Lean Six Sigma Impact Analysis on Sustainability

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Many world-class manufacturing companies use the concept of lean (L) as an improvement method. Its objectives are eliminating waste and non-value activities in production processes, cost reduction, and achieving faster service with less human effort, time, and equipment by applying tools and techniques that fulfill these objectives. Six Sigma (SS) is used in manufacturing industries to reduce and eliminate defects and variability in production, delivery and cycle times, forecasting, quality, customer service, and logistics, among others. It uses various methods, such as "define, measure, analyze, improve and control" (DMAIC) for existing processes, and "define, measure, analyze, design, and verify" (DMADV) for new products or processes. Both L and SS are complementary approaches to achieving good performance. Their integration is known as Lean Six Sigma (LSS). LSS identifies customer needs and eliminates waste while reducing process variability.

Keywords: lean ; Six Sigma ; Lean Six Sigma ; impact ; sustainability ; economic ; social ; environmental ; PLS-SEM

1. Introduction

The application of lean (L), Six Sigma (SS), and Lean Six Sigma (LSS) philosophy has spread in various sectors, ranging from manufacturing to public and private sectors, such as software industries, financial services, healthcare, education, sales [1], construction, human resources [2], the food industry [3], and the chemicals, petrochemicals, and pharmaceutical industries [4], among others. Malesios et al., Antony et al., Elkhairi et al., Gandhi et al., and Singh et al. [5][6][7][8][9] indicate that one of the main factors in adopting L practices corresponds to the company's size. Their application is more challenging in small and medium enterprises, due to technical barriers such as the lack of planning, experience, strategic perspective, management commitment, support, cooperation, and trust. Elkhairi et al. [7] consider limited resources to be economic barriers and resistance to change to be social barriers. In comparison, Vlachos and Siachou [10] mention knowledge acquisition, company organizational culture, and training as critical success factors in LSS implementation.

Despite the barriers presented in different industries, proper L, SS, and LSS applications improve the efficiency, flexibility, and quality of the processes and improve the sustainability of each of the projects [11][12]. Sustainable development integrates three pillars: economic, social, and environmental [13], and it has become one of the primary objectives of any organization [14]. According to Kader et al. and Khodeir et al. [15][16], there is a close relationship between the success of LSS implementation and operational performance by reducing resources and costs; in social performance, by ensuring health and safety of workers, generating a better company work climate; in environmental performance, by eliminating waste, reducing pollution and improving resource conservation.

Review articles by Caldera et al., Ruben et al., and Francis et al. [17][18][19] evaluate the impact of L on the environmental pillar. Cicculo et al. [20] analyze the impact on the social and environmental pillars without considering the economic pillar. Few studies consider the three pillars simultaneously [21][22][23]. However, only Henao et al. [21] refer to the methods used to evaluate the impact of L in terms of the economic, social, and environmental pillars.

Researchers' efforts to evaluate the impact of LSS on industries' sustainability use different methods, such as the analytic network process (ANP) [24], data envelopment analysis (DEA) [25], interpretive structural modeling (ISM) [26], multi-criteria decision-making (MCDM) [27], multilevel regression [28], multiple linear regression (MLR) [29], covariance-based structural equation modeling (CB-SEM) [30], and partial least squares structural equation modeling (PLS-SEM), among others.

Using PLS-SEM as a statistical method guarantees an adequate level of confidence and robustness by which to determine the relationships between the constructs [31]. PLS-SEM represents a significant advance compared to traditional analysis methods, making it the most widely welcomed emerging approach to determining the relationship between LSS and sustainability [5]. Furthermore, a study by Cataldo et al. [32] proposes the PLS-SEM method as being suitable for determining sustainability indicators. The nature of the model allows researchers to identify the critical variables that provide accurate and reliable information on the relationships between a series of constructs.

The preference for this method for the analysis of sustainable industries is based on the advantage of simultaneously analyzing a large number of dependency relationships [32][33]. PLS-SEM is suitable for models that seek prediction and theory development; it is also more flexible regarding research sample size, with a good model fit [34]. Additionally, PLS-SEM models do not require data normality [35] and can handle predictive and reflective models [36].

The data required for modeling can be obtained from secondary data such as files and primary data through surveys. The most common technique is the use of surveys. PLS-SEM will collect such data and use statistical techniques, such as Harman's single factor and the full collinearity assessment test, to determine whether there are common method biases that reveal an inadequate application of the external and internal measurement model. PLS-SEM requires the reliability and validity of the variables or constructs before establishing their relationship. Therefore, it will first measure the factor loadings, internal consistency (using Cronbach's alpha and composite reliability), convergent validity (using the average variance factor extracted), and discriminant validity (using the Fornell–Larcker criterion and the heterotrait–monotrait ratio of correlations). Finally, it will evaluate the effects between variables and the predictive quality that allows the acceptance or rejection of the hypotheses [37].

Researchers using PLS-SEM will have reliable constructs and indicators for analyzing the relationship between LSS and sustainability. Therefore, the importance of this research lies in providing the variables that address the impact of LSS on sustainability to avoid conceptual errors in future models or studies.

2. Lean Six Sigma Methodology Impact on Sustainability

Souza and Dekkers [38] indicate that not all constructs are related to the three pillars of sustainability; therefore, it is necessary to analyze the impact on sustainability individually. **Table 1** summarizes the L, SS, and LSS constructs studied in the articles reviewed. For each construct, the number of reviewed articles where the structural equation modeling results indicated positive, partial, negative, or no impact on the economic, social, and environmental pillars is shown. A value of zero in the table indicates that there have been no articles linking that LSS practice to one of the sustainability pillars. Furthermore, a positive impact indicates that the LSS practice has positively influenced performance improvement; a partial relationship indicates that not all LSS practices studied will perform well in all indicators measured in the model. However, if a negative impact is found, it indicates that the implementation of that LSS practice generated a detrimental effect on the sustainability pillar measured. Finally, when a null impact is obtained, it indicates that there is not enough statistical evidence to demonstrate the relationship between the LSS construct and the performance studied.

Table 1. The impact of L, SS and LSS principles and tools on the sustainability pillars.

Practice	Economic/Operational				Social				Environmental			
	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative
JIT	16	2	0	0	0	0	1	0	4	0	4	0
TPM	18	1	0	0	1	0	1	0	6	0	2	0
Supplier development	15	0	3	0	2	0	2	0	8	0	1	0
Setup	12	1	1	0	1	0	0	0	4	0	3	0
Customer involvement	11	0	2	0	2	0	2	0	6	0	1	0
Employee involvement	16	0	0	0	3	0	0	0	6	0	1	0
Continuous flow	11	1	0	0	0	0	0	0	3	0	1	0
Pull	9	1	1	1	1	0	0	0	4	0	1	0
SPC	11	0	0	0	0	0	0	0	4	0	1	0
HRM	6	1	3	0	3	0	1	0	3	0	2	0
5S	8	1	0	0	0	0	0	0	1	0	0	0
Lean training	9	0	1	0	1	0	0	0	3	0	0	0
Small lot production	6	1	1	0	1	0	0	0	1	0	1	0

Practice	Economic/Operational				Social				Environmental			
	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative
Continuous improvement	8	0	0	0	1	0	0	0	1	0	0	0
Cellular layout	7	0	1	0	1	0	0	0	1	0	0	0
Uniform production level	5	1	2	0	1	0	0	0	2	0	0	0
TQM	5	1	0	0	0	0	2	0	3	0	2	0
Quality information	5	0	0	1	0	0	1	0	0	0	0	0
Kanban	3	0	3	0	0	0	0	0	0	0	1	0
Manufacturing planning and control	3	0	2	0	0	0	3	0	1	0	1	0
Processes and tools	5	0	0	0	3	0	0	0	4	0	0	0
VSM	3	2	1	0	0	0	0	0	0	0	0	0
Lean leadership	2	0	1	0	1	0	1	0	1	0	0	0
Visual/sensory control system	4	1	0	1	0	0	0	0	0	0	0	0
Eliminate waste	4	1	0	0	1	0	0	0	2	0	0	0
Product design	3	0	0	0	2	0	0	0	2	0	0	0
Kaizen	3	1	1	0	0	0	0	0	0	0	0	0
Workload balancing	2	1	1	0	0	0	0	0	0	0	0	0
Incentives	4	0	0	0	1	0	0	0	1	0	0	0
Flexible resources	4	0	0	0	1	0	0	0	1	0	0	0
Improving facility layout	2	1	0	1	0	0	0	0	0	0	0	0
Quality improvement	3	1	0	0	0	0	0	0	1	0	0	0
Standardization	3	1	0	0	0	0	0	0	0	0	0	0
New process technology	2	1	0	0	0	0	0	0	1	0	0	0
Zero defects	3	0	0	0	1	0	0	0	1	0	0	0
Jidoka	2	1	0	0	0	0	0	0	0	0	0	0
Six Sigma role structure	3	0	0	0	0	0	0	0	0	0	0	0
Six Sigma structural improvement	3	0	0	0	0	0	0	0	0	0	0	0
Six Sigma focus on metrics	3	0	0	0	0	0	0	0	0	0	0	0
Reduction of inventory	3	0	0	0	0	0	0	0	1	0	0	0
Mindset and attitude	2	0	0	0	1	0	0	0	1	0	0	0

Practice	Economic/Operational				Social				Environmental			
	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative	Positive	Partial	No impact	Negative
Reduce cycle time	2	0	0	0	0	0	0	0	1	0	0	0
Lean progress target	2	0	0	0	1	0	0	0	1	0	0	0
Coordination between departments	2	0	0	0	0	0	0	0	0	0	0	0
QFD	0	1	1	0	0	0	0	0	0	0	0	0
Policy deployment	0	1	1	0	0	0	0	0	0	0	0	0
Lean culture	2	0	0	0	0	0	0	0	0	0	0	0
Lead time reduction	0	0	1	0	0	0	0	0	1	0	1	0
Quality at source	2	0	0	0	1	0	0	0	1	0	0	0
Performance oriented	1	0	0	0	1	0	0	0	1	0	0	0
CTQ	1	0	0	0	0	0	0	0	0	0	0	0
External integration	1	0	0	0	1	0	0	0	1	0	0	0
Problem solving	1	0	0	0	0	0	0	0	0	0	0	0
Safety health environment	1	0	0	0	0	0	0	0	0	0	0	0
Six Sigma methodology	1	0	0	0	0	0	0	0	0	0	0	0
Root cause	0	1	0	0	0	0	0	0	0	0	0	0
5 Why	1	0	0	0	0	0	0	0	0	0	0	0
Total	264	25	27	4	33	0	14	0	83	0	23	0
(%)	83%	8%	8%	1%	70%	0%	30%	0%	78%	0%	22%	0%

L, SS, LSS constructs positively impact 83% of economic indicators and 78% of environmental indicators in the reviewed articles. In the environmental pillar, 22% indicate that they have not found any relationship between the constructs. On the other hand, in the social pillar, 70% indicate that they have found a positive effect, and 30% indicate that L constructs are not related to the social pillar.

2.1. L, SS, LSS and Economic Pillar

TPM is the most widely evaluated practice regarding economic performance (19 articles), of which 95% result in a positive impact on performance; only one of the articles mentions partial performance, which means that it can influence some economic indicators. TPM impact economic performance by eliminating waste via performing planned maintenance, which ensures increased productivity [39] by having greater availability of equipment and avoiding equipment failure during production [40].

JIT is evaluated in 18 articles, of which 89% demonstrate positive results. It allows costs reduction in terms of storage or inventory levels [41], also influencing the speed, reliability, on-time deliveries, and flexibility of production [21]; however, 11% (2 articles) indicate that the application of JIT has only a partial relationship with economic performance.

Ghobakhloo et al. [42] indicate that JIT is positively related to the financial indicators and negatively related to the operational indicators, which contradicts the findings of Hadid et al. [43].

Employee involvement is considered relevant to economic performance; sixteen articles have used these practices to measure performance impact; 100% indicate that the relationship between the two constructs is positive. This result confirms the findings mentioned by Abreu-Ledón et al. [44], who focus on the workforce as one of the practices that substantially impact economic performance. Marín-Garcia et al. [45] state that employee involvement does not directly influence economic performance but is rather a means to obtaining a sustainable advantage when applying L, SS, or LSS.

2.2. L, SS, LSS and Social Pillar

Through the application of lean manufacturing focusing on the social aspect, it is intended that organizations should focus on meeting the needs of both employees and society [46]; among the practices where the result in terms of social impact has been of interest to the research can be found as follows:

Despite having been evaluated in only 3 articles, the processes and tools indicate that there is a positive relationship with the social pillar in 100% of these papers. This is happening because it mainly aids in using tools, methods, production techniques, equipment, and materials properly, ensuring that organizational processes are carried out without interruptions, and obtaining better workplace safety [47].

Employee involvement has been analyzed in 3 articles, all showing positive results in terms of its impact. It is because these practices are mainly responsible for keeping employees trained and empowered, giving them the ability to be participants in problem-solving meetings. Hence, it improves the morale and motivation of employees [48].

2.3. L, SS, LSS and Environmental Pillar

TPM evaluates the environmental impact of the tools in 8 articles. They contribute to the performance positively and significantly in 75% of the articles; this can happen, as TPM helps reduce waste produced by machines in terrible conditions [12], such as dust, chemical vapors, and oil leakage [49].

JIT, like TPM, evaluates environmental performance in 8 articles, of which 50% indicate that positive and significant performance is obtained, while the other 50% indicate that no impact is generated. There is a debate that is ongoing concerning the benefit of JIT implementation. Studies claim that JIT, by ensuring that products are delivered more frequently, also produces significantly more traffic congestion, causing an increase in the amounts of CO_2 emitted; therefore, it does not result in an improvement in the environmental performance of operations [49]. On the other hand, they emphasize the positive benefit of JIT by reducing the deterioration of materials by excess inventory, leading to the reduction of energy and emissions [18].

Additionally, customer involvement is among the most studied factor when measuring the impact on the environmental pillar, there is a positive effect in 86% (6 articles) of the seven articles found. This result is confirmed by Huo et al. [50], who mention that customer involvement allows processes to be adjusted according to accurate information regarding their demand, avoiding overproduction, ensuring the proper handling of raw materials, preventing them from becoming obsolete, reducing the use of resources, and avoiding pollution.

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