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Abstract

Design/ Methodology/ Approach: Green Lean Six Sigma (GLS) project selection has been done based on the six sustainability-oriented criteria formed from seventeen sub-criteria (found from the literature and developed by authors). The weights of the criteria have been determined through the entropy method. The projects have been ranked based on the criteria through the advanced decision-making approach: Grey relation analysis (GRA). The results of the study were validated using best worst method (BWM) and sensitivity analysis.

Purpose: The present study deals with the selection of the sustainability-oriented GLS project for the manufacturing industry in the complex decision-making environment. Moreover, the study also proposes a GLS implementation framework for improved organizational performance.

Findings: It has been found that the productivity-related criterion is the most significant among other criteria with entropy weight of 0.2721. GRA has been used in this research work to rank the potential GLS projects in a manufacturing industry based on six sustainability criteria, to select a project that exhibits the maximum potential for sustainable improvement. The machine shop has been found as the most significant GLS project with grey relation grade of 0.4742.

Originality: With increased globalized competition in recent times, new projects are being considered as the foundation stone for organizational success. The decision making becomes quite complex to select an effective project due to the intriguing nature of various criteria, sub-criteria, and different aspects of sustainability. The present study is the first of its kind that provides ways for the selection of sustainability-oriented GLS projects.

Practical Implications: The present study facilitates practitioners and industrial managers to implement an inclusive GLS approach for improved sustainability dynamics through effective GLS project selection and implementation framework.

Keywords: Green Lean Six Sigma; Sustainability; Entropy method; Grey relational analysis; Project selection; Lean Six Sigma; Framework.

1. Introduction

The anthropogenic activities and traditional methods of production have led to a substantial increase in the temperature of our planet over the last few decades (Kaswan and Rathi, 2020a). Industrial organizations mostly operate on fossil fuel-based energy methods and consume natural resources enormously (Vinodh et al., 2016). It has resulted in the increased emission of greenhouse gases (GHGs) that leads to adverse effects on the ecology. So, there is an immense need for industrial organizations to shift their operations towards sustainability (Siegel et al., 2019). The manufacturing organizations are in the continuous run to search for sustainable methods that lead to lesser environmental emissions (Cherrafi et al., 2017). The industry contributes nearly one-third of the total GHGs emission, and this can be attributed to conventional methods of production (Kaswan and Rathi, 2019). Moreover, the emission is further augmented by improper wastes disposal measures. The increased carbon footprint and other associated pollutants have led to severe health issues for the people (Kwon, 2020). The chemical and metrological changes associated with the CO_2 will lead to an increased mortality rate due to increased ozone and carcinogens in the air. The increased level of GHGs will result in an upward surge of more than 20000 deaths per year per degree Celsius and many more cases of respiratory illness and asthma (Jacobson, 2008). So, in the current scenario, the manufacturing organizations must contribute towards Mother Nature to maintain the balance between economic growth and ecology.

Green Lean Six Sigma (GLS) is a sustainable development approach that leads to improved productivity and profitability through the reduction of wastes, defects, and environmental emissions (Kaswan and Rathi, 2019). It is the integration of three organizational improvement methodologies developed over the time horizon; Green technology, Lean production, and Six Sigma (Garza- Reyes, 2015a). Figure 1 depicts the conceptual GLS model.

Figure 1: Conceptual Green Lean Six Sigma model (Kaswan and Rathi, 2021a)

The comprehensive implementation of GLS demands a substantial investment and changeover in the organizational culture (Pandey et al., 2018). The success of GLS implementation depends on the proper selection of a project that exhibits the maximum potential for sustainability improvement. The project of GLS is basically, a shop or section of the industry where GLS has to be implemented initially (Kaswan and Rathi, 2020b). It has been found that nearly 40% of the Six Sigma programs have failed due to improper selection of the project (Gupta et al., 2019). The project selection is a substantial work due to the limited finance, associated opportunity cost of the project, and inadequate management resources (Bilgen and Şen, 2012; Krueger et al., 2014). The evolution of the sustainability-oriented methods and potential loss or benefits of projects have led to selecting a project that has a maximum effect on organizational sustainability. Moreover, as a novel aspect, it is imperative to develop a comprehensive GLS framework that provides systematic guidelines to the industrial managers and practitioners to implement this sustainable methodology. The present study deals with the selection of a potential GLS project in a manufacturing industry based on the six sustainability-oriented criteria formed from seventeen sub-criteria (found in the literature and developed by authors). Moreover, the study also provides a GLS implementation framework with an associated tool set. The sub-criteria cover all the dimensions of sustainability and are formulated into main criteria based on the commonality characteristics that co-exist among them using principal component analysis (PCA). The weights of the criteria have been determined through the entropy method. This method has been widely used to estimate the weights of the criteria in a multi-criteria decision-making problem (Yuan et al., 2019). It is a mathematical theory-based model developed by C.E. Shannon in 1948 (Dey et al., 2019). In other decision-making approaches, like the analytical hierarchy process, decision-makers need to give opinions on different criteria to formulate a pairwise comparison matrix. In the entropy method, this is not needed as entropy weight is the parameter that describes how much different alternatives approach one another to a certain criterion (Wang et al., 2020). The projects have been ranked based on the criteria through the advanced decision-making approach: Grey relation analysis (GRA). GRA has been used in the present work as it offers distinct advantages over other methods like dynamic nature that gives opportunities for the change in the number of parameters and transformation in computer algorithm for the quick solution (Kuo et al., 2008; Li et al., 2019). The results of the study were validated using best worst method (BWM), and sensitivity analysis.

The present manuscript has been divided into five distinct sections, including the introduction. The 2nd section of the article depicts the literature review of the related work. The research methodology has been presented in the 3rd section of the manuscript. The selection and weighting of criteria for project selection have been presented in the 4th section. The case study, implementation framework, results, and discussion have been shown in the 5th section of the paper. The conclusion, limitations, and perspective have been presented in the 6th section of the manuscript.

1.1 Research objectives

The present study has been conducted to meet the following objectives.

- To select a prominent GLS project that exhibits the maximum potential to improve organizational sustainability.
- Prioritize projects of the GLS using GRA so that the industry can focus on the most sustainability-oriented project during the initial phase of the implementation.
- To develop a comprehensive GLS implementation framework with an associated toolset.

2. Literature review

The systematic literature review helps to develop the conceptual theory through the identification of the area where research is needed (Nadeem et al., 2017). A systematic literature review (SLR) is a method that adopts a transparent and explicit approach using different phases so that transparency in the literature review process can be ensured (Garza-Reyes, 2015). Figure 2 depicts different phases, tools adopted, methods used in the SLR process. The pertinent research articles were searched using keywords ‘Sustainability’, ‘Lean’, ‘Green’, ‘Six Sigma’, ‘Lean Six Sigma’, project selection, ‘Framework’ and ‘Green Lean Six Sigma’ and accessed using the electronic databases (EDB) of the Elsevier, Emerald, Springer, Taylor & Francis, and Inderscience, etc. The prominent criteria for the selection of the published articles were that these had to explore the interaction of Lean with Green technology, Lean with Six Sigma, sustainability aspects adhered to Lean, Green, and Six Sigma, articles exploring the field of GLS, and project selection, and prioritization methods. All 52 articles were identified through SLR and further explored to identify research gaps for the study. Table 1 depicts a list of the articles selected for this study.

Figure 2: Systematic literature review methodology

Table 1: Articles considered for the study through systematic literature search

The development of GLS can trace back to the evolution of the Toyota production system (TPS) or Lean manufacturing (Garza-Reyes, 2015). TPS was developed by Tachii Ohno to contest the mass production system of the USA (Antony, 2014). Lean production is a waste reduction approach that reduces the various non-value-added activities by making the system more streamlined (Antony, 2011). The manufacturing industries have the issue of the high rejection rate of the end product, due to some assignable causes associated with the process (Garza-Reyes et al., 2014; Oliveira et al., 2018). Lean production is not able to address this challenge of manufacturing. At this stage, Six Sigma originates that reduces the defects and leads to high specifications end products (Gupta et al., 2020). It is a project-based approach that reduces the defects up to 3.4 M /opportunities (Rathi et al., 2015). It was developed by the Motorola Corporation in the late 1980s (Burn, 2011). The integrated Lean Six Sigma (LSS) approach leads to reduced wastes and defects that subsequently results in increased organizational capability (Costa et al., 2020). Several studies on Green and integrated Lean Six Sigma (LSS) presented that industries that incorporates LSS merely assimilate Green measures to enhance environmental sustainability (Belhadi et al. 2021; Ben Ruben et al. 2017; Sony and Naik 2020). Also, it has been found from these studies when Green is implemented in conjunction with LSS leads to improved ecological performance. So it can deduced that the integrated LSS approach has lacune that it is not able to mitigate the negative environmental impacts associated with the process (Belhadi et al., 2020; Kaswan et al. 2021). It is not able to quantify green metrics like acidification, climate change; radiation associated with the process and does not provide measures hot spots for improvement in environmental sustainability (Kaswan and Rathi, 2020; Sony and Naik, 2020). This drawback of the LSS has been overcome by the inclusion of Green technology in the LSS. Green technology is a cohesive term that defines use of technology and science to make products and services that are eco- friendly (Ishak et al. 2017). The integration of Green technology in the LSS leads to the evolution of a new sustainable development method named Green Lean Six Sigma (GLS). So, Green technology integration with LSS leads in powerful strategy called Green Lean Six Sigma (Ershadi, Qhanadi Taghizadeh, and Hadji Molana 2021; Gholami et al. 2021). But GLS also not takes into the societal aspects related to the product, so it also needs incorporate social metrics and practices related to sustainability. Sustainable Green Lean Six Sigma encompasses all the dimensions of the sustainability in comprehensive ways that are not taken by LSS operational excellence approach (Singh et al. 2021). So, it can be deduced that LSS although incorporated operational excellence parameters in terms of quality and high specification products but have lacunae related to improvements related to green technology measures and metrics. Secondly, LSS does not incorporated social aspects to calculate industry social sustainability level, and parameters where industry can improve in terms of social sustainability.

Table 2 depicts common differences between LSS, GLS and Sustainable Green Lean Six Sigma. GLS reduces wastes, defects, and environmental emissions that lead to increased organizational sustainability (Pandey et al., 2017).

Table 2: Comparison between Lean Six Sigma, Green Lean Six Sigma and Sustainable Green Lean Six Sigma

GLS as a new approach found very limited applications in the literature. It has been applied for modeling of enablers and barriers (Kumar et al., 2016), integration and framework (Cherrafi et al., 2017; Kaswan and Rathi 2021b), and sustainability improvement in the automotive sector (Zamri et al., 2013). GLS is a novel approach and its implementation demands substantial investment and changeover within a particular organization (Kumar et al., 2015). So, it is always executed incrementally i.e. firstly implemented in a particular section of the industry and after successful execution, expanded in the entire organization. GLS is a project-based approach and its success primarily lies with the proper selection of a project (Sony and Naik, 2020). The effective GLS project selection requires training in GLS tools, assessment metrics, and the study of the entire supply chain of the product (Banawi and Bilec, 2014). So, GLS project selection is a substantial task for the effective execution of this eco-friendly approach. In the literature, the study pertains to project selection of Six Sigma (Kumar et al., 2009; Wang et al., 2014) and LSS (Hu et al., 2008; Vinodh and Swarnakar, 2015) has been found. But no study pertains to GLS project selection has been reported in the literature. Besseris (2011) developed a systematic model to deal with process efficiency and environmental facets together in a Green Lean project using LSS tools. A design of experiments (DOE) tool kit was employed to frame and modulate controlling parameters. Habidin and Yusof (2012) conducted an exploratory study to comprehend contextual relationships among LSS, environmental measures, and organizational performance metrics. The contextual relationship between GLS and management innovation for the Malaysian automotive industry was developed using interpretive structural modeling (Zamri et al. 2013). It has been determined that management innovation works as an intermediary to introduce effective GLS practices for the sustainable growth of the industry. A conceptual framework to integrate Lean, Green and Six Sigma with an overall layout of the DMAIC improvement model was formulated to improve process metrics (Banawi and Bilec, 2014). The developed model was validated in the construction process of a pile cap installation process. Garza-Reyes (2015) proposed a new business strategy Green LSS that integrates GL with Six Sigma methodology and pinpoint achieving financial sustainability through systematic reduction of wastes. Kumar et al. (2015) developed a systematic framework for the merger of Green technology with Lean and Six Sigma. Fatemi et al. (2016) investigated the application of sustainable Lean and Green strategies with the Six Sigma approach for the reduction of wastes and emissions in the manufacturing industry. Cherraffi et al. (2016) conducted a state of art literature study of possible integration of three management systems, i.e. Lean production, Six Sigma, and Sustainability. The authors' unearthed various challenges and opportunities for their integration and recommended future research direction for inclusive growth of the industry. Kumar et al. (2016) framed a hierarchical structural model of barriers of Green Lean Six Sigma (GLS) in the product development process using ISM. It has been found that a lack of management commitment is one of the key barriers to the successful execution of the GLS program during the product development process. Sagnak and Kazancoglu (2016) revealed limitations of GL approach and proposed a systematic model to overcome the same through the inclusion of Six Sigma. They found that variation in processes that cannot be overcome by GL can be overpowered by Six Sigma through the application of measurement system analyses and gage control. A VSM-DMAIC based LSS model with environmental facets to assess ecological impacts in the food processing industry of Norway was presented (Powell et al. 2017). Ruben et al. (2017) proposed a DMAIC based LSS framework with environmental aspects to reduce defects and carbon footprint in the automotive industry. Pandey et al. (2018) analyzed and prioritized enablers of GLS using a multi-criterion decision making (MCDM) approach for the smooth execution of the GLS program. The researchers made pursuits for the facilitation of GLS execution in different industrial sectors. A systematic method for the removal of different barriers in the execution of the GLS program was developed in the construction sector (Hussain et al. 2019). Table 3 depicts the list of different modes/frameworks reviewed to develop the proposed GLS framework.

Table 3: List of frameworks reviewed

Besides, different available frameworks, the authors also reviewed different case studies pertaining to GLS in different sectors. Table 4 depicts prominent case studies pertaining to Green Lean Six Sigma.

Table 4: Prominent case studies pertaining Green Lean Six Sigma

So, it has been observed from the available literature that no study that pertains to the GLS framework exists in the manufacturing environment that leads to improvement in the triple bottom line and that also embed different tools of Green, Lean and Six Sigma. Moreover, it is essential to weigh the project selection criteria to find out which factor or criterion the manufacturing industry considers in this age of high competitiveness and sustainability. So, the criteria for project selection have been prioritized by the entropy method. Based on the criteria, the various projects have been ranked to decide the project that exhibits the maximum potential to improve organizational sustainability. The literature also lacks any evidence of the prioritization of the GLS project through entropy-based GRA. For this, the present study deals with GLS framework development and sustainability-oriented GLS project selection for the manufacturing industry using the entropy-based GRA method.

2.1 Research gaps

Integrated Green Lean and LSS approaches have been extensively used by manufacturing organizations to improve productivity and profitability (Singh et al. 2020, Kaswan and Rathi, 2020). But GLS found very few applications pertain to manufacturing. It has been found that the study pertains to project selection of Six Sigma and LSS exist in the literature (Sreedharan and Sunder 2018). But, till now no study with regards to GLS project selection has been reported in the literature.. It has been found that in the literature to date no study exists in the literature that provides a stepwise GLS implementation framework for the manufacturing industry with an associated toolset. These identified research gaps in the study provide the motivation and direction to conduct the present research work.

3. Research methodology

The research methodology adopted in the present work consists of four distinct phases. Figure 3 demonstrates various phases of the adopted research methodology. The various phases of the methodology are as follows:

Phase 1: In the first phase, a comprehensive literature survey was done to identify the sub-criteria that affect the project selection of the GLS. Seventeen sub-criteria that cover all the dimensions of sustainability and individual concepts of Green, Lean, and Six Sigma have been found. A well-defined questionnaire was prepared and pilot tested using the responses from 15 academicians and industrial professionals. The recommendation from the pilot testing for the grouping of sub-criterion into major criteria was incorporated. Principal component analysis (PCA) was performed to group the sub-criteria into major criteria. Six major criteria were constituted using PCA. To check the internal consistency and reliability of the questionnaire Cronbach's alpha test was performed. Alpha has been recognized as an important concept for the assessment of the questionnaire in medical and statistical sciences. It was developed by Lee Cronbach in 1951 and its values vary between 0 and 1 (Cortina, 1993). The value of alpha from 0.7 to 0.9 has been recommended better for internal consistency, homogeneity, and length of the test (Tavacol and Dennick, 2011). The value of the alpha was found to be 0.83 that depicts the high reliability of the formulated questionnaire. The final questionnaire after pilot testing was sent to the practitioners at the mid and high level of management from the Indian manufacturing industry (170 experts) to weigh the criterion for estimation of criterion that affects much to the other. The respondents were required to put the responses on the Likert scale "1" refers to very low importance and "5" corresponds to very high importance. The experts were qualified lean Six Sigma personnel, quality managers, and project heads of the industry that have diverse experiences to deal with projects. The potential experts were identified through the purposive sampling technique using the Linkedin profiles. The questionnaire circulated mentions the main motive of the study and experts were requested to put their candid inputs. 170 professionals accepted to provide useful insights for the weights of criteria, and 68 response sheets were received, out of those responses from 60 experts completed in all respects were considered to weight the criteria.

Phase 2: In the second phase, the responses collected from 60 experts have been analyzed. The entropy method has been used in the present work to weight the criterion. The steps associated with the implementation of the entropy method are as follows:

Step 1: Formulate normalized decision matrix for calculation of the weights of the criteria.

In the first step, the normalized decision matrix is formulated using equation (1).

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (1)$$

Here, x_{ij} depicts the sum of responses of a criterion to a project.

m= number of projects or alternatives

n= number of criterion

Step 2: Compute the entropy value

$$e_j = -h\sum_{i=1}^{m} r_{ij} \ln r_{ij} \;, \qquad j=1, 2,\ldots\ldots\ldots\ldots\ldots\ldots n \quad (2)$$

$h = \frac{1}{\ln m}$, where m is the number of projects or alternatives

Step 3: Compute the weight vector

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{n} (1 - e_j)} \quad (3)$$

$d_j = 1 - e_j$,

here, d_j is called a degree of diversification

Phase 3: The 3rd phase of the adopted methodology deals with the prioritization and selection of the GLS projects in a manufacturing industry. The concerned industry deals with original equipment manufacturing and it is the vendor of prominent automobile industries of India. The annual turnover of the industry is around 28 Million US dollars. The selection of the appropriate GLS project based on sustainable development-oriented criteria has been made through the advanced decision making approach GRA. The concerned manufacturing organization wants to increase sustainability through the incorporation of the eco-friendly approach. The entire process of the project selection and the potential benefits has been discussed with the top management of the organization. The top management agreed on the initiation of the project selection and a team of twenty-one personnel (members of top and middle management of the organization, qualified LSS personnel, and academicians) has been formulated that helped in the project selection (Table 5). The LSS personnel and academicians have the experience of the project selection program pertains to Six Sigma and LSS and they were also parts of various quality improvement programs in the different manufacturing industries.

Table 5: Project selection team

The implementation of GRA demands the responses against each project to each alternative. These responses have been collected from the team formulated by the management of the organization. The GRA has been implemented through the following steps:

The steps of GRA are as follows:

Step 1: The first step of the GRA method is normalized or data processing. The responses collected from the personnel of the case industry (21 experts) against each alternative (project) to criterion have been summed up. x_i^0, represents the sum of the response of the project "i" criterion "o" The normalized values are obtained using equation (4). Here, x_i^{o*} represents the normalized value of the project "i" to the criterion "o".

$$x_i^{o*} = \frac{x_i^0 - \min x_i^0}{\max x_i^0 - \min x_i^0} \quad (4)$$

Step 2: In the second step of the grey relational analysis the deviation sequence (Δ_{oi}) is calculated using equation (5).

$$\Delta_{io} = \| \max x_i^{o*} - x_i^{o*} \| \quad (5)$$

Step 3: In this step, the grey relational coefficients (ξ_{io}) have been calculated using equation (6). Here, Δ_{min} represents the minimum value of the deviation sequence and Δ_{max} designates the maximum value of the deviation sequence. ξ value considered here is 0.5.

$$\xi_{io} = \frac{\Delta_{min} + \xi.\Delta_{max}}{\Delta_{oi} + \xi.\Delta_{max}} \quad (6)$$

Figure 3: Research Methodology

Step 4: In this step, the grey relational grade (γ_{i0}) is estimated using equation (7)

$$\gamma_{io} = \frac{1}{n}\sum_{o=1}^{n} w_o \xi_{io} \quad (7)$$

here, n = number of criterion and $w_o$stands for the weight of a particular criterion

To have more robustness in the results, the findings of the study have been validated firstly by the BWM and further using sensitivity analysis.

Phase 4: After the identification of GLS project, it is essential to develop an execution framework. In the final phase of the methodology, a GLS framework has been proposed with an associated toolset. To support this, research design consisted of developing a conceptual framework based on insights gained from literature and information from a panel of experts (LSS personnel, academicians, and experts from leading manufacturing companies). The framework was designed and rolled out, through two sub-phases: prototyping and fine tuning. During the prototyping phase, a first version of the GLS framework was developed based on cross-disciplinary bibliographical research and the insights from participants based on their experience in implementing GLS projects. The authors compared different tools and techniques of each component for the selected papers and were re-read and synthesized before a decision was reached whether to include or exclude them in the initial framework. Afterwards, the authors consulted a panel of aforesaid experts. This leads to the development of the conceptual framework. Afterwards, in order to fine tune developed framework, inputs form the case industry personnel were taken through brain storming sessions that leads to a refined GLS framework. Table 6 depicts inputs received from experts and case industry personnel.

Table 6: Experts and case industry personnel inputs on framework development

4. Selection and weighting of criterion for project selection

Project selection is a very key aspect for the effective implementation of GLS. The criteria are the parameters that affect the selection of a project within a manufacturing concern (Wang et al., 2014). In the present study, the various sub-criteria have been found from the literature review pertaining to sustainability, Lean Production, Six Sigma. Lean Six Sigma, and Green technologies. The various sub-criteria further have been formulated into main criteria based on the commonality characteristics that co-exist among the sub-criteria. Table 7 depicts the main criteria and sub-criteria that pertain to GLS project selection.

Table 7: Criteria for the selection of the GLS project

The sub-criteria have been constituted in six main criteria facility-related, environmental aspects, productivity, material related, wastes related, social, and material related. Each criterion exhibits its effect on the final project selection to others. So, it is indispensable to weight the criterion to ensure the maximum consistency and reliability in the final GLS project selection. GLS is a project-based approach and its success primarily lays with the successful project selection that exhibits maximum potential for sustainability improvement. The project in GLS is a particular section or shop of the industry where GLS has to be executed after considering all the aspects of sustainability (Kaswan and Rathi, 2020b). The LSS personnel involved with the quality improvement program of the industry advised continuing with seven projects for the selection of the most sustainability-oriented GLS project. The concerned manufacturing industry has seven shops that are involved in the realization of the product To weight the criterion a well-defined questionnaire was prepared and circulated among the manufacturing personnel of the different industries to give the response of each criterion concerning each project. The Cronbach's alpha test was performed and the value of the alpha is 0.83 that depicts the high reliability of the questionnaire. The collected responses have been analyzed through the entropy method to determine the final weight of the criteria. The steps associated with the entropy method are as follows:

Step 1: Formulate normalized decision matrix for calculation of the weights of the criterion

In this step, to calculate the weight of the criterion, the normalized decision matrix is made by using the responses of the manufacturing personnel. Table 8 indicates the responses of the manufacturing personnel of different industries to project selection criteria.

Table 8: Response collection from manufacturing personnel of different industries to weight criteria

The normalized matrix has been obtained using equation (1). Table 9 depicts the normalized matrix for the calculation of criteria weights.

Table 9: Normalize decision matrix for calculation of the weights of the criteria

Step 2: Compute the entropy value

The second step of the entropy method deals with the calculation of the entropy value. The entropy value is calculated using equation (2). Here, the comparison was made between project to criterion.

Table 10: Entropy Value

Step 3: Compute the weight vector

In the third step of the entropy method, the weight vector is formulated using equation (3), to calculate the weights of the criterion. Table 11 depicts the weights of the criterion.

Table 11: Weights of criteria for GLS project selection

It has been found that the productivity criterion has the highest weightage (0.2721) followed by the environmental criterion (0.2524). This also indicates the increased proclivity of the manufacturing organizations toward the environmental or ecological aspects. The manufacturing organization to be competitive in the long run must include the environmental and social aspects in their business to gain long term profitability and stability in the market. Once the weights of the criteria have been found, the GLS project was selected from the concerned manufacturing to initiate the implementation of the GLS.

5. Case Study

To select a sustainable oriented project and to develop a GLS implementation framework, a case study of the manufacturing industry has been considered in this study. The primary questions of this case study were:

RQ1: How to identify sustainable GLS project among the various project settings of the industry?

RQ2: How to execute GLS in the selected GLS project for improved organizational performance?

A case study is the most pertinent method where how types of questions have to be answered (Sony and Naik, 2020). A longitudinal case study has been used in this work as it not only develops a theoretical knowledge base but also provides an in-depth study of the change process as it takes place in the industry. The longitudinal case study differentiates from the conventional one in terms of that former provides researchers to observe the process change as it happens in the industry in real-time (Hout and Bingham, 2013). The study was conducted from October 2019 to May 2020 for identification of GLS project (define phase of GLS) and development of execution framework. This study is a sub-part of a complete GLS project implementation that is still going in the said industry. The manufacturing industry did not want to be recognized due to anonymous reasons, so pseudo name Z has been assigned to the industry. The industry Z was established in the year 2015 and is a manufacturer of original equipment. The estimated turnover of the industry for the year 2019 was nearly 110 Million US dollars. As a project in GLS is a particular section or shop of the industry, so the project has to be selected among the various shops of the case industry. The present study deals with the selection of GLS among seven shops (fabrication or weld shop, machine shop, sheet metal, finish machining, painting, and inspection and quality control shop) based on the six sustainable oriented criteria. Figure 4 represents the GLS project selection evaluation model.

The GRA has been used in the present study to select the GLS project based on six criteria. The steps associated with the GRA implementation are:

Step 1:

The very first step of the GRA is normalized or data processing. The responses from the twenty-one personnel (Table 5) have been used to rank the GLS projects. The responses collected from the personnel of the case industry for each project against each criterion has been summed up. Table 12 depicts the summed responses from five groups of industrial personnel in the case industry. The normalized values x_i^{o*} have been obtained using equation (4). Table 13 depicts the normalized values.

Figure 4: Final GLS project evaluation model

Table 12: Responses from experts to rank projects

Table 13 Normalised values

Step 2: In the second step of the grey relational analysis the deviation sequence (Δ_{oi}) is calculated using equation (5). Table 14 represents the deviation sequence.

Table 14: Deviation sequence

Step 3: In this step, the grey relational coefficients (ξ_{io}) are calculated using equation (6). Here, Δ_{min} represents the minimum value of the deviation sequence and Δ_{max} designates the maximum value of the deviation sequence. ξ value considered here is 0.5. Table 15 depicts the grey relational coefficients.

Table 15: Grey relational coefficients

Step 4: In this step, the grey relational grade (γ_{i0}) is estimated using equation (7). Here, n = number of criteria and $w_o$stands for the weight of a particular criterion. The grey relational grade

(GRG) is the 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 (Lo, 2002). The value of GRG between the two sequences is always between 0 and 1 (Ho and Lin, 2003). GRG signify the level of association between a reference sequence and the comparability sequence (Sallehuddin and Shamsuddin, 2008). The GRG is used here to specify the degree of influence that the comparability sequence (7 GLS projects) could employ over the reference sequence. So, if a particular comparability sequence is more significant than the other comparability sequences to the reference sequence then the GRG for that comparability sequence and reference sequence will be higher than other GRG. Table 16 depicts the grey relational grades (GRG) and ranks of the GLS projects. The values in the parenthesis represent the weights of the respective criterion.

Table 16: Grey relation grades and ranks of GLS projects

Moreover, ranks of the GLS projects have been further validated using BWM and it has been found that ranks of the GLS projects found through GRA are consistent with the results of the BWM. So, it can be deduced from the comparative analysis the projects' ranks are highly consistent and reliable. Table 17 depicts the comparative analysis of GLS project ranks using BWM.

Table 17: Validation of ranks of GLS projects using BWM

5.1 Sensitivity Analysis

Sensitivity analysis is an effective tool to check the robustness of the results found through MCDM techniques (Adelman and Hattka, 1986). In the present work, sensitivity analysis has been performed to check the effect of the variation in the input parameters on the GRA output parameters (grey relational grades and ranks) for GLS project selection. The sensitivity analysis has been performed for different variations of the input parameters of GRA. Table 18 depicts the sensitivity analysis for the variation in the input values of GRA. In the first case of table 18 with the variation of the input parameters of GRA from +20% to – 20%, the maximum variations in the GRG from the present value is 0.0472 that does not considerably change the ranks of top projects. Figure 5 depicts variation in the ranks with variations of the inputs, and it has been found from the radar chart of sensitivity analysis that there is no significant effect on ranks on top projects with variations in inputs. The outermost bluish layer in figure 5 presents the ranks of GLS projects with changing inputs of +20%. So, with variations in the input parameters, ranks of the GLS projects did not change considerably which is a characteristic of a consistent system. So, it can be deduced that the results of the study are consistent.

Table 18: GRG and ranks of GLS projects using sensitivity analysis

Figure 5: GRG of GLS projects using sensitivity analysis

From the GRA of the projects, it has been found that machine shop with GRG (0.4742) should be considered as the first project where GLS has to be implemented at the start in the concerned manufacturing industry**.** The selected GLS project will lead to improved operational efficiency, profitability, and reduced emission of GHGs. The systematic knowledge base gained from the first GLS project execution and potential benefits will provide impetus to the management of the industry to implement GLS in the 2nd ranked project (Finish machining project). GLS implementation with an organization requires substantial investment and major overhauls in the industry (Siegel, 2019). So, it is imperative that a selected project has the maximum potential for not only efficiency improvement but in the long term bring more financial stability. The GLS execution is initiated with a selected project and the current state is measured in terms of various indicators like standard deviation, sigma level, C_{pk}, carbon dioxide consumption, renewable energy content, etc., to find the defects level, process capability, and emission level. In the next step of GLS project execution, prominent causes associated with wastes, emissions, and imperfections are found. Furthermore, the solutions for the substantial improvement in organizational sustainability is proposed in the next step and the best solution is implemented and the performance indicator of the measure step of GLS is estimated here again to check for the performance improvement. The project is not only a key aspect of GLS but also for Six Sigma and Lean Six Sigma implementations. Once the selected GLS project has been implemented with full success, the pursuits are directed towards the 2nd most appropriate GLS project, i.e. finish machining shop. With the financial constraints and resources constraints, it is always advisable to start with the most potential project and then move towards the 2nd most suitable. It has been found that GLS implementation within an industry leads to substantial improvement in material and environmental efficacies that leads to increased profitability dynamics (Sony and Naik, 2020).

5.2 Green Lean Six Sigma Implementation framework

Six Sigma and LSS methodologies have been extensively adopted by industries to reduce associated wastes and rejections. But the increased intergovernmental pressure to cut the current level of emissions and sustainability-oriented customer demand industries to adopt sustainable practices (Kaswan and Rathi, 2020). GLS is an environmentally friendly approach that mitigates GHGs emissions, reduces wastes, and rejection to produce high-quality sustainable products. As a novel aspect of sustainability, there is a need for the dedicated execution model for GLS that provides a stepwise realization of this. Figure 6 demonstrates the execution framework of GLS. Table 19 depicts the toolset used at different steps of GLS execution.

In the first step of the GLS execution model, a project that shows the maximum potential for sustainability is selected based on the customer and business requirements. GLS project selection is one of the key aspects for effective execution as it has been found that nearly 40% of the GLS program has failed due to wrong project selection. Project in GLS is a particular segment or shop of the industry, where GLS has to be implemented initially. A detailed understanding of the case industry is indispensable to selecting a sustainability-oriented GLS project. The tools like the SIPOC diagram, Project charter, prioritization techniques, and VOC are used in this step to explore a GLS project that has the maximum prospective for the enhancement in organizational sustainability. The existing state of the selected project is estimated in the second step of GLS execution. Here, the present state of the project is measured against various indicators of the GLS, like sigma level, deviation, material efficiency, green energy coefficient, etc., using tools like life cycle assessment (LCA), environmental value stream mapping (EVSM), and other statistical tools. EVSM provides a current map of the various processes of the project and provides a complete estimate of cycle time, the material used, and other green estimates. LCA provides a detailed estimate of the processes of the project in different environmental categories. So, this step leads to the assessment of the various Green and Lean wastes that promote the basis for further perfection or improvement. The third step of GLS is related to finding out the main causes of the various wastes and inefficiencies in the project. A thorough investigation of the selected project is done to find various non-value-added activities, reasons for a high level of environmental emissions, variation in the 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. After the exploration of the main causes, the exploration is restricted to observing the main causes of the wastes using tools like principal component analysis, brainstorming, Pareto chart, etc. So, this step leads to the identification of the prominent causes that leads to the majority of the wastes and inefficiencies.

In the fourth step of the implementation model, various possible solutions for improvement in sustainability through reduction of wastes and improvement in efficiencies are proposed, evaluated and the best solution is implemented. This step of GLS demands high skill for the organizational members and other partners of the supply chain to find the best solution. Once the potential solutions have been identified, these are evaluated against several criteria using tools like the design of experiments (DOE), pugh matric, LCA, etc. The detailed exploration of possible solutions by GLS tools leads to the identification of the best solution that will exhibit the highest potential for the improvement in sustainability dynamics. The best solution is now implemented as a preliminary solution, activities to be done are documented, and personnel are educated in different aspects of the best-identified solution.

The successful GLS project selection and implementation of the proposed GLS framework will lead to improvement in the sigma level of the industry by reducing the number of rejected components. GLS execution will improve the lean metrics of cycle time and lead time through the improved process of the selected project. The successful deployment of GLS tools like LCA and EVSM will lead to improved environmental sustainability in terms of the reduction of raw material usage, reduced power consumption, water usage, and emission of GHGs. The industrial organizations with the proposed framework if implemented in real-time will be able to mitigate their current level of emissions. The inclusive implementation of the proposed GLS framework will enhance organizational productivity, environmental sustainability, and in the long run profitability dynamics.

Table 19: Toolset for GLS realization in the manufacturing environment

5.3 Implications for practitioners and researchers

The environmental policies on climate change and the changed quality perception of customers has forced the industries to incorporate social, environmental, and economic aspects in the project selection process. The present research work exhibits both research and managerial implications. The present research work prompts the managers and experts to implement Sustainable Green Lean Six Sigma through a systematic selection of the most viable project that unveils the highest prospective for increased organizational sustainability. The unique application of integrated entropy and the GRA method has been used to prioritize the projects of GLS. The GRA method provides highly reliable results with fewer data and sample size, and it is easy to comprehend (Wu, 2002). The benefits of the adopted method provide an impetus to the industrial managers to implement Sustainable GLS in the current process or system to turn it into eco-friendly ones. The current study offers a motivational sight for the application of the integrated entropy and GRA method in other sectors like hospitality, healthcare, heavy industries, etc. In the current scenario, manufacturing industries in developing nations are facing tremendous intergovernmental pressure to cut the rate of emission to meet nationally determined contributions (NDCs) under the Paris pact of climate change. The proper GLS project selection that is the key to its successful execution will lead not only reduce the current level of GHGs but also lead to improving the health of the industrial personnel. The prioritization of GLS projects enables the organizational managers to initiate the GLS program in the most influential project that has the maximum impact on organizational productivity, profitability, and environmental sustainability. Once the GLS program has been executed with full success in the selected GLS project (1st ranked GLS project with the highest GRG), GLS is initiated for the 2nd most influential project. The researchers will be facilitated from this research in terms of developing and understanding the criteria selection, weights determination, and more importantly the selection of appropriate GLS projects. The comprehensive learning on project selection will develop the decision making capability to select appropriate projects in other areas of the circular economy. Moreover, society will be promoted from present work as GLS successful execution leads to lesser rework, waste, and reduction in the current level of emission of the organization. So, Sustainable GLS implementation not only leads to better health of the case industry personnel but also the society.

6. Conclusion and future research agenda

Sustainability is being considered as a major parameter in the decision making process for project selection due to increased awareness of environmental concerns. GLS is an eco-friendly approach that leads to increased productivity, environmental sustainability, and profitability. The present study deals with the selection of the GLS project in a manufacturing organization based on six major sustainability-oriented criteria that have been formed from seventeen sub-criteria. As each criterion plays a different to other, so the weightage of the criteria has been found through the entropy method based on the responses from the sixty personnel of different manufacturing industries. A case study has been executed in an original equipment manufacturing industry of India to find the prominent GLS project that has the maximum potential for sustainability improvement. Grey relational analysis has been used in the present research work to prioritize GLS projects, so that project that exhibits the maximum potential for sustainability can be considered for incremental implementation of GLS. It has been found that the machine shop of the industry is the most suitable GLS project with GRG 0.4742. The case organization should initiate the GLS program with the selected project and once the GLS has been implemented with full success with selected projects, GLS can be expanded to other projects as per the ranks of the projects found using GRA.

Moreover, to foster strategic initiatives for improved environmental performance together with traditional priorities of productivity and profitability, a generic GLS implementation framework has been proposed along with toolset. The framework has been designed based on the insight gained from the literature and experts opinions. The term 'generic' implies that the proposed framework could be applied to manufacturing organizations with similar cultures and operating conditions. The features and constituents of the framework have been modeled in such a way that it would bring the deliverables more effectively when applied to manufacturing companies. The said framework provides an opportunity for the concerned industry to implement the best practices to reduce carbon footprint, wastes, and defects from the existing project or system. Successful execution of the proposed framework will lead to a reduction in the level of rework, defects, capacity waste, and environmental wastes in the case organization, together with an improvement in operational and monetary metrics. The framework will also have a positive effect on social consequences (due to reduced environmental impact), as improvements were observed concerning human health and workplace safety.

Although the study depicts the sustainability-oriented GLS project selection, there still exist some areas of improvement. Firstly, the present study considers six major criteria like environmental, facility-related, and others that are significant in attribute decision making. However, other criteria like cultural aspects and customer consensus related are also prominent factors for strategic GLS project selection. Secondly, the GLS project selection considered here takes into account the case of the original equipment manufacturing industry. So, to make the adopted approach more generalized the case studies from the different manufacturing sectors with varied nature (chemical, semi-conductors, construction, food and drinks, aerospace) and size (large, medium, and small enterprises) are required. The present research work can be extended in the future by systematic analysis of the project selection criteria using an advanced decision-making approach, DEMATEL that will provide a better estimate of the intriguing nature of the criteria. Moreover, the potential researchers can explore the grey areas of GLS like, integration of GLS with IoT and circular economy for improved environmental sustainability in small and medium enterprises, modeling and investigation of GLS adoption barriers in manufacturing industries using structural equation modeling (SEM) and best-worst method (BWM).

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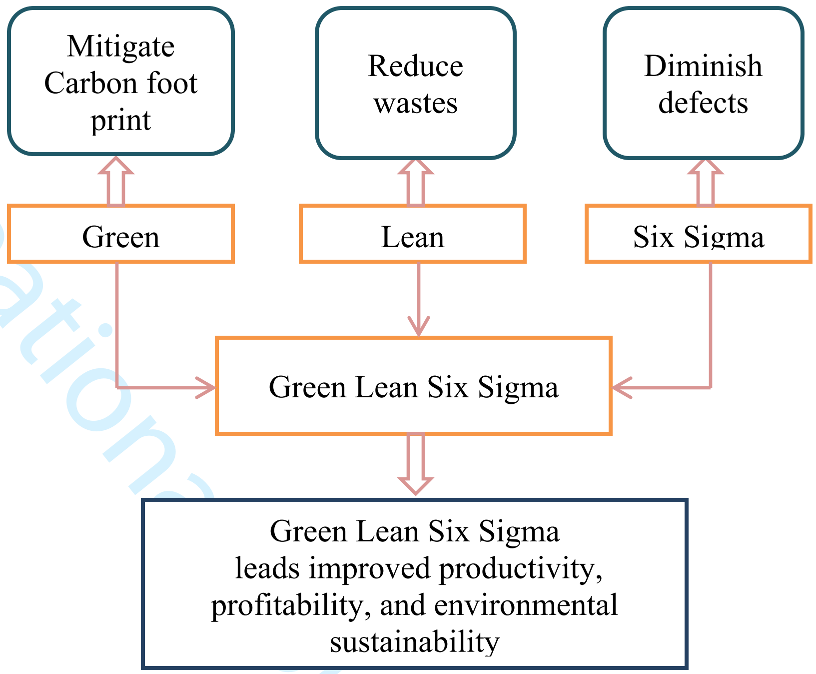


Figure 1: Conceptual Green Lean Six Sigma model (Kaswan and Rathi, 2021a)

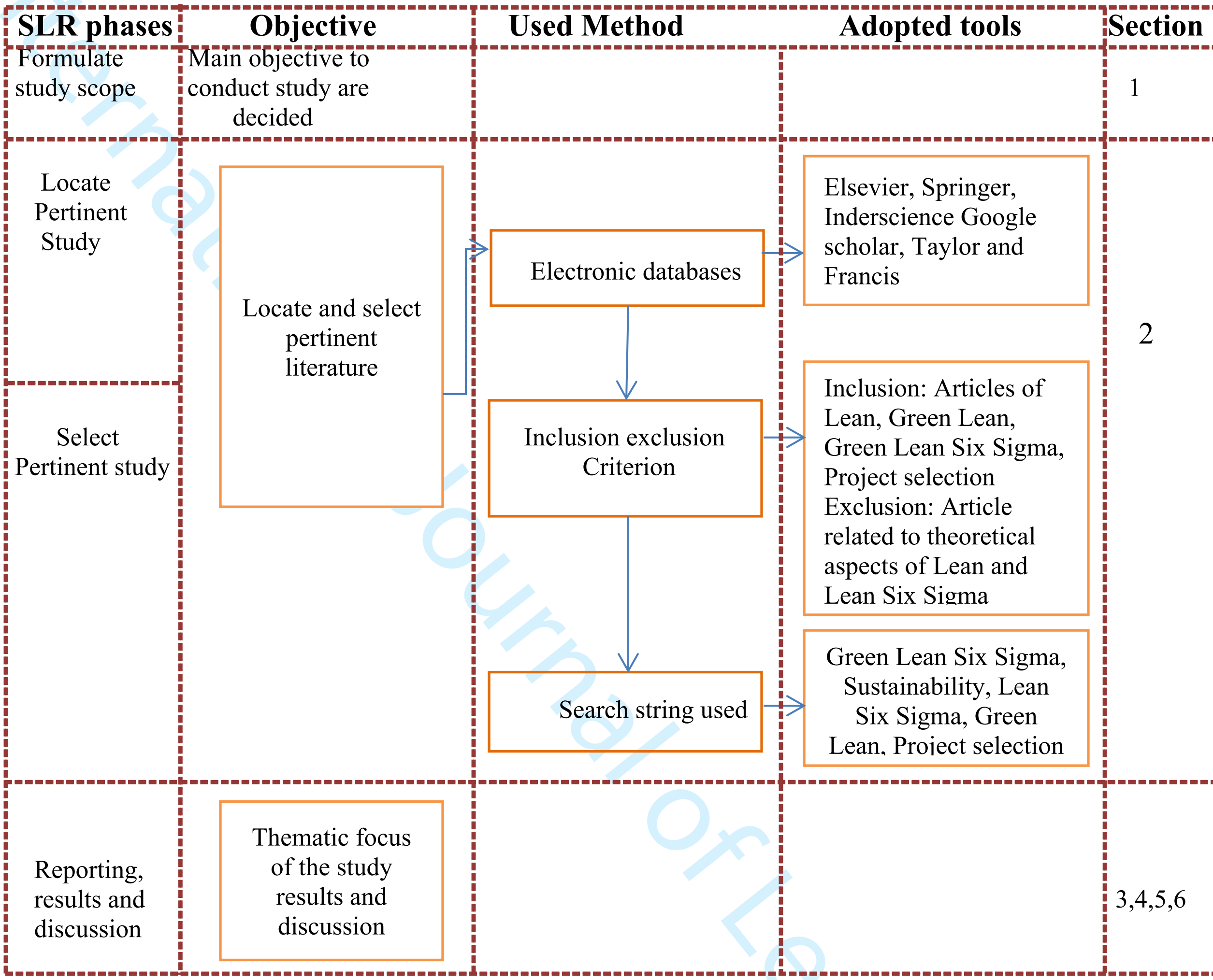
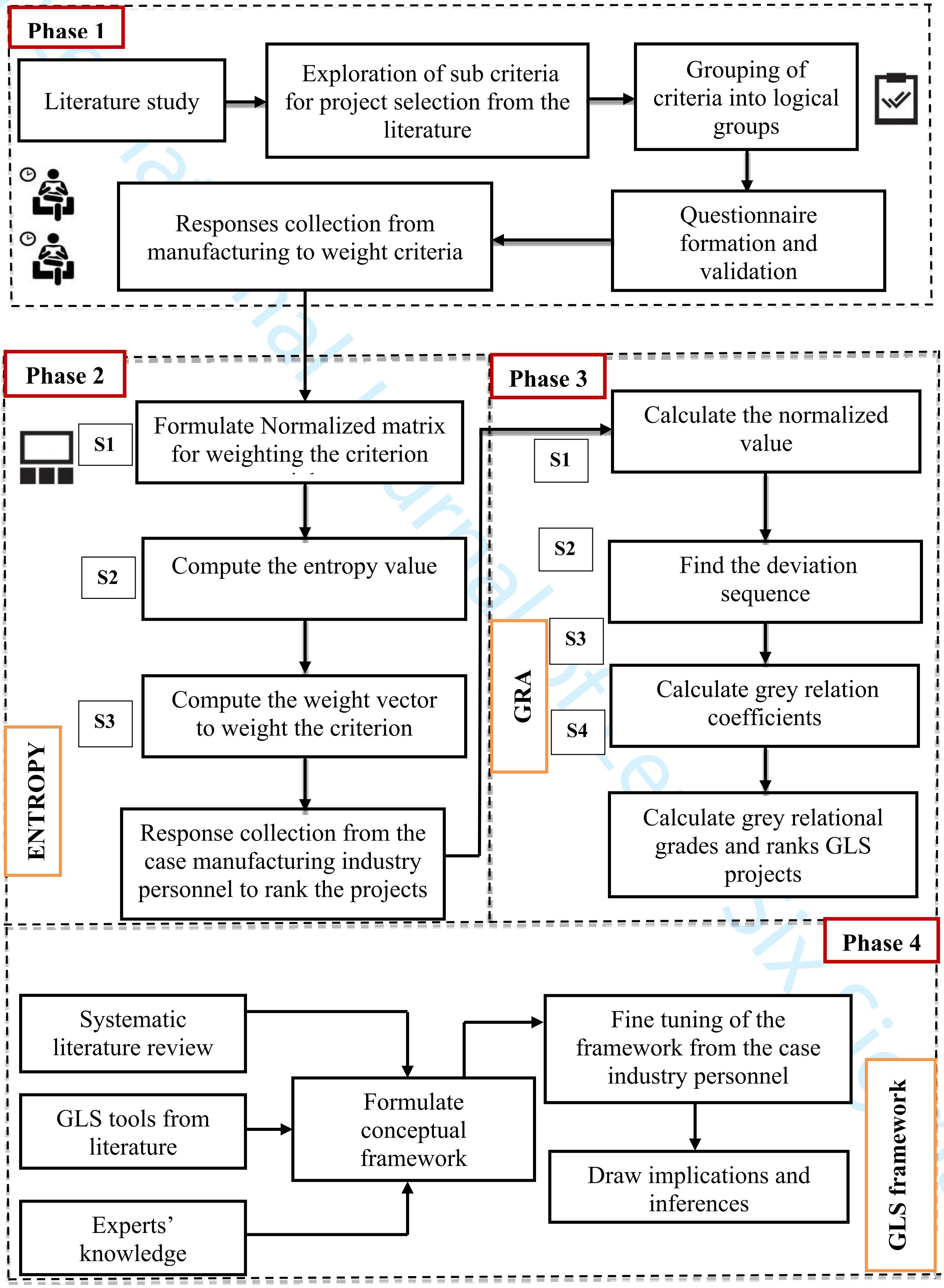


Figure 2: Systematic literature review methodology

Figure 3: Research methodology



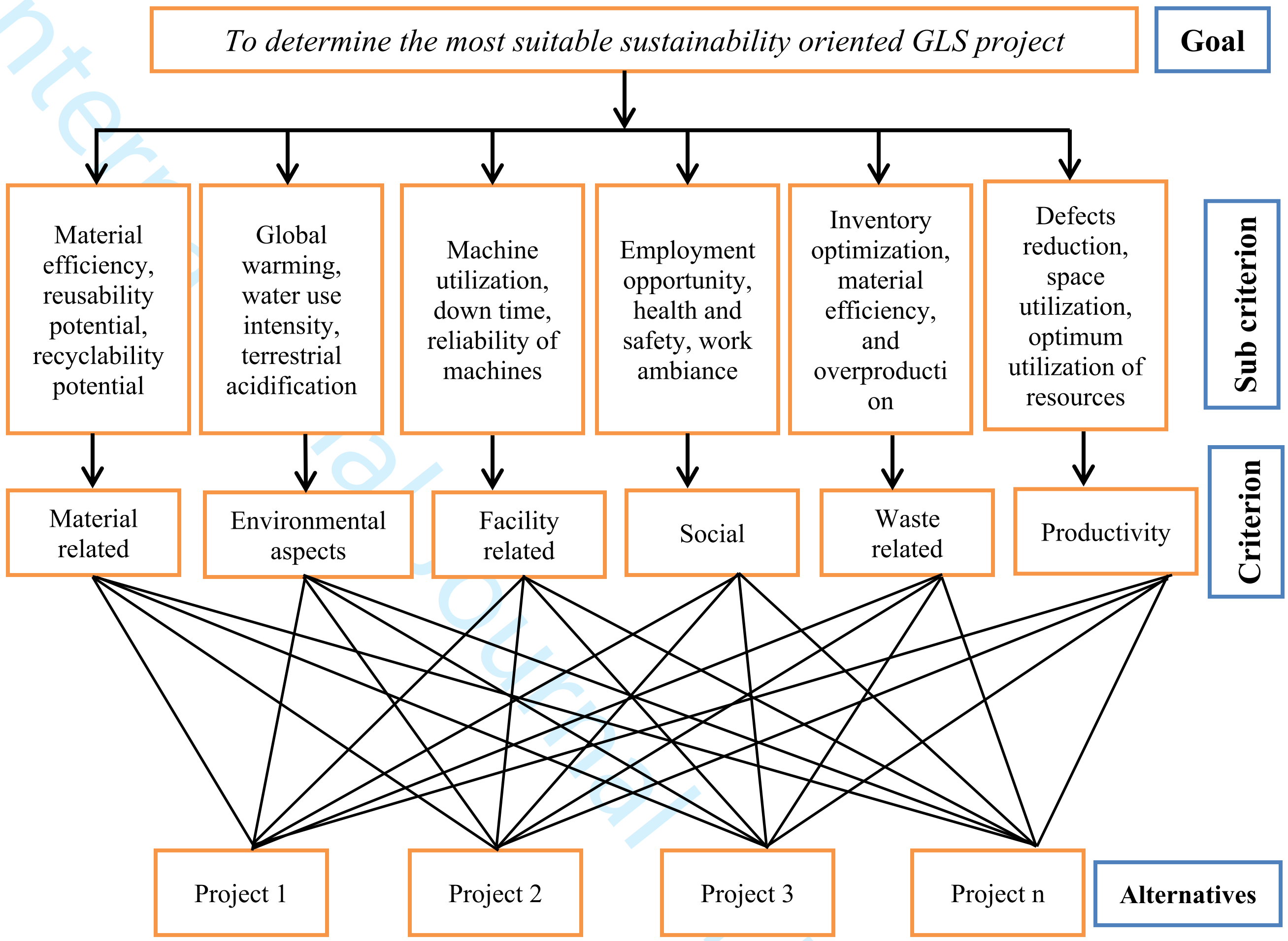


Figure 4: Final GLS project evaluation model

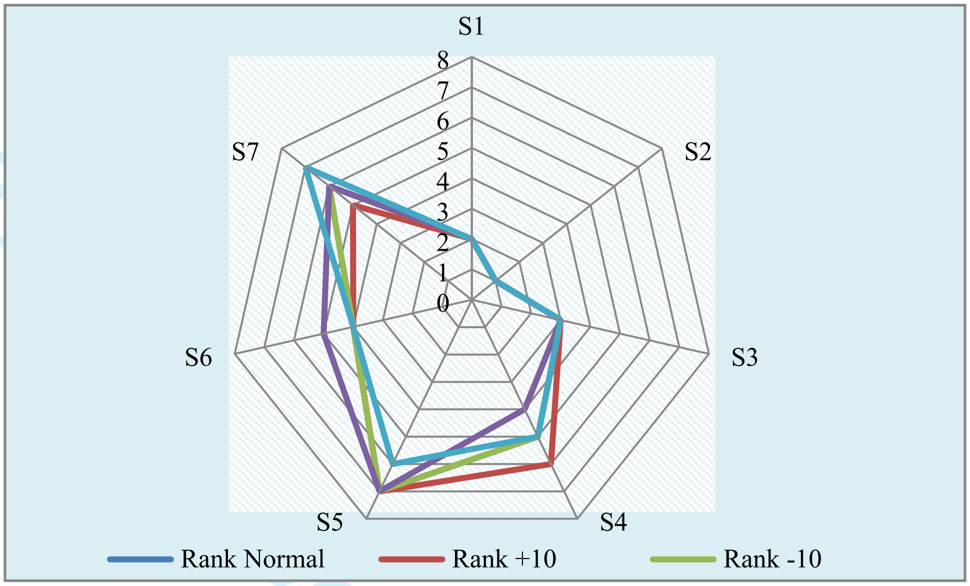


Figure 5: GRG of GLS projects using sensitivity analysis

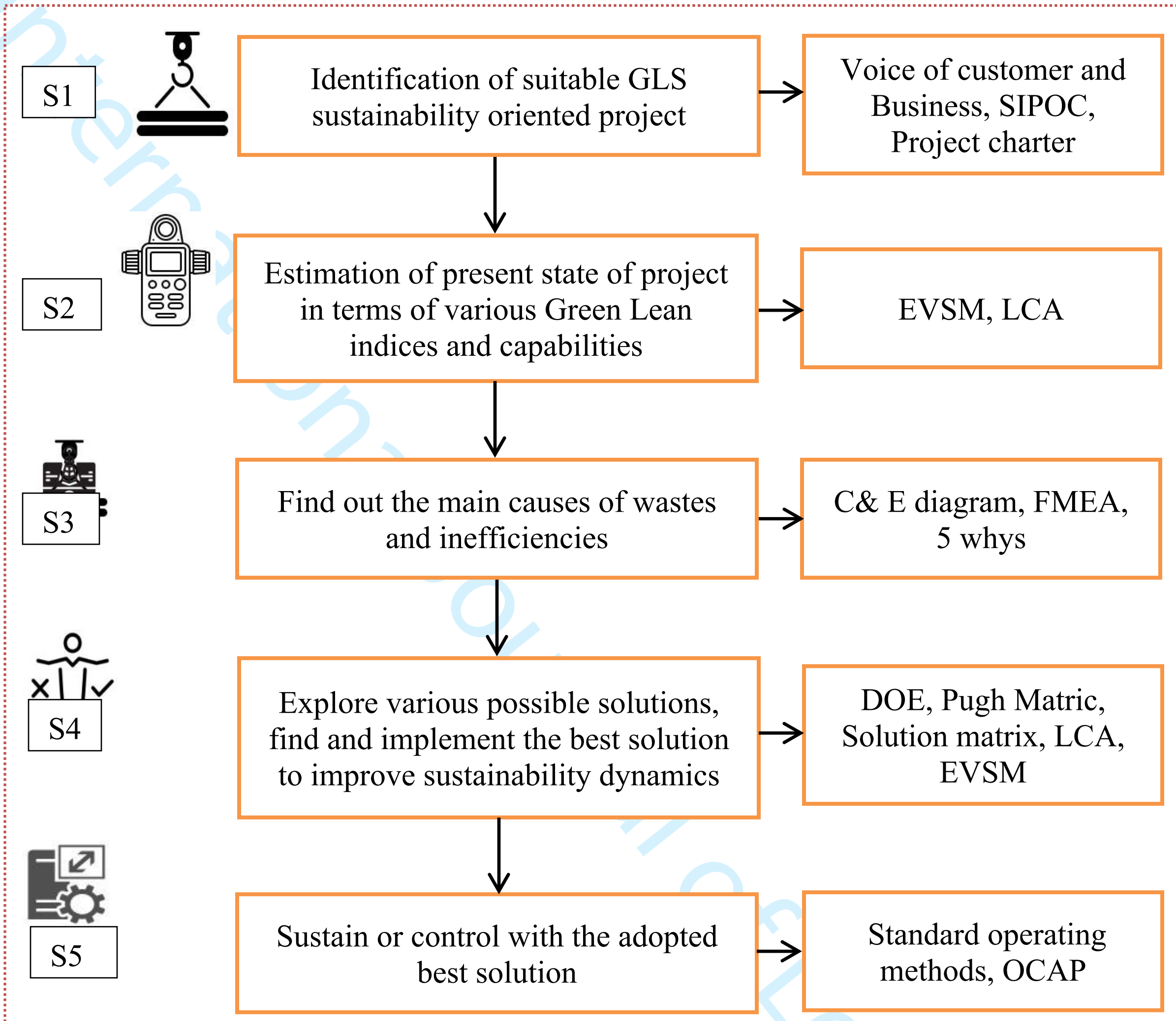


Figure 6: Green Lean Six Sigma execution mode

Table 1: Articles considered for the study through systematic literature search

Authors	Year	Title	Journal	Conceptual /Case study
Antony	2014	Readiness factors for the Lean Six Sigma journey in the higher education sector", International Journal of Productivity and Performance Management	International Journal of Productivity and Performance Management	Conceptual
Antony	2011	Six Sigma vs Lean: Some perspectives from leading academics and practitioners	International Journal of Productivity and Performance Management	Conceptual
Antony et al.	2019	A study into the reasons for process improvement project failures: results from a pilot survey	International Journal of Quality and Reliability Management	Conceptual
Banawi and Bilec	2014	A framework to improve construction processes: Integrating Lean, Green and Six Sigma	International Journal of Construction Management	Case study
Belhadi et al.	2018	Benefits of adopting lean production on green performance of SMEs: a case study	Production Planning & Control	Case study
Belhadi et al.	2021	A Big Data Analytics-driven Lean Six Sigma framework for enhanced green performance: a case study of chemical company	Production Planning & Control	Case study
Bilgen and Şen	2012	Project selection through fuzzy analytic hierarchy process and a case study on Six Sigma implementation in an automotive industry	Production Planning & Control	Conceptual
Chen	2019	Effects of normalization on the entropy-based TOPSIS method	Expert Systems with Applications	Conceptual
Chen et al.	2019	Developing a fuzzy green supplier selection model using six sigma quality indices	International Journal of Production Economics	Case study
Cherrafi et al.	2017	A framework for the integration of Green and Lean Six Sigma for superior sustainability performanc	International Journal of Production Research	Case study
Costa et al	2020	Lean six sigma in the food industry: Construct development and measurement validation	International Journal of Production Economics	Conceptual
de Freitas et al.	2017	Impacts of Lean Six Sigma over organizational sustainability	Journal of Cleaner Production	Conceptual
Erdil et al.	2018	Embedding sustainability in lean six sigma efforts	Journal of Cleaner Production	Case study
Ershadi et al.	2021	Selection and performance estimation of Green Lean Six Sigma Projects: a hybrid approach of technology readiness level, data envelopment analysis, and ANFIS	Environmental Science and Pollution Research	Conceptual

Farrukh et al.	2021	A comparative analysis of green-lean-six sigma enablers and environmental outcomes: a natural resource-based view	International Journal of Lean Six Sigma	Conceptual
Fatemi and Franchetti	2016	An application of sustainable lean and green strategy with a Six Sigma approach on a manufacturing system	International Journal of Six Sigma and Competitive Advantage	Case study
Gaikwad and Sunnapwar	2020	An integrated Lean, Green and Six Sigma strategies: A systematic literature review and directions for future research	The TQM Journal	Conceptual
Garza-Reyes	2015	Green lean and the need for Six Sigma	International Journal of Lean Six Sigma	Conceptual
Gholami et al.	2021	The application of green lean Six Sigma	Business Strategy and the Environment	Case study
Goyal et al.	2019	Quality management for sustainable manufacturing: Moving from number to impact of defects	Journal of Cleaner Production	Case study
Gupta et al.	2019	Systematic literature review of project failures: Current trends and scope for future research	Computers & Industrial Engineering	Conceptual
Hu et al.	2018	A multi-objective model for project portfolio selection to implement lean and Six Sigma	International journal of production research,	Conceptual
Huijbregts et al.	2017	A harmonised life cycle impact assessment method at midpoint and endpoint level	The International Journal of Life Cycle Assessment, 22(2), 138-147.	Conceptual
Hussain et al.	2019	Green, lean, six sigma barriers at a glance: a case from the construction sector of Pakistan	Building and Environment	Conceptual
Jacobson	2008	On the causal link between carbon dioxide and air pollution mortality	Geophysical Research Letters	Conceptual
Jasti and Kodali	2019	An empirical investigation on lean production system framework in the Indian manufacturing industry.	Benchmarking: An International Journal.	Conceptual
Kaswan and Rathi	2020	Green Lean Six Sigma for sustainable development: Integration and framework	Environmental impact assessment review	Conceptual
Kaswan and Rathi	2019	Analysis and modeling the enablers of green lean six sigma implementation using interpretive structural modeling	Journal of Cleaner Production	Conceptual
Kaswan and Rathi	2021	An inclusive review of Green Lean Six Sigma for sustainable development: readiness measures and challenges	International Journal of Advanced Operations Management	Conceptual
Kaswan et al.	2020	Integration of Green Lean Six Sigma: a novel approach for sustainable development.	International Journal of Six Sigma and Competitive Advantage	Conceptual
Kumar et al.	2016	Barriers in green lean six sigma product development process: an ISM approach	Production Planning & Control	Conceptual
Kumar et al.	2009	Project selection and its impact on the successful deployment of Six Sigma	Business Process Management Journal	Conceptual

Ma et al.	2020	Sustainability driven multi-criteria project portfolio selection under uncertain decision-making environment.	Computers & Industrial Engineering	Conceptual
Oliveira et al.	2018	Lean and green approach: An evaluation tool for new product development focused on small and medium enterprises	International Journal of Production Economics	Conceptual
Pandey et al.	2018	Identification and ranking of enablers of green lean Six Sigma implementation using AHP.	International Journal of Productivity and Quality Management	Conceptual
Powell et al.	2017	Lean Six Sigma and environmental sustainability: the case of a Norwegian dairy producer	International Journal of Lean Six Sigma	Case study
Prashar	2020	Adopting Six Sigma DMAIC for environmental considerations in process industry environment.	The TQM Journal	Case study
Ruben et al.	2017	Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study	Production Planning & Control	Case study
Ruben et al.	2018	Lean Six Sigma with environmental focus: review and framework	The International Journal of Advanced Manufacturing Technology	Conceptual
Sagnak and Kazancoglu	2016	Integration of green lean approach with six sigma: an application for flue gas emissions	Journal of Cleaner Production	Conceptual
Shokri and Li	2020	Green implementation of Lean Six Sigma projects in the manufacturing sector	International Journal of Lean Six Sigma	Case study
Siebert et al.	2018	Social life cycle assessment indices and indicators to monitor the social implications of wood-based products.	Journal of Cleaner Production	Conceptual
Siegel et al.	2019	Integrated green lean approach and sustainability for SMEs: From literature review to a conceptual framework	Journal of Cleaner Production	Conceptual
Sony and Naik	2020	Green Lean Six Sigma implementation framework: a case of reducing graphite and dust pollution	International Journal of Sustainable Engineering	Case study
Sreedharan and Sunder	2018	A novel approach to lean six sigma project management: a conceptual framework and empirical application	Production Planning & Control	Conceptual
Swarnakar et al.	2020	Evaluating critical failure factors for implementing sustainable lean six sigma framework in manufacturing organization: A case experience	International Journal of Lean Six Sigma	Conceptual
Vinodh et al.	2016	Application of interpretive structural modeling for analyzing the factors influencing the integrated lean sustainable system	Clean Technologies and Environmental Policy	Conceptual
Wang et al.	2019	Lean Six Sigma applied to process performance and improvement model for the development of electric scooter water-cooling green motor assembly	Production Planning & Control	Case study

Wang et al.	2014	Applying a hybrid MCDM model for six sigma project selection.	Mathematical Problems in Engineering	Conceptual
Zamri et al.	2013	Green lean six sigma and financial performance in Malaysian automotive industry.	Business Management and Strategy	Conceptual
Zhu et al.	2018	Lean six sigma and environmental sustainability: a hospital perspective	Supply Chain Forum: An International Journal	Case study

Table 2: Comparison between Lean Six Sigma, Green Lean Six Sigma and Sustainable Green Lean Six Sigma

Lean Six Sigma	**Green Lean Six Sigma**	**Sustainable Green Lean Six Sigma**
LSS is more likely to affect the economic dimension of the sustainability than the environmental due to wide variety of environmental metrics (Goyal et al. 2019)	GLS incorporates dimensions of the sustainability (Environmental and economic) and makes an organization more competitive at global platform (Kaswan and Rathi, 2020)	Sustainable Green Lean Sigma incorporates all dimensions of the sustainability (social, economic , and environmental) and leads towards a resilient industry and health society (Singh and Rathi, 2021)
LSS approach strives for systematic reduction of non-value added activities and process variations, advocating speed and accuracy at all levels within the organization (Cherrafi et al., 2017)	GLS prescribes a function of high product quality, reduced cost, and eco-friendly through eliminating waste, defects and negative environmental impact on the environment (Belhadi et al. 2020; Kaswan et al., 2021)	Sustainable Green Lean Six Sigma is an inclusive approach that reduces variation, waste, required resources improves production efficiency, flexibility, quality, profitability, customer satisfaction, environmental emission, improved employee wellbeing and participation, improved local community engagement, organization global perspective that all in terms result in a resilient industry (Kumar et al. 2015)
Companies implementing LSS could merely integrates green practices and improve their environmental performance (Sony and Naik, 2020; Cherrafi et al., 2021)	Integration of LSS with Green technology lead to a robust methodology named GLS that leads to improved organizational performance through systematic reduction of wastes, emission, and other non-essential activities (Belhadi et al., 2020)	Incorporation of social prospective in GLS leads to enhancement of organizational capability related to corporate social responsibility, improved level of employee participation, wellbeing, and enhanced procurement and recruitment form local community (Kaswan et al. 2021).

Table 3: List of frameworks reviewed

Authors	Contribution	Limitations	Use of LSS tools	Use of environment al mgt. tools	Operational benefits	Sustainable benefits	Practical case implementation
Banawi and Bilec, 2014	Formulated framework for the adoption of integrated Green, Lean, and Six Sigma for the construction industry to improve process performance through retrospective diagnosis. The developed framework estimates environmental impacts and assists contractors to measure the impacts of their traditional methods and improving the corresponding efficiency.	The major limitation of this study was that the adopted framework focused only on the construction sector. The integral measures of Green, Lean, and Six Sigma were also not provided.	👍	👍	👍	👍	👍
Sony and Naik, 2019	Developed a sustainability-oriented GLS framework for reducing dust and graphite pollution in the mining industry.	The developed framework exhibited limited application of Six Sigma tools and the adopted method was only applicable to the mining sector.	👍	👍	👍	👍	👍
Kaswan and Rathi, 2020	The researchers proposed integration based on theoretical measures and formulated a DMAIC based GLS implementation framework.	The framework developed was not validated within a case organization.	👍	👍	–	👍	–
Ruben et al. 2017	Formulated a generic framework of LSS with environmental facets and realized the same with a case of an automotive organization.	Developed framework more inclined towards the LSS measures the aspects of social sustainability was not explored to full throttle.	👍	👍	👍	👍	👍
Siegel et al. 2019	Presented a systematic model to integrate and implement Green Lean for manufacturing SMEs.	Six Sigma potential along with social sustainability aspects was not explored to improve organizational productivity and social performance.	👍	👍	👍	–	–
Cherrafi et al. 2016	Developed a five stages based framework to implement LSS with environmental facets. It has been found that the case industry reduced material and cost of energy through the inclusive implementation of the adopted framework.	The framework has not explored reduction in defects level, assessment of different environmental and social metrics.	👍	👍	👍	–	👍

Erdil et al. 2018	The formulated model framework to redefine the LSS (DMAIC) cycle for the incorporation of the sustainability measures in any LSS project based on the current practices.	The main limitation of the present study was that the developed model was not tested in a real-life industrial setting to validate the results.	👍	👍	👍	👍	-
Ruben et al. 2018	Based on the insights gained from the literature study developed an environmental focused LSS framework using benign LSS tools.	The developed framework was not tested practically and also did not incorporate societal aspects of the sustainability	👍	👍	👍	-	-
Caiado et al. 2018	Proposed an integrated framework of Green Lean and Six Sigma to enhance the sustainability of the service sector based on critical factors.	The developed model was not tested pragmatically and it was solely developed for the service sector.	👍	👍	👍	-	-
Sagnak and Kazancoglu, 2016	Developed an integrated framework of GLS based on commonality characteristics that coexist among individual approaches.	The study lacks practical validation of integrated framework and did consider social aspects of the sustainability	👍	👍	👍	-	👍
Gholami et al. 2020	Proposed and implemented GLS framework to enhance organizational sustainability based on DMAIC approach	The proposed have not considered the application of the Lean. Six Sigma tools, and also not address the societal dimension of the sustainability	👍	👍	👍	-	👍
Talapatra, and Gaine, 2019	Proposed and implemented GLS framework for jute industry to reduce defects, carbon footprints and energy usage.	The said framework was entirely focused for the jute industry and did not incorporated societal metrics.	👍	👍	👍	-	👍
Ershadi et al, 2021	GLS project selection was made based on the integral aspects of the data envelopment analysis (DEA) and technology readiness level (TRL).	The main limitation of this study was that the authors failed to address that how GLS works, how it can enhance the societal dimension of the industry.	👍	👍	👍	-	-

Table 4: Prominent case studies pertaining Green Lean Six Sigma

S. No.	References	Sector	Tools used	Main contribution
1	Banawi and Bilec (2014)	Construction	Brainstorming, Control charts, Pareto chart, Root cause analysis, DOE, ANOVA, LCA, EVSM	Reduction of dust pollution, reduction of 12,698 kg of CO2 emission annually,
2	Fatemi and Franchetti (2016)	Manufacturing	5W method, DOE, ANOVA, Cost-beneficial analysis, LCA , recycling	decrease in energy usage, increase in waste awareness, reduction in energy and water consumption, reduction in material consumption
3	Powell et al. (2017)	Food	VSM, SPC, KPI, 5M, EVSM	Increase in waste awareness, reduction in energy and water consumption
4	Ruben et al. 2017	Automotive	EVSM, LCA, SIPOC, DMAIC, Project charter, Kaizen, 7S, Pareto chart, DOE	Reduction of environmental impacts to 33 Pt from 42 Pt
5	Cherrafi et al. (2017)	Food	SIPOC, Voice of the stakeholders, Project charter, 5S, TPM, Statistical, process control, Pareto diagram, Cause effect daigram, Green VSM, 3 R	Reduction in energy and water consumption
6	Belhadi et al. (2018)	Mechanical	5S/ Housekeeping, JIT, Kaizen, Kanban, Visual control, Cellular manufacturing, Product/ Process Matrix, Pareto Analysis, Work standards, Knowledge Management, Green VSM, Green policy, Green Scoreboard	Decrease in crude metals consumption from 65.17 to 46.38 kg/product, Reduction of water and energy usage
7	Erdil et al. (2018)	Healthcare	Project Charter, Process Map, SIPOC, Voice of the Customer analysis, Stakeholder analysis, Kano analysis, VOB, Critical-to-Quality Tree, House of Quality, Measurement System Analysis, Spaghetti diagrams, Cause and Effect diagram, Pareto chart, five Whys	Reduction of hazardous chemicals in treated wastewater
8	Zhu et al. (2018)	Healthcare	VSM, 5S, root cause analysis, SIPOC, fishbone diagram, process mapping, Pull inventory systems, standard work	Elimination of paper waste and reduction of carbon emissions in the medication delivery system, efficient energy consumption and reduced carbon emissions from linen delivery trips

10	Sony and Naik (2020)	Mining	DMAIC, five whys, project charter, statistical analysis, standard operating procedures (SOP), cause-effect diagram, control charts, Pareto chart, Environmental Value Stream mapping, Green wastes, Environmental goals & metrics	Reduction of dust pollution
11	Chen et al. (2019)	Electrical	K-sigma level, quality index, statistical testing, process capability analysis, 4R principles (recycle, recycle, reduce, reuse, and recover)	Prolong maintenance intervals (increased rate of Reuse and recycling), Evaluation of suppliers based on green performance, Reduced amount of scrap and rework
12	Goyal et al. (2019)		Brainstorming, root causes analysis, cause and effect diagram, source reduction, Internal environmental management	Prolonged service life (increased Recovery rate), Zero waste generation in the process (Aluminum foil and conducting paint), Saving of raw material
13	Prashar (2020)	Pharmaceutical	Continuous Improvement framework, Quality policy, communication and reward mechanism, project prioritization, project charter, high-level, process mapping (SIPOC), VOC, VOB, Environmental Control	Reduction in electricity usage, reduction in emission of tons of CO_2 per kilowatt-hour of energy
14	Shokri and Li (2020)	Manufacturing	Quality-oriented CTQ, design of experiment, Green oriented CTQ, Environmental impact analysis	Reduced energy consumption, reduced environmental impact
15	Gholami et al. (2021)	Chemical	Process diagram, Pareto chart, SPC, EVSM, LCA	Reduced consumption of chemicals and energy in the operations of 28 and 21%, cost saving in operations

Table 5: Project selection team

Work profile	Number of person	Percentage	Average work Experience
Senior Manager	2	9.52%	25 Years
Manager	7	33.33%	19 Years
LSS Personnel	8	38.09%	14Years
Academician	4	19.06%	15 Years

Table 6: Experts and case industry personnel inputs on framework development

Steps in framework	Panel of experts inputs	Case industry personnel inputs	Changes made in the framework
Identification of suitable GLS sustainability oriented project	Sustainability oriented project selection was made based on the experts' opinions. Firstly, based on experts' opinions sub criteria were formulated into main criteria and then weighting of the main criteria was done. This leads to the formulation of the prominent criteria that significant role in the selection of a most sustainable focused project for the industry.	Case industry personnel inputs were used to evaluate each project against each main criterion to select the most sustainable focused project for the industry	The conventional framework only encompassed criteria related to economic dimensions of the sustainability. Based on expert inputs, criteria related to social and environmental sustainability were included to the select the most prominent sustainability oriented project.
Estimation of present state of project in terms of various Green Lean indices and capabilities	Incorporation of more prominent metrics related to environmental performance like green energy coefficient, acidification potential, etc. Experts also suggested to induce prominent lifecycle assessment in order to explore to different metrics related to the green performance and social performance	To assess current state of the system, case industry personnel suggested to estimate level of material, water waste and suggested to incorporated environmental value stream mapping in order to assess different lean and green metrics	Initial framework was more pinpointed to estimate current system state in terms of Lean metrics based tools of Six Sigma and traditional lean tools. Based on inputs of experts and industrial persons at this juncture metrics related to green performance like CO_2 consummation, green energy coefficient, material and water consumption in order to provide a more realistic measure of the current level of metrics related to sustainability

Find out the main causes of wastes and inefficiencies	Not particular opinions at this juncture	Identification of possible reasons of wastes, inefficiencies, and poor sustainability were entirely based on case industry personnel. The industry personnel suggested that to identify most likely reasons for low performance, all the responsible causes must be grouped into few prominent categories for the identification of most sustainability improvement centered solution	Initial project not encompass categorization of the reason for low performance related were in generic in nature. Based on inputs received from case industry personnel, they have been grouped in to sustainability dimensions
Explore various possible solutions, find and implement the best solution to improve sustainability dynamics	Experts suggested to incorporate tools like pugh matrix and solution so that strength and weakness of the proposed best solutions	Not particular opinions at this juncture	Based on experts suggestion more tools were incorporated at this step to find the best solution to improve sustainability dynamics of the industry
Sustain or control with the adopted best solution	Experts suggested to re-evaluate system for long run and re-estimate system performance metrics particularly related to environmental metrics using LCA to make sure level of improvement made in environmental metrics	Suggested to incorporate 'out of control action plan' to make system ready for correction	Based on experts and industrial personnel suggestion system performance re-monitored and out of control initiated and same measures incorporated in the final framework

Table 7: Criteria for the selection of the GLS project

S.No.	Sub criteria	References	Main criteria	Label
1	Material efficiency	Indicators, O. E. C. D. (2011).	Material related	CR1
2	Reusability potential	Amrina and Yusof (2011); Ma et al. (2020)		
3	Recyclability potential	Ma et al. (2020)		
4	Defects reduction	Indicators, O. E. C. D. (2011).	Productivity	CR2
5	Space utilization	Self-developed		
6	Optimum utilization of resources	Indicators, O. E. C. D. (2011).		
7	GHGs release intensity	Amrina and Yusof (2011); Huijbregts et al. (2017)	Environmental aspects	CR3
8	Water use intensity	Ma et al. (2020)		
9	Terrestrial acidification	Ma et al. (2020)		
10	Employment opportunity	Siebert et al. (2018)	Social aspects	CR4
11	Health and safety	Amrina and Yusof (2011);Siebert et al. (2018)		
12	Work ambiance	Siebert et al. (2018)		
13	Inventory optimization	Indicators, O. E. C. D. (2011).	Waste related	CR5
14	Overproduction	Self-developed		
15	Skill and training aspects	Indicators, O. E. C. D. (2011).	Facility related	CR6
16	Machine utilization	Self-developed		
17	Reliability of machines	Self-developed		

Table 8: Response collection from manufacturing personnel of different industries to weight criteria

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
Finish machining shop (SP1)	220	194	234	184	215	233
Machine shop (SP2)	189	213	214	219	219	247
Final assembly shop (SP3)	234	181	223	241	164	167
Sheet metal shop (SP4)	211	267	177	183	231	172
Inspection and quality shop (SP5)	230	215	244	192	214	228
Fabrication or weld shop (SP6)	245	173	169	211	184	178
Painting shop (SP7)	210	144	145	194	188	163

Table 9: Normalize decision matrix for calculation of the weights of the criteria

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
SP1	0.1429	0.1399	0.1664	0.1292	0.1519	0.1679
SP2	0.1228	0.1536	0.1522	0.1538	0.1548	0.1780
SP3	0.1520	0.1305	0.1586	0.1692	0.1159	0.1203
SP4	0.1371	0.1925	0.1259	0.1285	0.1633	0.1239
SP5	0.1494	0.1550	0.1735	0.1348	0.1512	0.1643
SP6	0.1592	0.1247	0.1202	0.1482	0.1300	0.1282
SP7	0.1365	0.1038	0.1031	0.1362	0.1329	0.1174

Table 10: Entropy Value

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
SP1	-0.2781	-0.2751	-0.2984	-0.2644	-0.2863	-0.2996
SP2	-0.2575	-0.2877	-0.2865	-0.2879	-0.2888	-0.3072
SP3	-0.2864	-0.2657	-0.2920	-0.3006	-0.2498	-0.2548
SP4	-0.2724	-0.3172	-0.2609	-0.2637	-0.2959	-0.2588
SP5	-0.2841	-0.2890	-0.3039	-0.2702	-0.2857	-0.2967
SP6	-0.2925	-0.2596	-0.2547	-0.2829	-0.2653	-0.2634
SP7	-0.2718	-0.2352	-0.2343	-0.2716	-0.2682	-0.2515
$\sum$	-1.9428	-1.9296	-1.9308	-1.9413	-1.9398	-1.9319
H	-0.5138	-0.5138	-0.5138	-0.5138	-0.5138	-0.5138
Ej	0.9982	0.9914	0.9920	0.9974	0.9967	0.9926

Table 11: Weights of criteria for GLS project selection

Criteria	CR1	CR2	CR3	CR4	CR5	CR6
ej	0.9982	0.9914	0.9920	0.9974	0.9967	0.9926
1-ej	0.0018	0.0086	0.0080	0.0026	0.0033	0.0074
wj	0.0562	0.2721	0.2524	0.0811	0.1048	0.2335

Table 12: Responses from experts to rank projects

Projects (Shops)/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
Finish machining (SP1)	83	76	68	94	74	61
Machine (SP2)	82	68	81	84	71	62
Final assembly (SP3)	94	71	79	72	83	89
Sheet metal (SP4)	86	82	85	77	81	95
Inspection and quality (SP5)	69	84	89	88	83	68
Fabrication or weld (SP6)	79	68	87	91	64	93
Painting (SP7)	93	91	77	72	68	82

Table 13: Normalised values

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
SP1	0.560	0.348	0.000	1.000	0.526	0.000
SP2	0.520	0.000	0.619	0.545	0.368	0.029
SP3	1.000	0.130	0.524	0.000	1.000	0.824
SP4	0.680	0.609	0.810	0.227	0.895	1.000
SP5	0.000	0.696	1.000	0.727	1.000	0.206
SP6	0.400	0.000	0.905	0.864	0.000	0.941
SP7	0.960	1.000	0.429	0.000	0.211	0.618

Table 14: Deviation sequence

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
SP1	0.440	0.652	1.000	0.000	0.474	1.000
SP2	0.480	1.000	0.381	0.455	0.632	0.971
SP3	0.000	0.870	0.476	1.000	0.000	0.176
SP4	0.320	0.391	0.190	0.773	0.105	0.000
SP5	1.000	0.304	0.000	0.273	0.000	0.794
SP6	0.600	1.000	0.095	0.136	1.000	0.059
SP7	0.040	0.000	0.571	1.000	0.789	0.382

Table 15: Grey relational coefficients

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
SP1	0.532	0.434	0.333	1.000	0.514	0.333
SP2	0.510	0.333	0.568	0.524	0.442	0.340
SP3	1.000	0.365	0.512	0.333	1.000	0.739
SP4	0.610	0.561	0.724	0.393	0.826	1.000
SP5	0.333	0.622	1.000	0.647	1.000	0.386
SP6	0.455	0.333	0.840	0.786	0.333	0.895
SP7	0.926	1.000	0.467	0.333	0.388	0.567

Table 16: Grey relation grades and ranks of GLS projects

Projects/ Criteria	CR1 (0.0562)	CR2 (0.2721)	CR3 (0.2524)	CR4 (0.0811)	CR5 (0.1048)	CR6 (0.2335)	GRG	Rank
SP1	0.5319	0.4340	0.3333	1.0000	0.5135	0.3333	0.4541	2
SP2	0.5102	0.3333	0.5676	0.5238	0.4419	0.3400	0.4742	1
SP3	1.0000	0.3651	0.5122	0.3333	1.0000	0.7391	0.4000	3
SP4	0.6098	0.5610	0.7241	0.3929	0.8261	1.0000	0.3414	5
SP5	0.3333	0.6216	1.0000	0.6471	1.0000	0.3864	0.2789	7
SP6	0.4545	0.3333	0.8400	0.7857	0.3333	0.8947	0.3904	4
SP7	0.9259	1.0000	0.4667	0.3333	0.3878	0.5667	0.3270	6

Table 17: Validation of ranks of GLS projects using BWM

Projects	GRG	GRA Rank	BWM weights	BWM rank
S1	0.4541	2	0.2124	2
S2	0.4742	1	0.2854	1
S3	0.4	3	0.1506	3
S4	0.3414	5	0.0864	5
S5	0.2789	7	0.0599	7
S6	0.3904	4	0.1382	4
S7	0.327	6	0.0671	6

Table 18: GRG and ranks of GLS projects using sensitivity analysis

Projects	GRG Normal	Rank Normal	GRG with +10%	Rank +10%	GRG with -10%	Rank -10%	GRG with +20%	Rank +20%	GRG with -20%	Rank -20%
S1	0.4541	2	0.4544	2	0.4601	2	0.4619	2	0.4147	2
S2	0.4742	1	0.4693	1	0.4757	1	0.4813	1	0.4258	1
S3	0.4	3	0.3944	3	0.4057	3	0.3982	3	0.3824	3
S4	0.3414	5	0.3292	6	0.3244	5	0.3688	4	0.3323	5
S5	0.2789	7	0.2858	7	0.2851	7	0.2839	7	0.2852	6
S6	0.3904	4	0.3561	4	0.3734	4	0.3596	5	0.3690	4
S7	0.327	6	0.3233	5	0.3429	6	0.3216	6	0.2561	7

Table 19: Toolset for GLS realization in manufacturing environment

GLS tools	Step 1	Step 2	Step 3	Step 4	Step 5	References
	Identification of suitable GLS project	Estimation of present state of project in terms of various Green Lean indices and capabilities	Find out the main causes of wastes and inefficiencies	Explore various possible solutions, find and implement the best solution to improve sustainability dynamics	Sustain or control with the adopted best solution	
EVSM		√				Sony and Naik, 2020; Banawi and Bilec, 2014; Powell et al. 2017; ; Wang et al. 2019; ;Gholami et al. 2021
LCA		√		√		Banawi and Bilec, 2014; Ruben et al. 2017; ;Gholami et al. 2021
Project charter	√					Erdil et al. 2018
VOC	√					Prashar, 2020
VOB	√					Erdil et al. 2018; Prashar, 2020
Environmental impact analysis				√		Shokri and Li, 2020
Pareto chart			√			Banawi and Bilec, 2014; Cherrafi et al. 2017
Cause and Effect diagram			√			Banawi and Bilec, 2014;Sony and Naik, 2019; Goyal et al. 2019
Green Scoreboard				√		Belhadi et al. 2016
BWM				√		Yadav et al. 2021
Internal environmental management				√		Goyal et al. 2019: Wang et al. 2019
GRA	√			√		Rathi et al. 2021
Pugh matrix				√		Erdil et al. 2018
5 whys			√			Erdil et al. 2018;Siegel et al. 2019; Gholami et al. 2021
7'S				√		Ruben et al. 2017; Cherrafi et al. 2017
3'R				√		Banawi and Bilec, 2014; Cherrafi et al. 2017;Kaswan and Rathi, 2019; Wang et al. 2019
SOP					√	Zhu et al. 2018; Goyal

						et al. 2019
Solution matrix				√		Kaswan and Rathi 2020b
DOE				√		Shokri and Li, 2019
OCAP					√	Siegel et al. 2019
Brainstorming			√	√		Goyal et al. 2019; Kaswan and Rathi 2020
Kaizen					√	Ratayake and Chaudry, 2017;Belhadi et al. 2018

Questionnaire cum Response Sheet for Ranking of GLS Projects for concerned Manufacturing Industry

Green Lean Six Sigma project selection

Green Lean Six Sigma (GLS) is an approach of sustainable development that mitigates negative environmental impacts; reduce the variations in the process and leads to inclusive growth of the organizations in terms of the increased productivity and profitability in the long run. It is a project-based approach and is executed project by project in an incremental way by covering each department or section individually. The project is classified as a particular section or division that is selected for the initiation of GLS. It has found that 40% of six sigma projects have failed due to inappropriate project selection. The execution of GLS demands substantial investment and structural changes in the organization. So, it is imperative to select an appropriate GLS project that exhibits the highest scope for sustainability improvement. The selection of the appropriate project depends on certain criterion. The criteria have selected through the literature survey (Table 1). As each criterion play a significant contribution with respect to other criterion, so it is imperative to weights the criterion. The weights of the criteria have found through the entropy method by collecting the responses from manufacturing personnel of the different manufacturing industries. To select an appropriate GLS project based on sustainability oriented criterion. The responses have collected from the case manufacturing industry. This is to solicit your participation in a survey of for ranking of the projects as a part of my Ph.D. thesis under the aegis of Lovely Professional University. It is assured that the information will be kept confidential and shall be used for academic purpose only. Please provide your useful insight in the table 2 to rank the GLS projects in the manufacturing sector.

Table 1: Criteria for GLS project selection

S. No.	Main criteria	Label	Description	Sub criterion
1	Material related	CR1	The material cost is the main part of the total cost of the final product. It has estimated that nearly 30% of the material goes into wastes if proper reusability and recyclability of the material are not ensured.	0.0561
2	Productivity	CR6	The manufacturing concerns to remain competitive in the global market makes rigorous pursuits to reduce defects, ensures maximum space utilization through Lean tools, and using organizational resources in the most effective way to get organizational objectives.	0.2720

3	Environmental aspects	CR2	The increased emission and sustainability-oriented customer quality perception demand the inclusion of the environmental aspects in the operating dynamics of the industry. The industry makes rigorous attempts to incorporate clean technologies, proper waste disposal measures, and proper carbon capture methods.	0.2523
4	Social	CR4	The intergovernmental policies on climates changes and regulation pacts have forced the organization to provide proper work ambiance, equal opportunity for learning and growth, proper safety measures at the place of operation, and health measures at the workplace.	0.0810
5	Waste related	CR5	The wastes lead to the increased cost of the end product and lead to ineffective utilization of the most precious organizational resources.	0.1048
6	Facility related	CR3	The facility criteria are associated with the machines or other equipment used at the shop floor of the industry. The industry is always in the constant run to maximize machine utilization, reducing the downtime of machines and increase the reliability of the machines by adopting proper maintenance measures.	0.2334

Please write the numeric value at appropriate place according to the nomenclature provided

1 Very low
2 Low
3 Neutral
4 High
5 Very high

Table 2: Response sheet for ranking of GLS projects

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
Finish machining (SP1)						
Machine (SP2)						
Final assembly (SP3)						
Sheet metal (SP4)						
Inspection and quality (SP5)						
Fabrication or weld (SP6)						
Painting (SP7)						

Questionnaire for Weights Calculation of Criteria

SECTION –A

1. Organization Name: ____
2. Location: ____
3. Name of the Authority____
4. Designation____

SECTION-B

Green Lean Six Sigma project selection

Green Lean Six Sigma (GLS) is an approach of sustainable development that mitigates negative environmental impacts; reduce the variations in the process and leads to inclusive growth of the organizations in terms of the increased productivity and profitability in the long run. It is a project-based approach and is executed project by project in an incremental way by covering each department or section individually. The project is classified as a particular section or division that is selected for the initiation of GLS. It has found that 40% of six sigma projects have failed due to inappropriate project selection. The execution of GLS demands substantial investment and structural changes in the organization. So, it is imperative to select an appropriate GLS project that exhibits the highest scope for sustainability improvement. The selection of the appropriate project depends on certain criterion. The criteria have selected through the literature survey (Table 1). As each criterion play a significant contribution with respect to other criteria, so it is imperative to weights the criteria. The responses provided by the manufacturing personnel and LSS personnel will facilitate in the appropriate weighting of criterion that helps in the appropriate selection of the GLS project. This is to solicit your participation in a survey of for weighting of the criterion as a part of my Ph.D. thesis under the aegis of Lovely Professional University. It is assured that the information will be kept confidential and shall be used for academic purpose only. Please provide your useful insight in the table 2 to weight the criterion pertains to GLS project selection in the manufacturing sector.

Table 1: Criteria for GLS project selection

S. No.	Main criterion	Label	Description	Sub criterion
1	Material related	CR1	The material cost is the main part of the total cost of the final product. It has estimated that nearly 30% of the material goes into wastes if proper reusability and recyclability of the material are not ensured.	Material efficiency, reusability potential, recyclability potential
2	Productivity	CR2	The manufacturing concerns to remain competitive and productive in the global market makes rigorous pursuits to reduce the defects, ensures maximum space utilization through Lean tools, and utilization the organizational resources in the most effective way to achieve the organizational objectives.	Defects reduction, space utilization, optimum utilization of resources
3	Environmental aspects	CR3	The increased emission and sustainability-oriented customer quality perception demand the inclusion of the environmental aspects in the operating dynamics of the industry. The industry makes rigorous attempts to incorporate clean technologies, proper waste disposal measures, and proper carbon capture methods.	Global warming, water use intensity, terrestrial acidification
4	Social	CR4	The intergovernmental policies on climates changes and regulation pacts have forced the organization to provide proper work ambiance, equal opportunity for learning and growth, proper safety measures at the place of operation, and health measures at the workplace.	Employment opportunity, health, and safety, work ambiance
5	Waste related	CR5	The wastes lead to the increased cost of the end product and lead to ineffective utilization of the most precious organizational resources.	Inventory optimization, material efficiency, overproduction
6	Facility related	CR6	The facility criteria are associated with the machines or other equipment used at the shop floor of the industry. The industry is always in the constant run to maximize machine utilization, reducing the downtime of machines and increase the reliability of the machines by adopting proper maintenance measures.	Machine utilization, downtime, reliability of machines

Please write the numeric value at appropriate place against each criterion according to the nomenclature provided corresponding to each criteria.

1 Very low
2 Low
3 Neutral
4 High
5 Very high

Table 2: Response sheet for weightage calculation of criteria GLS project selection criterion

Projects/ Criteria	CR1	CR2	CR3	CR4	CR5	CR6
Finish machining (SP1)						
Machine (SP2)						
Final assembly (SP3)						
Sheet metal (SP4)						
Inspection and quality (SP5)						
Fabrication or weld (SP6)						
Painting (SP7)						