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Implementation of green, lean and six sigma operations for sustainable manufacturing. A Review

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Abstract:

With ever increasing environmental concerns and global warming, green manufacturing has gained momentum to make the manufacturing processes sustainable and efficient. This review aims to analyse the models to integrate three different management systems that are green, six sigma and lean for the sustainability of various manufacturing processes. Research gaps for such integration are identified through a literature review of various studies. The importance of the concepts of eco-friendly and sustainability in business operations and practices is growing rapidly as a result of public pressure, government regulations and social responsibilities. The first step is the identification of sustainability assessment for the current industrial processes and then to make them eco-friendly and more efficient through different green, six sigma and lean tools available. The methodology presented in this review will not only help in sustainability but also is helpful in the integration of various models for the improvement of the processes. Green Lean Six Sigma (GLS) is an approach known to minimize emissions and carbon footprints while improving process efficiency. GLS includes green, six sigma and lean methodologies for high performance, sustainability, social development, economic progress and environmental protection. The successful integration of this GLS approach is dependent on different theoretical indicators and the model is developed based on DMAIC. Various tools, enablers and integration methods are employed for the GLS approach.

Key words:

Green, manufacturing, lean, six sigma, sustainability.

1. Introduction

Poverty, inequality, climate change, population increases, pollution, and the rising cost of energy and raw materials represent the most significant issues humanity faces in the contemporary global context. Customers, regulators, and other stakeholders are pressuring businesses throughout the world to run their operations responsibly to enhance the performance and to alter behaviours at both environmental and social levels. Due to this, increasing sustainability and operational performance, decreasing the adverse environmental impacts and social effects of these industrial operations has become an essential corporate requirement: sustainability has evolved into new competitive criteria (Garza-Reyes, 2015). The rising consumer awareness of sustainability and appetite for environmentally friendly products has led businesses to reconsider their value chains and production methods. In today's competitive economy, manufacturing firms are taking the lead. Its goal is to occupy a strong market position and please clients by meeting their needs to maximize profit. Manufacturing companies have a significant impact on the economy because they sell goods and services on a worldwide scale. Organizational greening has become a growing issue in a range of industries, owing to the competitive and strategic challenges

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that these companies face. The costs and penalties that may arise from poor environmental performance represent tangible concerns. Organizations must also handle intangible factors such as image and reputation as strategic priorities (Zhu et al., 2018). The ability of contemporary enterprises to evolve alongside the external environment is critical to their survival (Kaswan & Rathi, 2020a). To remain competitive, industrial companies should develop and adopt technologies for lower carbon emissions (Duarte & Cruz-Machado, 2019). Nowadays, businesses are investing a lot of money in developing sustainable production and consumption practices. Many concepts and methodologies, such as Green, Lean, and Six Sigma, have emerged in recent decades amid part of efforts to generate high-quality goods.

Sustainability is frequently characterized as the means of achieving a balance between current and future generations' environmental, economic, and social demands via a strategy that is referred to as a "triple bottom line" approach. While this triple bottom line strategy encompasses all three main areas, aspects related to environmental sustainability are the most discussed after the introduction of sustainability notion of sustainability worldwide. This is certainly the case in the manufacturing context. The phrase "green manufacturing," which is sometimes used synonymously with "sustainability," was created to describe manufacturing processes and tactics that are conscious of environmental implications throughout production and operations (Erdil et al., 2018). The methodologies of Lean and Six Sigma are becoming increasingly popular in the search for more efficient production practices. Lean provides value by pinpointing and removing waste in the manufacturing and distribution process, which improves the flow of the process and lead time. Six Sigma adds value by detecting and minimizing variance in the process output. Lean Six Sigma (LSS) is a next-generation framework and model to improve quality that incorporates both methodologies. LSS is associated with a myriad of advantages, including fewer errors and rework, more rapid production, reduced inventory levels, reduced space requirements, less transportation, less downtime, and higher employee engagement. Lean Six Sigma (LSS) is used to improve the process and to solve different operational problems for businesses and individuals. Companies may gain a competitive edge by using LSS, which has been found to reduce lead time by up to 80%, costs by up to 20%, and quality and delivery time improvements of up to 99%. The relentless pursuit of Six Sigma zero process variation while disregarding the needs of consumers might result in non-optimal use of resources. As a balanced implementation technique, LSS meets customer expectations by producing enough worth to sustain and retain market share while also lowering necessary variety and, thereby, minimizing the associated costs. Critical success factors (CSFs) are some of the fundamental input variables for a successful and effective LSS deployment (Flor Vallejo et al., 2020). As a result, there are substantial similarities in terms of the underlying goals of LSS and sustainability. Green, Lean, and Six Sigma are methods of increasing profitability by reducing rework, waste, and emissions. At all levels of a company, Lean pushes for the methodical reduction of waste via excellence within the value chain. Green technology decreases a product's harmful environmental effects by making it more environmentally friendly. Six Sigma lowers variability in the process, resulting in fewer product rejections. However, when Green and Lean Six Sigma are merged, the resultant approach can lead to the development of a cost-effective product that is both of satisfactory quality and environmentally beneficial (Hussain et al., 2019).

A research study examined financial data spanning 170 manufacturing organizations to determine the average delivery timeframe and the overall percentage of improvements. The findings revealed that although some businesses can successfully use LSS, others fail to do so. Practically half of the organizations studied had their average delivery time fall over time, signifying a drop in quality. This was due to the errors made during the shift from theory to practice, rather than a lack of LSS expertise. That said, a large proportion of businesses reported an improvement rate of between 100% and 300%. Despite this, because there is a lack of a standardized LSS roadmap or change in plans, LSS deployment is frequently doomed to fail. Companies and organizations must employ a plan or roadmap as a guide to ensure a successful LSS deployment. This roadmap should define the activities or requirements that must be completed to achieve the required and desired goals. LSS roadmaps may be customized for different businesses based on their requirements (Baker, 2003).

Manufacturing companies face multiple challenges in the contemporary world, including low-quality products, excessive production costs, inability to fulfil customer demand, due to demand mismatches, and long delivery times, among others, all of which are caused by a lack of an effective operational plan.

Quality, adaptability, and customer happiness have arisen as competitive factors in more recent years, adding to the traditional criteria of manufacturing efficiency and profitability. According to Bergmiller & McCright (2009), organizations must address the three elements of sustainability (economic, social, and environmental) to achieve and maintain a competitive advantage. The challenge for businesses in this environment is to adequately address stakeholder requirements while achieving strong economic performance and striking the correct balance between each element that forms the triple bottom line of sustainability. The possibility of combining Lean, Six Sigma, and sustainability is gaining popularity; numerous academics and business professionals have contributed to the field's study and development, resulting in over 118 publications. However, despite the significant number of publications, very few literature reviews of the existing literature have been published. Only six of the publications we looked at were designed to assess the current level of research into the linkages between lean, Six Sigma, and sustainability. However, there is no systematic assessment that examines the drivers, challenges, advantages, and critical success factors (CSFs) with the underlying objective of developing a potential integrated model. The current state of information about possible synergies and contradictions among the three techniques is nascent. Furthermore, the presented frameworks, patterns, and approaches for integrating lean, Six Sigma, and sustainability have not been investigated (Cherrafi et al., 2016; Johansson & Sundin, 2014).

2. Terminologies

2.1. Sustainability

One of the most commonly used keywords in the last two decades has to be "sustainability." There appears to be nothing that can't be defined as "sustainable": anything can be hyphenated or coupled with it. Cities, resource management, careers, businesses, and livelihoods are all discussed within the concept of sustainable development (Scoones, 2007). The most commonly used definition for sustainability is a development that satisfies the requirements of current populations while also guaranteeing that future generations are provided for. The term "sustainable development" first emerged in a publication of a study by the United Nations World Commission on Environment and Development (WCED) in 1987. The notion or term for sustainable development subsequently referred to as "sustainability," received international recognition and the focus of state representatives throughout the world in the aftermath of the publication of the report (Erdil et al., 2018). EPA report (Kidwell, 2006) contains a comparable definition that emphasizes the importance of preserving a balance between profit, the environment, and people: "Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations." If any of the triple bottom line aspects—environment, economy, or society—deteriorate or collapse, systems and organizations will not be able to withstand the test of time. Institutions are sustained by the balance of these three elements, not by the supremacy of one over the other two.

In the initial TBL research (Elkington, 1994), the three pillars of the triple bottom line (TBL), which are these days generally referred to as social impact, environmental concerns, and economic benefits, were characterized as the 3Ps: People, Planet, and Profit. The environmental aspect (Planet) is concerned with the activities and practises that are associated with the use of natural resources, consumption of energy, ecological health, and pollution; the social aspect (People) is centred around human needs and spans aspects such as the provision of education, availability of jobs, living standards, and health and safety; the economic aspects examines strategies that promote and enhance economic prosperity and profitability, enhance cost efficiencies, and promote health and safety. Sustainability in the manufacturing sector attempts to generate manufactured goods that maximize profitability while minimizing negative environmental consequences, conserving energy and raw materials, and maximizing safety for employees, end users, and communities. In addition, production practices should guarantee that a population's demands are addressed. As a result, attaining manufacturing sustainability necessitates a holistic approach that considers not just the product and the procedures associated with its creation, but also the end-to-end supply chain and production system (Faulkner & Badurdeen, 2014).

Since the focus on sustainability emerged, numerous systems for environmental control, health and safety, and social responsibility management have been established to achieve sustainability. Many procedures and guidelines have been established for this purpose to assist businesses in implementing good corporate social responsibility.

2.2. Lean Six Sigma

In the late 1990s and the start of the 2000s, the phrase "Lean Six Sigma" emerged to characterize and explain the relevance and overlapping of Lean and Six Sigma ideas. The goal of this integration was to address the flaws inherent in each approach. Businesses were able to achieve a notable increase in improvement by combining the two continuous improvement approaches (Byrne et al., 2007). Lean Six Sigma is a corporate strategy and technique that enhances quality, timeliness, and cost to improve process capability and achieve customer happiness, leadership, and bottom-line outcomes. It does this by combining lean and Six Sigma frameworks and methodologies. Many firms worldwide have adopted Lean Six Sigma as one of the most well-known hybrid continuous improvement approaches to solve their operational challenges and increase their competitiveness (Singh & Rathi, 2019). Lean strives to increase customer satisfaction by reducing waste within the value chain, be it in the form of inventory, movement, motion, rework, waiting, over-processing, and overproduction. These seven forms of waste are referred to using relatively conventional definitions in the literature. Another type of waste that has attracted attention in more recent times is skills. Skill wastage arises when people's abilities, skills, and expertise are not fully leveraged. Six Sigma is a data-driven technique for eliminating variance in processes. The Define, Measure, Analyze, Improve, and Control (DMAIC) cycle is used in most Six Sigma deployments. DMAIC is a proven paradigm for achieving large improvements in performance by providing a disciplined approach to improvement efforts. Improvements made using either strategy have an influence on long-term sustainability (Singh & Rathi, 2019).

3. Embedding sustainability into lean manufacturing and Six Sigma model

3.1. Lean manufacturing and the Six Sigma model

Lean Six Sigma is the widely utilized method for improving processes and ensuring their long-term viability. It is an effective technique that concentrates on four essential aspects: profitability, quality, productivity, and cost (Evans & Lindsay, 2014). The five-step Define, Measure, Analyze, Improve, and Command (DMAIC) method provides a systematic approach to project management and implementation that covers a wide variety of LSS tools in a goal-focused way. DMAIC is a tried-and-true method for achieving considerable performance gains.

To integrate the model with sustainability, the DMAIC framework assists in the absence of implementation strategies. This framework will give access to tools and well-known practices to achieve sustainability goals and pave the path for wider implementation of sustainability principles and goals for the success of businesses. The important goals in the process are attained with the use of LSS and its widespread implementation throughout different industries. This integration begins in the define phase with the identification of sustainability prospects that can be linked to an improvement of the project and proceeds with the definition of corresponding benchmarks to allow follow-ups in the later stages to reach the required sustainability performance.

Table 2 summarises the steps required to apply DMAIC to ensure its long-term viability and overall continuous improvements (Kaswan & Rathi, 2019).

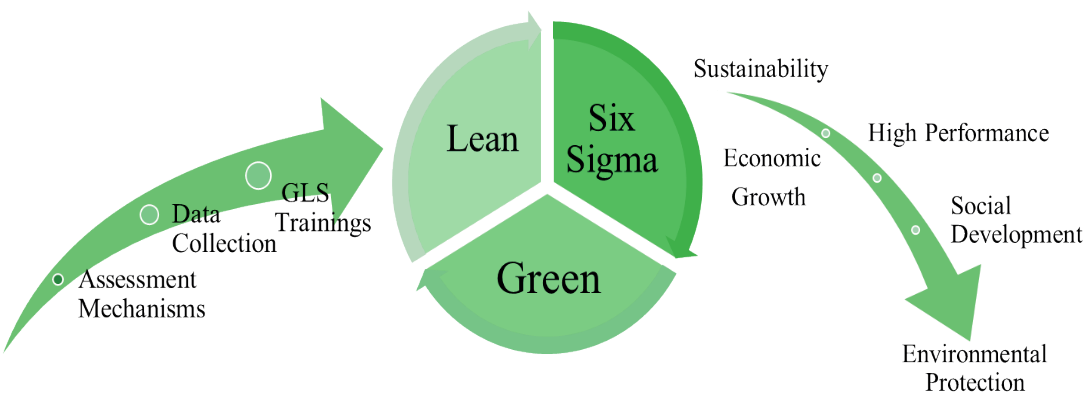

Figure 1. Integration and implementation of GLS model (Kaswan & Rathi, 2020b)

Table 1. Tasks for systematic approach using DMAIC.

Tasks				
Define	Measure	Analyze	Improve	Control
Development of project charter that includes problem statements, , and total resources	Establishment of performance met-rics	Analysis of data in identification of sources for varia-tion and discrepan-cies	Development and evaluation of solu-tions	Verification of implemented im-provements
Mapping the pro-cess	Validation of measurement sys-tem	Examination of the process in identifi-cation of root caus-es	Implemention of selected alternatives	Development of standard operating procedures (SOPs)
Project aims and goals,	Data collection			Development and implementation of control plans
Quality needs and requirements Team and group members and asso-ciated roles and total available resources	Determination of process baseline			

The most significant step in the integration of sustainability into any form of the improvement process is to establish a link between the firm's sustainability objectives and the various aims of the concerned project. It is crucial to define the sustainability demands and goals of a company for this to be effective and for the targets to be aligned successfully. As a result, before any firm embarks on an LSS project with sustainability features, it must first conduct a sustainability assessment in order to define and prioritize the company's sustainability aims in terms of environmental, social, and economic factors. This type of evaluation includes the assessment and evaluation of the present sustainability performance of a company, as well as producing documentation about the company's requirements and objectives to improve teams or groups to use as a guide for creating sustainability goals and KPIs for their initiatives (Cherrafi et al., 2016).

The next section describes an Importance-Impact-Implementation analysis that was created for sustainability evaluation. Table 3 compiles a list of the common sustainability indicators described within the literature. This table offers a variety of indicators, which may be changed depending on the goals of the organization (Cherrafi et al., 2016, 2017).

3.2. Sustainability importance-impact-implementation analysis

First, as indicated in Tables 2 and 3, sustainability indicators are defined in line with importance, effect, and implementation criteria. The importance of an indicator is determined by its relevance to the firm's operations. The items that are of direct significance to company operations are considered vital metrics. The significance of indicators is used to assess the anticipated improvements. If these metrics improve, the company will see a considerable increase in profits (Miller et al., 2010*)*. Finally, to ensure the process's long-term viability and efficiency, these elements must be implemented. Table 4 lists the DAMIC duties, which are detailed below.

Table 2. DMAIC process for the sustainability of the process.

Tasks	Actions
Define	Identification of sustainability indicators and clarification of final sustainability goals
Measure	Development of sustainability goals matrices
Analyze	Analysis the problems in context with sustainability goals
Improve	Cost and benefit analysis of the solutions for sustainable goals
Control	Verification of the solutions and impact on sustainability goals

Table 3. Common sustainability indicators.

Sustainability Indicators		
Economic	Environmental	Social
Consumption analysis	Control over emissions	Risk and safety analysis of industrial workers
R&D for improving existing processes, technologies and addition of new products	Waste water treatment for environmentally sustainable process	Talent acquisition
Growth analysis	Use of carbon capturing technologies in industries to reduce emissions	Education for latest skills
Financial distribution	Utilization of energy efficient processes	Equality and diversity
		Community development

3.2.1. Define and measure

Every DMAIC-based improvement project begins with the creation of a project charter, which summarizes the background, definition, scope, performance criteria, deliverables, and definition associated with the project. The project charter serves as a road map that guides the project, keeping teams geared towards achieving the project's objectives. As a result, the define phase is critical for incorporating sustainability goals into continual improvement and project charters.

Table 4. Literature review of studies using lean, green and six sigma approaches.

Sector	Model	Contribution	Short Comings
Automobiles	Green and lean	A model was analyzed to integrate lean and sustainability factors. The model employed kaizen concept for the conversation of energy and to improve the efficiency of production line.	Application of the model is limited as it is implemented at pilot project. Large scale implementation is needed to check the sustainability of the model.
Semiconductor manufacturing unit	Green and lean	A model and framework were incorporated to indulge human and physical factors in lean operations for the sustainability of the manufacturing unit.	Economic and environmental factors were not taken into consideration for sustainability.
-	Green and six sigma	A framework was proposed in order to combine six sigma and sustainable manufacturing.	Economic factors for sustainability were not included and the model is not implemented for real time manufacturing environment.
Metal industry	Green and lean	A model was proposed for the analysis for the relationship be-tween environmental factors and lean operations of different manufacturing processes in metal industry.	The scope of the model is limited to only few manufacturing processes in metal industries.
Foundries and casting industries	Green and lean	A framework was analyzed to study the scope of sustainability and lean. The implementation of lean and environmental factors was studied too.	The scope of this model is limited to few particular manufacturing and casting industrial processes.
Automobiles	Green and lean	The study analyzed the supply chain operation management for green and lean operation ability for the sustainable overall performance.	The study is only limited to Portugal automobile industry and necessarily does not cover the approach for other countries.
Metal industry	Green and lean	The aim of the study was to im-plement and integrate green and lean methodology in the manufac-turing. Matric system was pro-posed to integrate and implement green and lean operations.	The scope of this study is lim-ited to few industries and the study does not have universal approach.

4. Green Lean Six Sigma model

The origins of GLS may be known back to the adoption of the Lean concept. After WWII, Japan developed the lean idea to compete with the United States' mass manufacturing method (Bhamu & Singh Sangwan, 2014). The Toyota Production System (TPS), which was developed by Japanese engineers Taiichi Ohno and Shigeo Shingo (Kaswan et al., 2019), gave birth to the contemporary notion of lean manufacturing. Although the lean strategy helps to decrease waste, it does not help to mitigate negative environmental impacts. The use of green technology can help to overcome the constraints of Lean frameworks. Green technology contributes to Lean because it eliminates hazardous environmental consequences and waste. It is a long-term solution that minimizes global warming, acidification, and other environmental issues along the supply chain. Even though green technology minimizes environmental pollutants, it is unable to reduce lean wastes (Dües et al., 2013). As a result, a combined Green Lean (GL) strategy is needed which eliminates lean wastes and decreases carbon footprints. The two strategies that aim to reduce waste and involve waste management practices have a lot in common (Sureeyatanapas et al., 2018).

The combined GL technique has certain shortcomings, according to the literature. Although GL minimizes wastes and emissions, it does not employ statistical methods to eliminate fluctuations in the process. Even though it saves waste and pollution, the GL method is incapable of manufacturing high-quality products. As a result, there is a pressing need to devise a strategy that combines tools and strategies to overcome these constraints. Six Sigma is a project-based statistical data-driven strategy that utilizes certified tools to augment GL methodology (Siegel et al., 2019). Six Sigma is based on the principle that if flaws can be accurately pinpointed a solution can be devised to overcome them. This is a well-known statistical method that can cut faults down to 3.4 per million. Although the Six Sigma process decreases variability, it does not eliminate waste or emissions. Based on the extensive examination of Green, Lean, and Six Sigma, it may be settled that each strategy has its own set of advantages and disadvantages (Sreedharan et al., 2018). Each one of the Green, Lean, and Six Sigma methods complements the others, resulting in the evolution of Green Lean Six Sigma. GLS is known for a sustainable development method and technique that focuses on reducing waste, pollution, and faults while delivering high-quality and environment friendly goods. Despite the evolution of GLS, little effort has been made to implement this long-term strategy in industrial organizations. The absence of Green, Lean, and Six Sigma integration methods to implement different frameworks is one of the key causes behind this. Furthermore, no paradigm exists in the literature that is appropriate regardless of the size, kind, or culture of the organization (Kaswan & Rathi, 2019). Figure 2 depicts the GLS framework as well as the specific procedures needed. To make the GLS process viable, the framework is separated into six different interconnected aspects. Figure 2 depicts the GLS framework as well as the associated procedures. To make the GLS process viable, the framework is separated into six different interconnected aspects. Figure 2 shows the framework for the implementation of lean, green and six sigma.

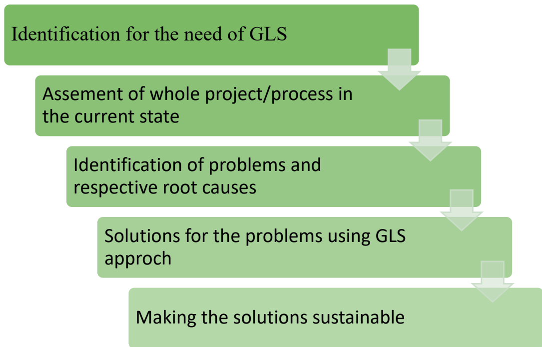

Figure 2. Framework for green, lean and six sigma.

4.1. Identification of the need for GLS

The GLS framework's initial step involves choosing an acceptable project that is based on the amount of waste, faults, emissions, and customer feedback. GLS is a method that is to be implemented on one project at a time, addressing each department or component separately. The implementation of GLS necessitates a significant financial commitment as well as structural changes in the organization or processes. It's critical to pick a GLS project that has the most room for development in terms of sustainability. Complete research of the various segments of the industry is required for this purpose. The comprehensive analysis of the whole industry reveals wastes, faults, and corresponding environmental emission levels for various industrial segments.

After an appropriate project has been chosen, a framework or roadmap is created that is based on the timetable, scope and team members involved in the concerned project (Bhamu & Singh Sangwan, 2014).

4.2. Assessment of the project/process in the current state

The GLS framework's second phase is to estimate the current level of the project or system of the said project. The performance and efficiency of the chosen GLS project is evaluated using multiple Green, Lean, and Six Sigma indicators. Furthermore, green technology methods such as life cycle assessment are used to estimate CO2 consumption, green energy coefficient, material usage, and so on (LCA). Value stream mapping (VSM) is a valuable lean method used to determine the present scope or level of different connected wastes. Furthermore, in the measuring process, life cycle assessment (LCA) is used to analyze the environmental effect of the different subprocesses in several environmental impact groups. The combination of VSM and LCA results in the measurement of different lean and green wastes, providing a foundation for future development (Faulkner & Badurdeen, 2014).

4.3. Identification of problems and root causes

The GLS framework's next step is to identify the causative factors of high-level wastes, emissions, and faults in the chosen project. First, non-value-added activities and value-added are recognized from both a customer and a company standpoint. The process cycle efficiency is then calculated and compared to world-class standards to ascertain the level of improvement that is required. Simultaneously, a thorough study of the project is carried out to detect bottlenecks and limits in the chosen project. After a thorough, in-depth examination of the project in question, the probable causes of waste, emissions, variances, and faults are identified. At this point, procedures like failure mode effect analysis (FMEA), brainstorming, cause and effect analysis (C& E), five whys analysis, life cycle impact assessment, and others are used to determine the probable causes of the flaws that have been detected. After looking into all of the various causes, the search is narrowed down to only a few key factors for project inefficiency. This stage leads to an investigation of the primary sources of inefficiencies that must be addressed in order to improve the present project or system in question (Erdil et al., 2018).

4.4. Solutions for the problems using GLS

Once the root causes of waste and inefficiency have been identified, various solutions or strategies are tested and delineated, and the best one among the solutions is implemented to eliminate the root causes. During this phase, the established and defined cause and effect relationship (from the analyzing phase) is employed to generate a wide range of viable solutions. Upcycling, anaerobic digestion (AD), refuse-derived fuel (RDF), recirculation or recycling of water, and other options may be suggested. Those involved are expected to be very creative during this phase. To find the best answer, various solutions (alternatives) are fleshed out, criteria are defined, and the solutions are assessed. To define the assessment criteria, all sources of data are examined, including stakeholders, consumers, project sponsors, and personnel (Kaswan & Rathi, 2020b). Following the selection of the best available solution, the existing VSM is changed to represent the process after the modifications have been implemented. Enhanced VSM is also used to estimate time savings, improved quality, and other related quality metrics. The best option is subsequently implemented as a pilot project. The tasks to be completed are documented, and the pilot participants are instructed on various components of the best solution. During the pilot project, the pilot solution is deployed in a specific industry sector (Faulkner & Badurdeen, 2014).

4.5. Sustainable solutions

If the existing system or process under evaluation records a significant improvement, this stage deals with maintaining or controlling the optimal option. To determine the degree of waste and emissions reduction, the entire process is re-evaluated using VSM and LCA. Numerous observations, data collecting, and control charts are utilized in this stage to revaluate the sigma level, water, electricity, and material usage, among other things. If the re-evaluated performance characteristics are better than those measured in the previous stage, the chosen solution is maintained. Once a viable solution for the pilot project has been established for a long time, it is replicated in other areas of the industry. Through the distribution of eco-friendly products, the broad application of GLS in the sector leads to better sustainability and a higher reputation on a worldwide scale (Garza-Reyes, 2015).

5. Factors influencing Lean Six Sigma models

The proposed frameworks represent systems that describe the strong correlation between green lean, Six Sigma, and sustainability, along with the drivers and associated barriers, different conflicts, compatibility issues, and crucial success factors, that are associated with the integration's benefits in addition to frameworks and techniques. These components operate in combination as a distinct, integrated approach to assist the company in identifying strengths and areas for development, as well as monitoring the effect and depth of change inside the business to reach conclusions and address various economic, environmental issues, and social effectiveness. These approaches enable businesses to take advantage of this combination of green lean, six Sigma, and sustainability to increase efficiency and performance through understanding different drivers and obstacles, synergies, various conflicts and compatibility issues, essential success factors, and leveraging lean Six Sigma tools and procedures (Banawi & Bilec, 2014).

5.1. Drivers and barriers to integrating the systems

Because some drivers and obstacles impact the adoption of Lean/Six Sigma and sustainability efforts, it is vital to investigate the primary drivers and barriers to lean/Six Sigma and sustainability integration. Both external and internal factors directly impact the combination of Lean/Six Sigma and sustainability. Cost savings, profitability, risk management, brand image enhancement, and resource management are examples of internal motivations (Herrmann et al., 2008). For example, the cost of raw materials, energy, and resources is always increasing due to rising demand and associated resource limitations. Furthermore, because it is challenging to predict cost trends, companies must improve their material efficiency to improve their competitiveness and performance. To improve one's market position, the triple bottom line of sustainability must be met at the same time. Many studies have linked trash reduction, emissions reduction, and increased recycling to improved financial performance (Wadhwa, 2014). According to King & Lenox (2001), a dedication to reducing environmental effects may help a company's brand image, which can help it perform better in the industry. In fact, better environmental performance is regarded as a good indicator of corporate social responsibility. Consumers, regulators, and stockholders are all external drivers (Kadry, 2013). Customers, regulators, rivals, and other stakeholders put pressure on all businesses, regardless of their size, location, or sector, to analyze and adjust their operations to enhance their social and environmental performance (Wilson, 2010). Furthermore, the general public is becoming more environmentally conscious, and customers are actively seeking "greener" alternatives. Environmental reporting, compliance, and openness are being reshaped by regulators and politicians. Environmental and social performance has become a key priority for investors, shareholders, banks, and insurance corporations (Kadry, 2013). Many companies have responded to these forces by introducing lean/Six Sigma and sustainability initiatives that enable them to enhance their operational, environmental, and social outcomes. Even though lean/Six Sigma and sustainability have been successfully integrated within many settings, the road ahead is not without obstacles. Lack of environmental knowledge (Rothenberg et al., 2001), a perception of increased costs, and organizational structures that separate environmental and continuous improvement choices (Dakov & Novkov, 2007) are some of the barriers that impact achievement. The traditional belief that improving environmental and social performance is an impediment to economic progress (Found, 2009) has persisted due to a lack of environmental responsibility. Companies will only substantially integrate environmental and social features if they are confident that doing so would drastically increase revenues, according to Simboli et al. (2014). Furthermore, research has shown that excluding human resources from lean Six Sigma programmes reduces the likelihood of achieving greater long-term advantages.

5.2. Benefits of the integration of Lean/Six Sigma and sustainability

Business techniques and operations such as Lean/Six Sigma and sustainability may be beneficial to businesses. Previous studies have consistently found that implementing Lean/Six Sigma and sustainability can have a favourable impact on a company's performance (Dües et al., 2013). When Lean/Six Sigma and sustainability are adopted in combination as opposed to individually, they can have a greater and more favourable influence on an organization's achievements (Miller et al., 2010). Internal benefits are relatively more valued than external advantages because, unlike the choice to implement sustainability, the reasons for integrating the two strategies are more internal than external. Furthermore, because of the broader scope involved in the integration, the benefits rendered as a result of the integration are more significant when strategies are implemented in combination as opposed to independently.

5.3. Tools, techniques and methods

Lean Six Sigma provides a number of methods to help businesses decrease waste. According to several researchers, these technologies appear to decrease manufacturing enterprises' environmental and social consequences (Chiarini & Vagnoni, 2015; EPA, 2003). Value stream mapping, cellular manufacturing, standard work, visual management, just in time, SMED, supplier relationship, Six Sigma, statistical process control, analysis tools, and plant layout reconfiguration are all examples of these methodologies. Many of these strategies have been modified and expanded to achieve greater environmental and social improvement (Langenwalter, 2006). Many factors encourage the adoption of Lean/Six Sigma technologies and approaches to enhance sustainable development. First, the tools are already in place and have been tested comprehensively. Second, employees already understand and use them (Chiarini, 2014). There are several scenarios where lean/Six Sigma tools and techniques have the potential to enhance environmental and social risks or impacts (Herrmann et al., 2008), but these risks can be reduced or eliminated if environmental and social considerations are integrated pro-actively and deliberately as part of Lean/Six Sigma implementation. Putting tools and processes in place and keeping them up to date typically involves a large amount of time and effort. As a result, it's critical to ensure that this work pays off in all aspects of consideration over time (Herrmann et al., 2008). The use of techniques and technologies in the integration of Lean/Six Sigma and sustainability has been deemed critical (Chiarini, 2014). The tools/techniques must be carefully chosen and utilized strategically, and they must be compatible with the existing structure (EPA, 2003).

5.4. Synergies and conflicts between lean/ Six Sigma and sustainability

Numerous researchers have looked into the relationship between lean/Six Sigma and long-term sustainability. Others have studied the relationship between lean/Six Sigma and sustainability (King & Lenox, 2001), while others still have examined the interconnections between the two ideas (Bergmiller & McCright, 2009). According to this research, combining lean/Six Sigma with sustainability can have both positive and negative consequences for economic, social, and environmental performance. Corporations can close the gap between lean/Six Sigma and sustainability by comprehending the synergies and tensions between the two strategies.

5.4.1. Synergies and compatibility

Lean/Six Sigma and sustainability frequently go hand-in-hand, according to Ng et al. (2015), and this link is apparent in the extant literature. Many scholars (Bergmiller & McCright, 2009; Herrmann et al., 2008; Pampanelli et al., 2014) have found that lean/Six Sigma and sustainability have a substantial synergy, implying that firms experienced with lean/ Six Sigma would quickly comprehend sustainability and vice versa. Dües et al. (Dües et al., 2013) recently discovered that the two worlds have a positive and powerful interaction. The United States Environmental Protection Agency (EPA) recognized this synergistic link more than 15 years ago, and they are now using Lean/Six Sigma concepts and techniques to generate economic, social, and environmental advantages. According to Larson & Greenwood (2004), there are significant prospects for combining these two parallel worlds, which would result in significant competitiveness and sustainability improvements. Lean/Six Sigma and sustainability strategies are frequently seen to be complementary. Furthermore, Prasad and Sharma (Prasad & Sharma, n.d.) argued that lean/Six Sigma and sustainability might be combined to provide better financial and operational results. Waste reduction, a continuous improvement mentality backed by supply chain relationships, performance measurement, management commitment and staff participation, customer happiness, and common tools and techniques are all accessible as a result of the implementation of Lean/Six Sigma and sustainability strategies.

5.4.2. Conflicts and potential shortcoming

Despite the numerous synergies mentioned in the preceding section, lean/Six Sigma and sustainability cannot be combined perfectly (Dües et al., 2013). Some conflicts exist between lean/Six Sigma and sustainability because of lean/Six Sigma's focus on ensuring customer demands for quality and durability are met, even if this necessitates additional packing or the use of more harmful chemicals. The goal of Lean/Six Sigma is to reduce waste by eliminating faulty goods. This strategy, however, pays little regard to the long-term value of goods, as well as the environmental risk of the materials and transformation processes utilized to make them (Larson & Greenwood, 2004; Wilson, 2010). Furthermore, several researchers have found that lean/Six Sigma focuses their long-term efforts on transformation processes, ignoring material extraction, product usage, and final disposition (Dakov & Novkov, 2007; Larson & Greenwood, 2004; Maskell & Pojasek, 2008). Furthermore, there are rare instances where the use of particular lean/Six Sigma principles is incompatible with long-term viability. Several studies show that even a single-time adoption increases the frequency of deliveries in small-scale quantities and smaller vehicles, increases traffic congestion, and increases greenhouse gas emissions (Carvalho et al., 2011; Venkat & Wakeland, 2006). The continuous improvement mindset, according to Pagell & Gobeli (2009), may help a company become more sustainable. However, when a company needs to drastically restructure its operations to become sustainable, the same concept may impede dramatic innovation (Benner & Tushman, 2003). On the social side, Wilson (Wilson, 2010) pointed out that the Lean/Six Sigma methodology does not address social factors. The ideology exclusively considers customer safety and ignores the health and safety of employees. In addition, the lean/Six Sigma approach does not manage other social sustainability problems like as human rights and community impact.

5.5. Frameworks, models and methods

Companies have been pushed to apply lean/Six Sigma and sustainability to enhance their performance because of the beneficial association between the two (Dües et al., 2013; EPA, 2003). To combine and apply lean/Six Sigma with sustainability, several scholars have presented numerous models, frameworks, and approaches. These models, frameworks, and approaches were examined in this literature review. This examination exposes several flaws that are present in the majority of business models, frameworks, and approaches. These models, frameworks, and methods emphasize the importance of leadership, employee involvement, and a mature deployment level in using and applying Lean/Six Sigma tools, as well as a high level of environmental awareness for cultural transformation and continuous improvement that leads to a high-performing organization (Ng et al., 2015; Pampanelli et al., 2014). A culture of continual improvement underpins all of the models, frameworks, and methodologies.

6. Conclusion

This study includes a literature review for the successful integration of six sigma, lean and sustainability in different industrial manufacturing processes. The review helped in the determination of research gaps and identification of theoretical elements for efficient integration of the green, lean and six sigma models. Major gaps were identified to integrate the GLS model. The integration of GLS involves the identification of the need for GLS, assessment of current manufacturing processes, identification of problems and root causes, solutions using the GLS approach and making these solutions sustainable. GLS approach not only addresses the sustainability but also the economic, social and environmental aspects of any manufacturing process. Moreover, barriers and enablers for six sigma and lean operations were identified using the DMAIC model. GLS is known to reduce the overall negative environmental implications with highly efficient manufacturing processes. There is a need to understand and identify different crucial elements for the successful implementation of the GLS approach to achieve sustainability goals. The successful integration of GLS is dependent on various theoretical elements, enablers and integration tools. Integration tools and methods aid in the implementation of the GLS approach by overcoming the barrier along the path of integration. DMAIC model works well to execute the integration of the GLS approach that identifies the enablers for successful integration. This review presents a complete roadmap for GLS implementation and integration through assessment and identification of desired improvements in existing manufacturing processes.

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