates policymakers to incorporate clean technologies measures that will address the most urgent challenge of climate change through reduced emission of GHGs. The policymakers can adjudicate new policies on climate change for the industries through systematic replacement of the traditional operational dynamics with GL measures. Society will be benefited from present work in terms of better health and motivation of industrial works due to reduced emissions, improved cultural aspects, and impetus for quality. Moreover, lesser environmental emission will lead to a healthy society and a better planet for the living being.

6.2 Theoretical Implications

The present study also has theoretical implications for potential researchers and newcomers in the area of sustainability and GLSS. The present research work extends knowledge base by defining and understanding relationship among the barriers that will facilitate integration and implementation of GLSS. The study further facilitates practitioners and potential researchers to understand different measures that lead to removal and reduction in intensity of different barriers that hinders GLSS execution. This study is beneficial particularly for manufacturing industries, which aim to effectively deploy GLSS in their processes to improve both operational and sustainable performance. In this context, results of the study, particularly prioritization of GLSS barriers through IF-DEMATEL, can be used managers to make judgment which barriers must be removed at the initial stage of GLSS barriers removal initiative. So, this research work contributes to the practice of GLSS by assisting top management of the organization in identifying, managing, addressing the barriers that may impede successful execution of sustainable GLSS approach. This will also benefit policy makers by facilitating then in formulation of better policies that facilitates organizations in their sustainability journey. Moreover, this enrich theoretical knowledge base of researchers by covering hidden aspects of GLSS, and this will impetus pursuits for development of different adoption measures that will boost GLSS execution in business organizations.

6.3 Limitations and future research agenda

Despite several contributions, the present study has its limitations. Given the infancy of GLSS involvements in research and practice pertains to the manufacturing sector, analysis presented in this work was based on the expert's opinion, so biasness in experts' judgment may prevail. Although, it is expected that findings may have wider applicability further studies in different manufacturing industries, size, and country context should be undertaken to endorse findings. Moreover, in present work, 18 prominent barriers that hinder GLSS implementation in manufacturing industries have been identified, but in offing, with growing literature of GLSS, list can be extended by including some other barriers that may arise from rapid organizational and technological advancements. Besides, lack of implementation of GLSS tools and methods across a wide range of process or industries may make the application of survey approach impractical. This underlines future research to enhance survey data using case studies in different industries so that comparative insights into GLSS barriers can be provided. Furthermore, a process based approach that focuses on barriers at each step of process through which GLSS project is executed is another interesting avenue for future research. Overall, the study provides some useful insights into the implementation of GLSS in manufacturing context, boosting in these ways its application. So, it provides trustworthy evidence for practitioners and industrialists of GLSS barriers that hinders its execution. Hence, validation of barriers in different manufacturing industries according to size, type, and culture is a future research agenda derived from the current research work. Moreover, to understand contextual relationship among barriers future studies can consider interpretive structural modeling (ISM) and structural equation modeling (SEM) to supplement DEMATEL and BWM. The researchers in offing can also develop integral measures and systematic framework of integrated GLSS and Industry 4.0 approach, as both approaches focus to make organizations more competitive through reduction of wastes and making system more responsive to the current challenges of manufacturing. Besides, researchers and practitioners in the future can focus on the grey areas in the development of GLSS, like identification and measurement of metrics of green and lean, assessment of the effects of GLSS for capacity waste reduction in manufacturing organizations.

References

[1] M. Sony and S. Naik, "Green Lean Six Sigma implementation framework: a case of reducing graphite and dust pollution," *Int. J. Sustain. Eng.*, vol. 13, no. 3, pp. 184–193, 2020, doi: 10.1080/19397038.2019.1695015.

[2] J. Antony, D. Setijono, and J. J. Dahlgaard, "Lean Six Sigma and Innovation – an exploratory study among UK organisations," *Total Qual. Manag. Bus. Excell.*, vol. 27, no. 1–2, pp. 124–140, 2016, doi: 10.1080/14783363.2014.959255.

[3] A. Bhattacharya, A. Nand, and P. Castka, "Lean-green integration and its impact on sustainability performance: A critical review," *J. Clean. Prod.*, vol. 236, p. 117697, 2019, doi: 10.1016/j.jclepro.2019.117697.

[4] R. Ben Ruben, S. Vinodh, and P. Asokan, "Lean Six Sigma with environmental focus: review and framework," *Int. J. Adv. Manuf. Technol.*, vol. 94, no. 9–12, pp. 4023–4037, 2018, doi: 10.1007/s00170-017-1148-6.

[5] R. Siegel, J. Antony, J. A. Garza-Reyes, A. Cherrafi, and B. Lameijer, "Integrated green lean approach and sustainability for SMEs: From literature review to a conceptual framework," *J. Clean. Prod.*, vol. 240, 2019, doi: 10.1016/j.jclepro.2019.118205.

[6] G. M. Duman, A. El-Sayed, E. Kongar, and S. M. Gupta, "An Intelligent Multiattribute Group Decision-Making Approach with Preference Elicitation for Performance Evaluation," *IEEE Trans. Eng. Manag.*, vol. 67, no. 3, pp. 885–901, 2020, doi: 10.1109/TEM.2019.2900936.

[7] M. S. Kaswan and R. Rathi, "Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method," *Clean Technol. Environ. Policy*, vol. 22, no. 4, pp. 865–876, 2020, doi: 10.1007/s10098-020-01827-w.

[8] M. S. Kaswan and R. Rathi, "Green Lean Six Sigma for sustainable development: Integration and framework," *Environ. Impact Assess. Rev.*, vol. 83, 2020, doi: 10.1016/j.eiar.2020.106396.

[9] A. Banawi and M. M. Bilec, "A framework to improve construction processes: Integrating lean, green and six sigma," *Int. J. Constr. Manag.*, vol. 14, no. 1, pp. 45–55, 2014, doi: 10.1080/15623599.2013.875266.

[10] K. Hussain, Z. He, N. Ahmad, M. Iqbal, and S. M. Taskheer mumtaz, "Green, lean, Six Sigma barriers at a glance: A case from the construction sector of Pakistan," *Build. Environ.*, vol. 161, no. April 2021, p. 106225, 2019, doi: 10.1016/j.buildenv.2019.106225.

[11] R. Caiado, D. Nascimento, O. Quelhas, G. Tortorella, and L. Rangel, "Towards sustainability through green, lean and six sigma integration at service industry: Review and framework," *Technol. Econ. Dev. Econ.*, vol. 24, no. 4, pp. 1659–1678, 2018, doi: 10.3846/tede.2018.311910.3846/tede.2018.3119.

[12] S. Kumar, N. Kumar, and A. Haleem, "Conceptualisation of Sustainable Green Lean Six Sigma: An empirical analysis," *Int. J. Bus. Excell.*, vol. 8, no. 2, pp. 210–250, 2015, doi: 10.1504/IJBEX.2015.068211.

[13] J. A. Garza-Reyes, "Green lean and the need for Six Sigma," *Int. J. Lean Six Sigma*, vol. 6, no. 3, pp. 226–248, 2015, doi: 10.1108/IJLSS-04-2014-0010.

[14] A. Cherrafi, S. Elfezazi, A. Chiarini, A. Mokhlis, and K. Benhida, “The integration of lean manufacturing, Six Sigma and sustainability: A literature review and future research directions for developing a specific model,” *J. Clean. Prod.*, vol. 139, pp. 828–846, 2016, doi: 10.1016/j.jclepro.2016.08.101.
[15] A. Cherrafi, S. Elfezazi, K. Govindan, J. A. Garza-Reyes, K. Benhida, and A. Mokhlis, “A framework for the integration of Green and Lean Six Sigma for superior sustainability performance,” *Int. J. Prod. Res.*, vol. 55, no. 15, pp. 4481–4515, 2017, doi: 10.1080/00207543.2016.1266406.
[16] R. Rathi, D. Khanduja, and S. K. Sharma, “A fuzzy MADM approach for project selection: A six sigma case study,” *Decis. Sci. Lett.*, vol. 5, no. 2, pp. 255–268, 2016, doi: 10.5267/j.dsl.2015.11.002.
[17] D. Setijono, A. Laureani, and J. Antony, “Critical success factors for the effective implementation of Lean Sigma: Results from an empirical study and agenda for future research,” *Int. J. Lean Six Sigma*, vol. 3, no. 4, pp. 274–283, 2012, doi: 10.1108/20401461211284743.
[18] R. Ben Ruben, S. Vinodh, and P. Asokan, “Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study,” *Prod. Plan. Control*, vol. 28, no. 15, pp. 1193–1211, 2017, doi: 10.1080/09537287.2017.1357215.
[19] R. Sreedharan V, G. Sandhya, and R. Raju, “Development of a Green Lean Six Sigma model for public sectors,” *Int. J. Lean Six Sigma*, vol. 9, no. 2, pp. 238–255, 2018, doi: 10.1108/IJLSS-02-2017-0020.
[20] S. Kumar, S. Luthra, K. Govindan, N. Kumar, and A. Haleem, “Barriers in green lean six sigma product development process: An ISM approach,” *Prod. Plan. Control*, vol. 27, no. 7–8, pp. 604–620, 2016, doi: 10.1080/09537287.2016.1165307.
[21] M. S. Kaswan and R. Rathi, “Analysis and modeling the enablers of Green Lean Six Sigma implementation using Interpretive Structural Modeling,” *J. Clean. Prod.*, vol. 231, 2019, doi: 10.1016/j.jclepro.2019.05.253.
[22] M. Sagnak and Y. Kazancoglu, “Integration of green lean approach with six sigma: an application for flue gas emissions,” *J. Clean. Prod.*, vol. 127, pp. 112–118, 2016, doi: 10.1016/j.jclepro.2016.04.016.
[23] M. G. Aboelmaged, “Reconstructing Six Sigma barriers in manufacturing and service organizations: The effects of organizational parameters,” *Int. J. Qual. Reliab. Manag.*, vol. 28, no. 5, pp. 519–541, 2011, doi: 10.1108/02656711111132562.
[24] P. S. Parmar and T. N. Desai, “Evaluating Sustainable Lean Six Sigma enablers using fuzzy DEMATEL: A case of an Indian manufacturing organization,” *J. Clean. Prod.*, vol. 265, p. 121802, 2020, doi: 10.1016/j.jclepro.2020.121802.
[25] I. Gölcük and A. Baykasoılu, “An analysis of DEMATEL approaches for criteria interaction handling within ANP,” *Expert Syst. Appl.*, vol. 46, pp. 346–366, 2016, doi: 10.1016/j.eswa.2015.10.041.
[26] S. M. Seyed-Hosseini, N. Safaei, and M. J. Asgharpour, “Reprioritization of failures in a system failure mode and effects analysis by decision making trial and evaluation laboratory technique,” *Reliab. Eng. Syst. Saf.*, vol. 91, no. 8, pp. 872–881, 2006, doi: 10.1016/j.ress.2005.09.005.
[27] M. Abdel-Basset, G. Manogaran, A. Gamal, and F. Smarandache, “A hybrid approach of neutrosophic sets and DEMATEL method for developing supplier selection criteria,” *Des. Autom. Embed. Syst.*, vol. 22, no. 3, pp. 257–278, 2018, doi: 10.1007/s10617-018-9203-6.
[28] A. Karaşan and C. Kahraman, “A novel intuitionistic fuzzy DEMATEL - ANP - TOPSIS integrated methodology for freight village location selection,” *J. Intell. Fuzzy Syst.*, vol. 36, no. 2, pp. 1335–1352, 2019, doi: 10.3233/JIFS-17169.
[29] K. T. Atanassov, “New operations defined over the intuitionistic fuzzy sets,” *Fuzzy Sets Syst.*, vol. 61, no. 2, pp. 137–142, 1994, doi: 10.1016/0165-0114(94)90229-1.
[30] L. Abdullah, N. Zulkifli, H. Liao, E. Herrera-Viedma, and A. Al-Barakati, “An interval-valued intuitionistic fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management,” *Eng. Appl. Artif. Intell.*, vol. 82, no. April, pp. 207–215, 2019, doi: 10.1016/j.engappai.2019.04.005.
[31] Z. Xu and H. Liao, “Intuitionistic fuzzy analytic hierarchy process,” *IEEE Trans. Fuzzy Syst.*, vol. 22, no. 4, pp. 749–761, 2014, doi: 10.1109/TFUZZ.2013.2272585.
[32] K. Govindan, R. Khodaverdi, and A. Vafadarnikjoo, “Intuitionistic fuzzy based DEMATEL method for developing green practices and performances in a green supply chain,” *Expert Syst. Appl.*, vol. 42, no. 20, pp. 7207–7220, 2015, doi: 10.1016/j.eswa.2015.04.030.
[33] A. Raghunath and R. Jayathirtha, “Barriers for implementation of Six Sigma by Small and Medium Enterprises,” *Int. J. Adv. Res. Technol.*, vol. 2, no. August, pp. 1–7, 2013.
[34] S. Albliwi, J. Antony, S. A. H. Lim, and T. van der Wiele, “Critical failure factors of lean Six Sigma: A systematic literature review,” *Int. J. Qual. Reliab. Manag.*, vol. 31, no. 9, pp. 1012–1030, 2014, doi: 10.1108/IJQRM-09-2013-0147.
[35] V. K. Mittal, R. Sindhwani, and P. K. Kapur, “Two-way assessment of barriers to Lean–Green Manufacturing System: insights from India,” *Int. J. Syst. Assur. Eng. Manag.*, vol. 7, no. 4, pp. 400–407, 2016, doi: 10.1007/s13198-016-0461-z.

[36] H. Pandey, D. Garg, and S. Luthra, “Identification and ranking of enablers of green lean Six Sigma implementation using AHP,” *Int. J. Product. Qual. Manag.*, vol. 23, no. 2, pp. 187–217, 2018, doi: 10.1504/IJPQM.2018.089156.
[37] M. A. Shamsi and A. Alam, “Exploring Lean Six Sigma implementation barriers in Information Technology industry,” *Int. J. Lean Six Sigma*, vol. 9, no. 4, pp. 523–542, 2018, doi: 10.1108/IJLSS-06-2017-0054.
[38] G. Yadav, D. Seth, and T. N. Desai, “Prioritising solutions for Lean Six Sigma adoption barriers through fuzzy AHP-modified TOPSIS framework,” *Int. J. Lean Six Sigma*, vol. 9, no. 3, pp. 270–300, 2018, doi: 10.1108/IJLSS-06-2016-0023.
[39] M. S. Kaswan and R. Rathi, “Investigating the enablers associated with implementation of Green Lean Six Sigma in manufacturing sector using Best Worst Method,” *Clean Technol. Environ. Policy*, 2020, doi: 10.1007/s10098-020-01827-w.
[40] C. Singh, D. Singh, and J. S. Khamba, “Analyzing barriers of Green Lean practices in manufacturing industries by DEMATEL approach,” *J. Manuf. Technol. Manag.*, vol. 32, no. 1, pp. 176–198, 2020, doi: 10.1108/JMTM-02-2020-0053.
[41] M. Tavakol and R. Dennick, “Making sense of Cronbach’s alpha,” *Int. J. Med. Educ.*, vol. 2, pp. 53–55, 2011, doi: 10.5116/ijme.4dfb.8dfd.
[42] S. Al Zaabi, N. Al Dhaheri, and A. Diabat, “Analysis of interaction between the barriers for the implementation of sustainable supply chain management,” *Int. J. Adv. Manuf. Technol.*, vol. 68, no. 1–4, pp. 895–905, 2013, doi: 10.1007/s00170-013-4951-8.
[43] M. Abdullah, S. Zailani, M. Iranmanesh, and K. Jayaraman, “Barriers to green innovation initiatives among manufacturers: the Malaysian case,” *Rev. Manag. Sci.*, vol. 10, no. 4, pp. 683–709, 2016, doi: 10.1007/s11846-015-0173-9.
[44] K. Mathiyazhagan, K. Govindan, A. NoorulHaq, and Y. Geng, “An ISM approach for the barrier analysis in implementing green supply chain management,” *J. Clean. Prod.*, vol. 47, pp. 283–297, 2013, doi: 10.1016/j.jclepro.2012.10.042.
[45] D. Mollenkopf, H. Stolze, W. L. Tate, and M. Ueltschy, “Green, lean, and global supply chains,” *Int. J. Phys. Distrib. Logist. Manag.*, vol. 40, no. 1–2, pp. 14–41, 2010, doi: 10.1108/09600031011018028.
[46] R. K. Mudgal, R. Shankar, P. Talib, and T. Raj, “Greening the supply chain practices: an Indian perspective of enablers’ relationships,” *Int. J. Adv. Oper. Manag.*, vol. 1, no. 2/3, p. 151, 2009, doi: 10.1504/ijaom.2009.030671.
[47] A. Cherrafi *et al.*, “Green and lean: a Gemba–Kaizen model for sustainability enhancement,” *Prod. Plan. Control*, vol. 30, no. 5–6, pp. 385–399, 2019, doi: 10.1080/09537287.2018.1501808.
[48] H. Walker, L. Di Sisto, and D. McBain, “Drivers and barriers to environmental supply chain management practices: Lessons from the public and private sectors,” *J. Purch. Supply Manag.*, vol. 14, no. 1, pp. 69–85, 2008, doi: 10.1016/j.pursup.2008.01.007.
[49] N. Mohd Razali and Y. Bee Wah, “Power comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling tests,” *J. Stat. Model. Anal.*, vol. 2, no. 1, pp. 13–14, 2011.
[50] M. S. Kaswan, R. Rathi, and M. Singh, “Just in time elements extraction and prioritization for health care unit using decision making approach,” *Int. J. Qual. Reliab. Manag.*, vol. 36, no. 7, 2019, doi: 10.1108/IJQRM-08-2018-0208.
[51] T. H. Lee, J. T. Yang, Y. S. Ko, H. Kato, Y. Itoyama, and K. Kogure, “Influence of ischemic preconditioning on levels of nerve growth factor, brain-derived neurotrophic factor and their high-affinity receptors in hippocampus following forebrain ischemia,” *Brain Res.*, vol. 1187, no. 1, pp. 1–11, 2008, doi: 10.1016/j.brainres.2007.09.078.
[52] Y. Aït-Sahalia and D. Xiu, “Principal Component Analysis of High-Frequency Data,” *J. Am. Stat. Assoc.*, vol. 114, no. 525, pp. 287–303, 2019, doi: 10.1080/01621459.2017.1401542.
[53] A. Field, “Comparing several means: ANOVA (GLM 1). Discovering Statistics Using SPSS for Windows,” *1st ed. SAGE Publ. Ltd., London*, pp. 243–294, 2000.
[54] M. S. Kaswan, R. Rathi, and D. Khanduja, “Integration of green lean six sigma: A novel approach for sustainable development,” *Int. J. Six Sigma Compet. Advant.*, vol. 12, no. 4, pp. 389–405, 2020, doi: 10.1504/IJSSCA.2020.112369.
[55] R. Rathi, V. Yadav, P. Gahlot, and M. S. Kaswan, “Green Lean Six Sigma critical barriers: exploration and investigation for improved sustainable performance,” *Int. J. Six Sigma Compet. Advant.*, vol. 1, no. 1, p. 1, 2020, doi: 10.1504/ijssca.2020.10036079.
[56] F. E. Boran, S. Genç, M. Kurt, and D. Akay, “A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method,” *Expert Syst. Appl.*, vol. 36, no. 8, pp. 11363–11368, 2009, doi: 10.1016/j.eswa.2009.03.039.
[57] L. Abdullah, N. Zulkifli, H. Liao, E. Herrera-Viedma, and A. Al-Barakati, “An interval-valued intuitionistic

fuzzy DEMATEL method combined with Choquet integral for sustainable solid waste management," *Eng. Appl. Artif. Intell.*, vol. 82, no. April 2018, pp. 207–215, 2019, doi: 10.1016/j.engappai.2019.04.005.

[58] J. Kaur, R. Sidhu, A. Awasthi, S. Chauhan, and S. Goyal, "A DEMATEL based approach for investigating barriers in green supply chain management in Canadian manufacturing firms," *Int. J. Prod. Res.*, vol. 56, no. 1–2, pp. 312–332, 2018, doi: 10.1080/00207543.2017.1395522.

[59] H. H. Wu and S. Y. Chang, "A case study of using DEMATEL method to identify critical factors in green supply chain management," *Appl. Math. Comput.*, vol. 256, pp. 394–403, 2015, doi: 10.1016/j.amc.2015.01.041.

[60] J. Rezaei, "Best-worst multi-criteria decision-making method," *Omega (United Kingdom)*, vol. 53, no. May, pp. 49–57, 2015, doi: 10.1016/j.omega.2014.11.009.

[61] J. Ren, H. Liang, and F. T. S. Chan, "Urban sewage sludge, sustainability, and transition for Eco-City: Multi-criteria sustainability assessment of technologies based on best-worst method," *Technol. Forecast. Soc. Change*, vol. 116, pp. 29–39, 2017, doi: 10.1016/j.techfore.2016.10.070.

[62] Saaty T.L., "The Analytic Hierarchy Process. McGraw-Hill, New York.," 1980.

[63] A. Cherrafi, S. Elfezazi, J. A. Garza-Reyes, K. Benhida, and A. Mokhlis, "Barriers in green lean implementation: A combined systematic literature review and interpretive structural modelling approach," *Prod. Plan. Control*, vol. 28, no. 10, pp. 829–842, 2017, doi: 10.1080/09537287.2017.1324184.

[64] G. W. Wei, "Gray relational analysis method for intuitionistic fuzzy multiple attribute decision making," *Expert Syst. Appl.*, vol. 38, no. 9, pp. 11671–11677, 2011, doi: 10.1016/j.eswa.2011.03.048.

[65] Z. C. Lin and C. Y. Ho, "Analysis and application of grey relation and ANOVA in chemical-mechanical polishing process parameters," *Int. J. Adv. Manuf. Technol.*, vol. 21, no. 1, pp. 10–14, 2003, doi: 10.1007/s001700300001.

[66] C. Prakash and M. K. Barua, "Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment," *J. Manuf. Syst.*, vol. 37, pp. 599–615, 2015, doi: 10.1016/j.jmsy.2015.03.001.

[67] S. A. Suhi, R. Enayet, T. Haque, S. M. Ali, M. A. Moktadir, and S. K. Paul, "Environmental sustainability assessment in supply chain: An emerging economy context," *Environ. Impact Assess. Rev.*, vol. 79, no. August, p. 106306, 2019, doi: 10.1016/j.eiar.2019.106306.

[68] EPA, "The Environmental Professional's Guide to Lean and Six." Accessed July 15, 2016. Sigma.www.epa.gov/lean/," 2009.

[69] S. K. Mangla, K. Govindan, and S. Luthra, "Prioritizing the barriers to achieve sustainable consumption and production trends in supply chains using fuzzy Analytical Hierarchy Process," *J. Clean. Prod.*, vol. 151, pp. 509–525, 2017, doi: 10.1016/j.jclepro.2017.02.099.

[70] D. L. Gadenne, J. Kennedy, and C. McKeiver, "An empirical study of environmental awareness and practices in SMEs," *J. Bus. Ethics*, vol. 84, no. 1, pp. 45–63, 2009, doi: 10.1007/s10551-008-9672-9.

[71] M. Sony, J. Antony, S. Park, and M. Mutingi, "Key Criticisms of Six Sigma: A Systematic Literature Review," *IEEE Trans. Eng. Manag.*, vol. 67, no. 3, pp. 950–962, 2020, doi: 10.1109/TEM.2018.2889517.

[72] J. Antony, F. L. Lizarelli, and M. Machado Fernandes, "A Global Study Into the Reasons for Lean Six Sigma Project Failures: Key Findings and Directions for Further Research," *IEEE Trans. Eng. Manag.*, pp. 1–16, 2020, doi: 10.1109/TEM.2020.3009935.

[73] G. F. G. Teixeira and O. Canciglieri Junior, "How to make strategic planning for corporate sustainability?," *J. Clean. Prod.*, vol. 230, pp. 1421–1431, 2019, doi: 10.1016/j.jclepro.2019.05.063.

[74] M. MacIel-Monteon, J. Limon-Romero, C. Gastelum-Acosta, Di. Tlapa, Y. Baez-Lopez, and H. A. Solano-Lamphar, "Measuring Critical Success Factors for Six Sigma in Higher Education Institutions: Development and Validation of a Surveying Instrument," *IEEE Access*, vol. 8, pp. 1813–1823, 2020, doi: 10.1109/ACCESS.2019.2962521.

[75] J. Lee, K. Yuvamitra, K. Guiberteau, and T. A. Kozman, "Six-sigma approach to energy management planning," *Strateg. Plan. Energy Environ.*, vol. 33, no. 3, pp. 23–40, 2014, doi: 10.1080/10485236.2014.10781519.

[76] Washington State Department of Ecology, "Lean & Environment Case Study : Columbia Paint & Coatings Lean and Environment Pilot Project Case Study : Columbia Paint & Coatings," no. 07, 2008.

[77] E. Loiseau *et al.*, "Green economy and related concepts: An overview," *J. Clean. Prod.*, vol. 139, pp. 361–371, 2016, doi: 10.1016/j.jclepro.2016.08.024.