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Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era

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Abstract: Green Lean Six Sigma has emerged in the Industry 4.0 era as a business strategy contributing to the circular economy by adopting the 3R concept, i.e., reduce, reuse, and recycle. Despite its broadly acknowledged capabilities in the manufacturing industry, practitioners continue to be cautious about its implementation, owing to insufficient knowledge and culture. Hence, there is a need to systematize the existing knowledge regarding this green initiative and also to recognize the key factors enabling its implementation. In the Malaysian manufacturing context, the enabling factors have yet to be identified and evaluated. This current study is the first of its kind to identify and examine these factors and to create a structural model to conceptualize and operationalize this business strategy. The implemented methodological approach includes two steps. Firstly, it performs a systematic review of leading studies on the topic, which are rather scarce in the current context. The second step entails a principal component factor analysis using varimax rotation to finalize the findings. The theoretical and empirical results revealed a structural model with five interconnected key factors, including twenty-seven enablers, that can be used to narrow the existing knowledge gap in the understudied context.

Keywords: green production; lean implementation; Six Sigma; circular economy; Industry 4.0; systematic review; factor analysis; electronics manufacturing

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1. Introduction

The rising global awareness of environmental risks and the demand for competitive efficiency have driven the evolution of manufacturing paradigms from the substitution-oriented traditional manufacturing, to the waste-reducing lean manufacturing and eventually to green manufacturing, driven by the 3Rs: reduce, reuse, and recycle [1]. Many organizations have taken environmentally-driven proactive steps to develop cleaner and more eco-friendly manufacturing processes, as well as to produce greener products. However, numerous industrial operations have a detrimental effect on the environment and society due to the fact that they consume an inordinate amount of precious resources and generate hazardous wastes and emissions. For example, the U.S. Environmental Protection Agency (EPA) noted that, in 2020, the domestic manufacturing sector accounted for a staggering 89% of the 28.3 billion pounds of production-related waste generated in the United States [2]. Based on the National Association of Manufacturers, the industrial sector accounts for 31% of all the energy consumed in the United States, from which the manufacturing industry alone accounts for around 65% of the industrial sector's energy consumption [3]. To counter this immense pollution and its accompanying environmental and health impacts, a transition to environmentally-sustainable manufacturing is urged [2]. Therefore, the green paradigm is now a recognized philosophy and operational method for enhancing the environmental efficiency of organizations and for minimizing the environmental repercussions of products and services while maintaining organizational financial objectives [4,5]. Based on Rao [6] and Galeazzo et al. [7], the green concept basically involves the application of green methods to reduce negative environmental effects and, ultimately, to lessen the environmental footprint of organizations.

The green paradigm has motivated organizations to devise new ways of incorporating traditional performance measurements to attain profit and other business objectives via environmentally-friendly measures. With its emphasis on waste elimination at all production stages, the applicability of lean tools has been extended to include environmental aspects. Drawing from the Toyota Production System (TPS) concept, the US EPA [8] described the objective of environmentally-extended lean as "to develop the highest quality products, at the lowest cost, with the shortest lead time by systematically and continuously eliminating waste, while respecting people and the environment" which, in the context of this current study, is rather extensive. One study [9] highlighted 5S practices to enable the creation of a proper working environment to simultaneously improve water efficiency and plant performance. To this end, approaches integrating the green and lean concepts have been developed by prolific scholars (e.g., [4,10–14]) with the aim of not only minimizing waste production, but also, and more importantly, to reduce green waste, which has been defined by the US EPA [8] as all needless or unwarranted forms of resource consumption or the release of substances due to such consumptions which are detrimental to humans and the environment. For instance, wasteful use of energy, water, chemicals, materials, and/or transportation can have disastrous effects on the ecosystem [1,15].

Despite being recognized as a highly effective approach for making operations more eco-friendly via the reduction of waste, emissions, and reworking, the integrated green lean approach still suffers from several drawbacks that impede its successful implementation [1,4,16]. One key drawback is its incapability to establish a project-oriented approach that can scrutinize, target, and reduce process variability. In the context of lean, it is basically a toolbox that provides tools for identifying waste elimination prospects. The green lean approach is hence oriented towards this objective. For that reason, this approach may not be helpful in achieving profit-oriented or business objectives. Additionally, variability identification is pertinent as it informs and facilitates decision making, thus resulting in sustainability performance improvements. Another drawback to the green lean approach is its lack of quality-driven and mathematical tools. Statistical data for the purposes of process monitoring and identifying residual issues may be uncollectable until after waste removal has been conducted. All these, therefore, give rise to the need for Six Sigma [4] to reduce or eliminate these drawbacks. Six Sigma was first outlined in the 1980s as a quality enhancement approach, with origins tracing back to the US-based electronics company, Motorola [17,18]. According to Matthew et al. [19], Six Sigma is especially beneficial for companies that seek to improve their bottom-line and to reduce defects. It treats defects as process- or product-based prospects via a well-structured project management approach. A Six Sigma program primarily eliminates subjective decision-making by consistently incorporating data collection, analysis and presentation in both the manufacturing and service industries, promoting organizational competitiveness and enhancing product or service quality [20–22].

It is believed that this current study contributes valuable insights both theoretically and empirically. Owing to the drawbacks of green and lean as separate approaches and as an integrated paradigm, as discussed above, it is evident that Green Lean Six Sigma (GLSS) serves as a novel environmental developmental agenda for overcoming the aforementioned limitations and boosting the performance of green lean initiatives. However, this effective integration is driven not only by the proven cohesiveness of the lean principles and tools apparent in both approaches, but also by the ostensibly shared attributes of the concepts. Delving into the effectiveness of such an integration, which was demonstrated by many studies (reviewed in Section 3), more cutting-edge studies on the topic are required [1,4,23–27], such as empirical investigations that offer systematic guidelines for the application of GLSS in a variety of areas [24,26]. The concept, however, has yet to be precisely defined, requiring the systematization of the available knowledge on this green initiative. Despite its broadly acknowledged capabilities in the manufacturing industry, practitioners continue to be cautious about its implementation. Moreover, no previous studies have explicitly and systematically addressed a comprehensive model of GLSS in practice—in other words, a common model is still missing. Because of this, there is a research demand to analyze the factors enabling GLSS implementation [1]. Thus, this study aims to enrich the current body of knowledge and propel the implementation of GLSS by (1) analyzing the GLSS literature, (2) identifying key factors enabling the GLSS implementation, and (3) developing a factorial structure towards the implementation of GLSS in the Malaysian electronics manufacturing sector. This sector is one of Malaysia's main economic drivers, but its industrial operations are to blame for a 46% increase in GHG emissions, according to the Malaysian Biennial Update Report [28]. The green concerns and other environmental compliance and societal regulation issues underlined by the Malaysian Environmental Quality Act [10,18] stress a growing need for strategic approaches to assess and develop environmental sustainability in such industries. As highlighted in the Malaysian Green Technology Master Plan [28], there is a need to adopt green initiatives to meet the aspirational goal of up to a 50% increase in establishing green manufacturing by 2030. Yet, with the new Industry 4.0 technology invasion and shockwaves caused across global markets and emerging green trends, Malaysian industries are projected to have difficulties achieving this goal.

To meet the research objectives, this article is organized as follows: Section 2 presents the research methodology to clarify the procedures and methods utilized. Section 3 provides the theoretical results contributed by a systematic review, whilst Section 4 discusses empirical findings contributed by the analyses. Finally, Section 5 contains the conclusion as well as future directions for this research.

2. Research Methodology

This study is exploratory research, conducted on an issue that has not been previously investigated in Malaysia. It is descriptive and analytic from the viewpoint of the exploratory objective, including two steps. The first step entails systematically reviewing the existing literature, followed by developing an analytical method for finalizing the research. Both steps are explained further in the following sub-sections.

2.1. Systematic Review

The GLSS strategy is a hybrid of the Green, Lean, and Six Sigma concepts; this well-integrated approach has yet to be studied in Malaysia [1]. Hence, a systematic review is needed to analyze the GLSS literature to explore its strategic factors. In this current study, a systematic literature review was conducted with the goals of (a) conducting a thorough analysis of the leading studies and applying the findings to emergent issues [29,30], and (b) evaluating and summarizing available studies on the issue as well as providing a framework/model for new research [31,32]. The systematic review entailed the two main parts described below.

2.1.1. Review Protocol Design

A systematic review requires a protocol [33,34]. In this current study, the review protocol was designed based on the quality assessment checklist proposed by Kitchenham [33], which was used to evaluate the relevant studies derived from the Scopus database, the largest database for global studies, with titles from over 5000 publishers worldwide including ScienceDirect, Wiley, Emerald, Springer, Taylor and Francis, MDPI, etc. [30]. The checklist includes the following questions [34]: (1) "Does the article clearly specify the methodological approach?", (2) "Is the methodological approach relevant to the problem under study?", and (3) "Does the article perform properly its analyses?" An article was considered fit for the review if it fulfilled all the inclusion criteria.

2.1.2. Article Selection

In this step, a systematic search was conducted for all studies related to GLSS up to May 2021. The Scopus database was used as the search engine for keywords such as "Green Manufacturing", "Lean Manufacturing", and "Six Sigma", as well as for interchangeable terms like "Green Production", "Lean Production", and "6Sigma". Accordingly, the query string was TITLE-ABS (("Green") AND ("Lean") AND ("Six Sigma" OR "6Sigma")), which derived 106 articles post-screening. A manual article selection was conducted next, by examining the abstracts and full texts to remove duplications and unrelated articles. A total of 66 articles were derived to review; the earliest document dated back to 2011, showed how Six Sigma techniques can be used to control process efficiency and environmental Muda in a lean-green project [35].

Lastly, GLSS articles written from the perspective of enablers, drivers, and/or critical success factors were carefully scrutinized theoretically and empirically. Ultimately, ten articles that fulfilled the assessment criteria were selected for the next round of analysis, which entailed a critical appraisal of their contents, as discussed in Section 3.

2.2. Analytical Method

This step involves an exploratory factor analysis (EFA) to measure the identified variables and to reveal the underlying structure among the measured variables. It provides the researcher with two distinct, but interrelated, outcomes: data summarization and data reduction. In summarizing the data, EFA derives underlying dimensions that, when interpreted and understood, describe the data in a much smaller number of concepts than the original individual variables. Data reduction extends this process by deriving an empirical value (factor score) for each dimension (factor), and then substituting this value for the original values [36]. According to Hair et al. [36], many researchers consider it useful in searching for structure among a set of variables or as a data reduction method. From this perspective, EFA takes what the data gives us and does not set any a priori constraints on the estimation of components or the number of components to be extracted. This analytic approach includes three key parts, which are explained in detail below.

2.2.1. Exploratory Survey Design

Two key questions were considered in designing the EFA [36,37]: (1) "What are the variables (i.e., enablers) included?" and (2) "What is the desired sample size for measuring the enablers?" The first question was answered via the review of the state-of-the-art literature, as elaborated above. This exploratory review sought to address the idea that the success of GLSS rested on the examination of the core GLSS enablers. The initial checklist was created by examining the key enablers from the leading studies and the brainstorming performed by two professional engineers who are certified LSS Black Belts versed in environmental management and an academician who is a leading expert on GLSS. Ultimately, 30 enablers were identified and amended, as discussed in Section 4.

Non-probabilistic convenience sampling is used in operational and managerial research to gather primary data based on opinions, such as the perception of consumers regarding the design of a certain product or service. This broadly applied technique entails the continuous collection of samples until the desired sample size is achieved. There is no agreement on the exact sample size suitable for EFA due to multiple rules of thumb. According to Hair et al. [36], the sample size for implementing EFA should be at least 50 observations, but favorably 100 or more. In this regard, Gholami et al. [37] employed a sample size of 97 observations for the implementation of EFA. This current study, accordingly, utilized 102 samples of local professional or chartered engineers (i.e., P.Eng. and C.Eng.), collected during July–August 2021, to examine the identified enablers and to reveal their factorial structure. In survey-based research, data collection can be conducted using multiple scientifically backed methods, settings, and sources. However, questionnaires are the primary method for collecting data in such research [36,38,39]. Upon determining the enablers and samples, the correlation matrix is then assessed to identify the fundamental structure of the relationships. Decisions must then be made regarding (1) the factor method selection for factor extraction, and (2) the factor matrix specification for determining the data's fundamental structure.

2.2.2. Factor Method Selection and Matrix Specification

Based on Hair et al. [36], Gholami et al. [37], and Rezaei et al. [40], the most widely used factor method is the principal component factor analysis (or component analysis) with varimax rotation. This method is advantageous as it takes into consideration the total variance and identifies factors with small amounts of unique variance. The aggregate of the required loadings variances of the factor matrix is maximized by the varimax rotational approach. It has a simple fundamental and shows a clearer division of the factors. This method has been proven to be a successful analytical approach for attaining an orthogonal rotation of factors [36,40,41]. The current study hence employed this method for generating a fundamental structural model via SPSS 26 software.

2.2.3. Testing Reliability and Validity

Bartlett's Test of Sphericity (BTS) and the Kaiser–Meyer–Olkin (KMO) measure were used to examine the factorability and adequacy of the sampling, respectively. These tests are highly recommended when the participant-to-variable ratio is less than 5:1. To ensure a good EFA, the BTS should be at a 0.05 significance level, whilst the KMO index should be between 0 and 1, with a minimal adequacy of 0.5 [36,37].

The common criteria for distinguishing the total extraction factor number are: (1) the contribution percentage to the total variance, whereby the principal factor should be higher than 20% in the valid scales, (2) the eigenvalues, whereby each factor should be more than one, and (3) the Scree test, which is applied to determine the optimum number of factors for extraction [37]. Additionally, Hair et al. [36] proposed that factor loadings exceeding 0.5 can be significantly taken into account. Lastly, the scale's overall consistency was assessed by calculating the internal consistency coefficient or reliability coefficient (Cronbach's Alpha), which should be higher than 0.6 in the exploratory survey [38,39,41].

3. Findings and Discussion on the Systematic Review: Theoretical Contribution

To further the research purpose, this study performed a systematic review using the methodological approach explained in Section 2.1. Based on the review of the 66 articles sorted by publication year, it was found that GLSS research has evolved progressively over the years. The topic of this green initiative was only found in one article published in 2011: Besseris [35], but the number grew significantly to 20 articles in 2020 (Figure 1). This number is projected to increase even further in light of the growing significance of GLSS in the environmentally-sustainable manufacturing paradigm, which is also regarded as an application of the circularity principle to manufacturing under the emerging concept of the circular economy. Notably, this growing global research trend has emerged since the advent of the new industrial wave, i.e., Industry 4.0, which became widely known in 2011. This is mainly viewed as a technology diffusion and adoption issue, and this diffusion–adoption process often flows from leading countries [31]. A number of countries have formed their own strategies to accelerate the adoption and advancement of Industry 4.0. In this regard, Germany, where the notion originated, has launched a program called "High-Tech Strategy 2020". Such national strategies, whether in developed or emerging countries, aim to disseminate Industry 4.0 concepts and technologies to local and national businesses [31]. In this regard, there are some significant studies investigating the capability of Industry 4.0 to develop lean manufacturing [42–45], green lean [30,46,47], lean Six Sigma [48–52] and green lean Six Sigma [31,52,53]. Nevertheless, the movement seems to be relatively small and in need of movement to generate a significant outlook, in particular, in its understudied context.

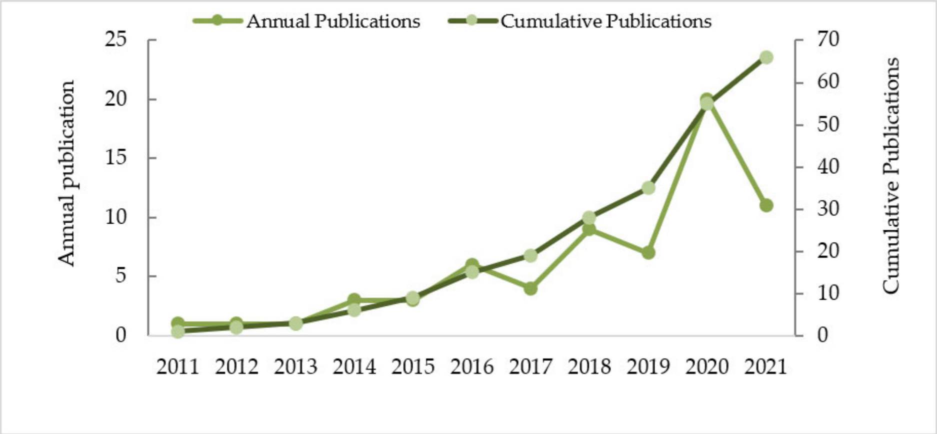

Figure 1. GLSS annual and cumulative publications.

It was apparent from the literature that GLSS is very young, and that there is still work to be done to establish a definition or a commonly accepted conceptual model, develop valid and reliable scales to investigate the degree of implementation, analyze its main factors and impacts on business results, and conduct rigorous empirical studies on the topic. Based on the literature review, GLSS is a business strategy that contributes to the circular economy by adopting the 3R concept, i.e., reduce, reuse, and recycle [1], delivering superior quality green products by lessening process variations and implementing the 3Rs [26], improving environmental issue management and productivity [25], making improvements to operational processes, emissions, and finance [54], using resources effectively and minimizing of wastes, emissions, and defects [55], enhancing profit, producing environmentally-sustainable products [4], reducing waste, and improving the processes and systems that are devoid of excessive environmental pollution [56]. The appraisal indicates that a precise concept of GLSS has yet to be agreed upon [1]. We hereby define the concept of GLSS, which has emerged in the Industry 4.0 era, as a business strategy contributing to the circular economy through adopting the 3R concept, i.e., reduce, reuse, and recycle.

The three international journals with the highest number of related articles have been: (1) the International Journal of Lean Six Sigma, which had six papers, (2) the TQM Journal, which had five articles and (3) the Journal of Cleaner Production, which had four papers. In terms of authors, three were found to have published more than five papers on the topic, namely Garza-Reyes, who wrote "Green lean and the need for Six Sigma [4]" and published seven papers, Rathi, with seven papers, and Kaswan with six papers. Figure 2 presents the distribution of GLSS publications from 20 different countries. The top three countries with the highest number of affiliations were India with 24, the UK with 15, and the US with 6. The most influential articles based on the number of citations were Kumar et al. [55], with 120 citations, Cherrafi et al. [23], with 119 citations, and Garza-Reyes [4], with 109 citations. These were followed by the other considerable studies, namely Banawi and Bilec [56], Kumar et al. [57], Chugani et al. [58], Kaswan and Rathi [59], Hussain et al. [60], Sagnak and Kazancoglu [16], and Belhadi et al. [53] with a sizable number of 90, 39, 80, 49, 38, 50, and 31 citations, respectively. Remarkably, the article by Gholami et al. [1] was the only one to discuss GLSS implementation in Malaysia. This paper indicated that the implementation of GLSS could lower chemical intake by 28% and energy intake by 21%. It is also stated that "it is essential to identify and analyze key enablers to the clearer implementation of the application" (p.1927) [1]. This is an affirmation that no past cutting-edge studies had investigated this topic in the context of Malaysian manufacturing.

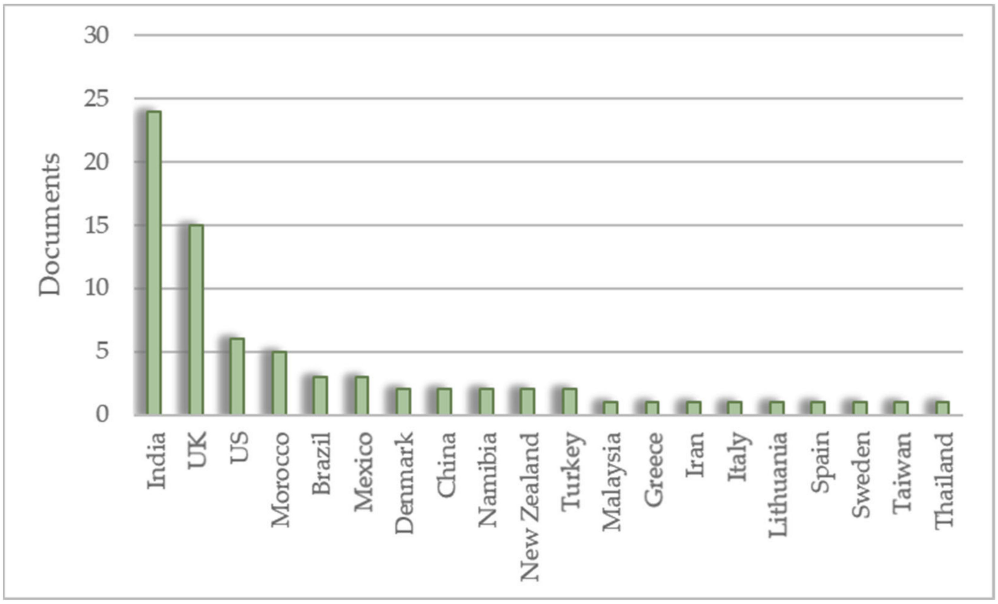

Figure 2. Distribution of GLSS publications worldwide.

The existing literary gap was narrowed down by thoroughly analyzing the research investigating the GLSS implementation in terms of enablers, drivers, and/or critical success factors. This may offer an understanding of the matter through the scenarios performed in other countries, particularly developing countries (e.g., the Indian scenarios). Based on Pandey et al. [54] and Kaswan and Rathi [26], enablers are the prerequisites stimulating organizations to adopt a new strategy. Enablers for the implementation of Lean, Six Sigma, or Lean Six Sigma have been identified in many past studies, but none had identified and analyzed the enablers for GLSS, specifically in the Malaysian manufacturing sector, which is both a key economic contributor and a generator of adverse environmental and social impacts, as it consumes excessive scarce resources and produces dangerous wastes and emissions. Hence, this current study sets out to determine the key enablers in order to fulfill the research purpose. Ten articles were identified, i.e., Kumar et al. [57], Gandhi et al. [61], Pandey et al. [54], Mishra [62], Kaswan and Rathi [59], Kaswan and Rathi [26], Parmar et al. [63], Farrukh et al. [64], Singh et al. [65], and Ershadi et al. [27] which were used to develop a list of 44, 15, 18, 5, 12, 12, 26, 35, 30, 28 enablers, respectively. These cutting-edge studies, as explained by Letchumanan et al. [66], have proposed a number of enablers that can be regarded as the starting points for GLSS research in a variety of contexts. The enablers can enable researchers and practitioners to develop suitable measurement scales for GLSS implementation. Accordingly, our study annotates key references beneficial to the assessment process and the implementation of GLSS on an enablers-based checklist (Table 1).

After examining the enablers from the aforementioned studies and the interviews performed with two professional engineers (P.Eng.) who were certified LSS Black Belts versed in environmental management and an experienced academician with expertise in GLSS, 30 key enablers were identified and amended, as shown in Table 1. Following the creation of the complete list of enablers, a questionnaire was created. To undertake content validation, the questionnaire was given to three experts from academia and industry to confirm that the was accurate and served the intended purpose. It should be noted that, while ten academics and ten professional engineers were invited to participate in this research, three specialists agreed. Two successive segments of interviews were conducted. The first segment was conducted with an academic GLSS expert with a direct connection to this project. The goal was to determine the relevance of each enabler and its scale objective, as well as to revise each enabler in accordance with the suggested criteria [36,39], including: (1) the relevance and applicability of each enabler, (2) the clarity and consistency of each enabler in relation to the objective of the scale, (3) the usage of easy-to-understand terms, (4) the removal of ambiguous terms, (5) approval of the enablers that took an excessive amount of time, (6) confirmation of statements that contained an excessive number of technical terms or terms that were not regularly used in the practitioner context, and (7) verification and eradication of jargon, colloquialisms, slang, and acronyms. The scale revealed 30 enablers at the end of this segment. The second segment was performed with the assistance of two professional engineers who had significant experience in environmental management and the execution of LSS projects. However, the target group needs to understand and evaluate the enablers as the objective of the scale was measurement. An enabler needed to be re-analyzed or excluded if both engineers agreed that it was irrelevant, which was not the case in this study. As a result, there was no comment on exclusion, inclusion, or revision, indicating that all 30 enablers were relevant and easy to understand.

Table 1. EFA-based structure of GLSS enablers.

Enablers [a]	**References**	**Factors** [b]					**Communalities**	**Coding**
		1	**2**	**3**	**4**	**5**		
Organizational readiness for GLSS implementation	[26,57,59,62–65]	0.696					0.626	E1
Linking GLSS to organizational vision/mission statements	[26,27,54,57,59,61–65]	0.673					0.735	E2
Top management commitment and support for adopting GLSS throughout all stages of the product development cycle	[26,27,54,57,59,61–65]	0.657					0.669	E3
Culture and supportive ambiance	[26,54,57,59,61–65]	0.640					0.708	E4
Project selection and management	[27,57,62–65]	0.636					0.621	E5
Effective scheduling	[54,57,63,65]	0.599					0.621	E6
Funds' availability	[26,27,54,57,59,63–65]	0.543					0.707	E7
Expedite resources and skills in the implementation process	[62–64]	0.518					0.636	E8
Firm's reputation	[61,63]	[c]					[c]	[c]
Market demands for environmentally-friendly products	[63,65]	[c]					[c]	[c]
Employee training and developmental programs	[26,27,54,57,59,61,63–65]		0.731				0.704	E9
Employee involvement and empowerment	[27,54,61–65]		0.658				0.584	E10
Teamwork	[26,27,57,59,64,65]		0.654				0.655	E11
Reward and recognition of employees	[27,57,62–65]		0.584				0.628	E12
Attracting and selecting employees	[27,57,62,65]		0.528				0.593	E13
Knowledge management	[64]		[c]				[c]	[c]
Technological readiness for GLSS implementation	[27,64]			0.799			0.670	E14
GLSS tools and techniques for effective data collection and measurement	[26,27,57,59,63–65]			0.629			0.607	E15
Equipment up-gradation	[26,27,59,62–65]			0.556			0.529	E16
Technology up-gradation (e.g., use of cleaner technologies)	[54,57,61,64]			0.534			0.641	E17
Continuous improvement practices in environmentally-sustainable manufacturing processes	[54,63–65]				0.786		0.722	E18
Material selection and modification	[54,57,63,65]				0.636		0.599	E19
Use of environmentally-friendly packaging	[54,65]				0.530		0.543	E20
Use of environmentally-friendly transportation	[54,57,63,65]				0.525		0.530	E21
Environmentally-friendly product design practices	[54,63–65]				0.505		0.514	E22
Supplier relationship management	[54,57,63,65]					0.600	0.638	E23
Customer relationship management	[27,54,57,63–65]					0.579	0.655	E24
Government rules and regulations	[57,63,64]					0.572	0.621	E25
Environmental management System	[54,63,64]					0.521	0.542	E26
Effective communication of GLSS schemes among departments	[57,63,65]					0.501	0.518	E27

[a] Enablers are classified according to their loadings on each factor. [b] Rotation was performed by the varimax method in 9 iterations. [c] Indicates the enablers excluded due to low factor loadings.

4. Findings and Discussion on the Analytic Method: Empirical Contribution

To achieve the main research objectives, EFA was used to disclose the factorial structure of GLSS with 30 identified enablers, as presented in Table 1. In this regard, the principal component factor analysis was applied to assess the scores obtained from the responses given by the 102 experts who work as Professional Engineers (P.Eng.: 62%) and Chartered Engineers (C.Eng.: 38%) in different Malaysian electronics manufacturing industries. Understanding their perception in such a context is especially important as it gives the decision-makers a better sense of the evaluation in the view of one of their major groups of stakeholders.

To assess the enablers, a five-point Likert scale with a range of 1 (strongly disagree) to 5 (strongly agree) was used, according to the adopted methodological approach discussed in Section 2.2. Of a total of 261 questionnaires distributed, 183 completed questionnaires were received. Following the flexible pointing system developed by Hallowell and Gambatese [67] in selecting experts for an in-depth analysis, 102 questionnaires were found to be totally usable, resulting in a response rate of 39.08%, which was considered acceptable [36,39]. The survey's overall reliability coefficient (α) was 0.956, which was appropriate [36]. The correlation matrix analysis indicated that the majority of the correlations were significant at the 0.05 level, revealing a sufficient basis for developing an empirical examination of sufficiency for EFA both on a general basis and for each enabler. The BTS and KMO tests were also utilized, to confirm the adequacy of sampling and assess the data factorability, respectively. In this investigation, the BTS was determined to be significant at $p < 0.001$ and the KMO index was found to be 0.901, demonstrating that the data was suitable for EFA implementation.

Next, the most widely used criteria, i.e., the proportion of contribution to the total variance, eigenvalues and Scree plot, were considered for determining the total factor number for extraction. Five factors dropped sharply and then leveled out on the Scree plot, suggesting that the data should be examined for five factors. Appendix A (Figures A1 and A2) gives concrete proof of the outcome. As detailed in Table 2, the discovered enablers distinctively constituted five factors, with a total variance explained of 62.183% which was appropriate [36,37]. As shown in Table 1, three enablers were excluded due to low factor loadings. Consequently, 27 out of 30 initial enablers were meticulously maintained, with factor loadings exceeding 0.5. Therefore, one enabler per factor with loading greater than 0.5 was investigated to extract the five key factors, as described below.

Table 2. Total variance, eigenvalues, and reliability coefficients of structured factors.

Total Variance Explained [a]		**Factors** [b]				
		1. SI	**2. HRM**	**3. TT**	**4. EP**	**5. EN**
Initial Eigenvalues	Total	13.274	1.602	1.321	1.264	1.195
	Variance (%)	44.246	5.339	4.403	4.213	3.983
	Cumulative (%)	44.246	49.585	53.988	58.200	62.183
Rotation Sums of Squared Loadings	Total	5.182	4.077	3.239	3.093	3.063
	Variance (%)	17.274	13.592	10.795	10.312	10.210
	Cumulative (%)	17.274	30.866	41.661	51.973	62.183
Cronbach's alpha (α) [c]		0.906	0.844	0.769	0.798	0.782

[a] Extraction method: principal component analysis. [b] Rotation has been performed by the varimax method in 9 iterations. [c] Overall reliability and KMO are 0.956. and 0.901, respectively. BTS is significant at $p = 0.000$.

Eight enablers ($E_{1–8}$) with significant loadings exceeding 0.5, as shown in Table 1, were included in the first factor, which had an initial eigenvalue of 13.274. This major factor was predicted to explain 44.246 percent of the total variance (Table 2), demonstrating the presence of one core component at the internal consistency of the GLSS initiative's factorial structure [36,37]. Based on the common features of the loaded enablers, this factor concentrated on strategic integrity for the sake of the application's implementation in the organization. Thus, the term Strategic Integrity (SI) was used to label this factor. The internal consistency coefficient (α) of the SI structure was computed using SPSS and was found to be 0.906 (Table 2), which was statistically significant. As a result, the analyses indicated the validity of this articulated eight-enabler structure.

Five enablers ($E_{9–13}$) with significant loadings exceeding 0.5, as shown in Table 1, were included in the second factor, which had an initial eigenvalue of 1.602. This major factor was predicted to explain 5.339% of the total variance (Table 2). Based on the common features of the loaded enablers, this factor concentrated on managing human resource for the sake of the GLSS implementation in the organization. Thus, the term Human Resource Management (HRM) was used to label this factor. The internal consistency coefficient (α) of the HRM structure was computed using SPSS and was found to be 0.844 (Table 2), which was statistically significant. This indicated the validity of this articulated five-enabler structure.

Four enablers ($E_{14–17}$) with significant loadings exceeding 0.5, as shown in Table 1, were included in the third factor, which had an initial eigenvalue of 1.321. This major factor was predicted to explain 4.403% of the total variance (Table 2). Based on the common features of the loaded enablers, this factor concentrated on having apt technologies and tools for the sake of the GLSS implementation in the organization. Thus, the term Technologies and Tools (TT) was used to label this factor. The internal consistency coefficient (α) of the TT structure was computed using SPSS and was found to be 0.769 (Table 2), which was significant. This indicated the validity of this articulated four-enabler structure.

Five enablers ($E_{18–22}$) with significant loadings exceeding 0.5, as shown in Table 1, were included in the fourth factor, which had an initial eigenvalue of 1.264. This major factor was predicted to explain 4.213% of the total variance (Table 2). Based on the common features of the loaded enablers, this factor concentrated on developing green production practices for the sake of the GLSS implementation in the organization. Twhus, the term Eco-production (EP) was used to label this factor. The internal consistency coefficient (α) of the EP structure was computed using SPSS and as found to be 0.798 (Table 2), which was statistically significant. This indicated the validity of this articulated five-enabler structure.

Five enablers ($E_{23–27}$) with significant loadings exceeding 0.5, as shown in Table 1, were included in the fifth factor, which had an eigenvalue of 1.195. This major factor was predicted to explain 3.983% of the total variance (Table 2). Based on the common features of the loaded enablers, this factor concentrated on advancing green networks among major stakeholders for the sake of the GLSS implementation in the organization. Thus, the term Eco-network (EN) was used to label this factor. The internal consistency coefficient (α) of the EN structure was computed using SPSS and was found to be 0.782 (Table 2), which was statistically significant. This indicated the validity of this articulated five-enabler structure.

It is important to note that one of the key factors enabling GLSS implementation as Technologies and Tools (TT). The concept can thus be strengthened by considering Industry 4.0 technologies since the use of such technologies in advancing GLSS tools will result in increased efficiency [31,52]. While da Silva et al. [52] gave an overview of Industry 4.0 capabilities to deploy GLSS, the effective convergence of these two emerging concepts is still in its infancy. Further innovative research is needed on the topic. According to Lee et al. [30], such studies would provide research professionals, practitioners, and those who are interested in realizing the benefits of this convergence with new perspectives and guidelines.

5. Conclusions, Implications and Future Directions

This study contributes valuable insights into which key factors enable Green Lean Six Sigma (GLSS) implementation in the manufacturing industry. It theoretically identified and clarified the factors based on a systematic review. This paper also presents empirically a factorial structure of GLSS key enablers through the perceptions of some major stakeholders who work in the Malaysian electronics manufacturing industry as professional engineers

(P.Eng.: 62%) and chartered engineers (C.Eng.: 38%). To this end, an exploratory factor analysis (EFA) was, accordingly, applied.

The output of the theoretical and empirical analyses indicated that GLSS, which has emerged in the Industry 4.0 era, is a multi-dimensional business strategy, so if a manufacturing company gains experience in it, the required organizational learning, excellence and system improvements for the company to benefit from GLSS performance support circular economy-based models, where the resources remain in the cycle until one of the 3Rs (reduce, reuse, and recycle) is practiced. The theoretical findings indicated that publication growth has been significant since 2011, and it is projected to keep rising owing to its intellectual contribution to the environmentally-sustainable manufacturing paradigm, which is regarded as an application of the emerging concept of the circular economy. Interestingly, this growing global research trend has developed since the advent of Industry 4.0, which came to light in 2011. It was also observed that India, the United Kingdom, and the United States each have a large number of publications and strong international collaborations. These entities may provide an opportunity for scholars from other countries to expand their collaborative research efforts. More significantly, this study offered a concept of GLSS and also a set of key enablers that can be used for its operationalization. Following the established set, the empirical results were used to produce a structural model with twenty-seven validated enablers forming five key factors: Strategic Integrity (α = 0.906), Human Resource Management (α = 0. 844), Technologies and Tools (α = 0. 769), Eco-production (α = 0. 798) and Eco-network (α = 0. 782). The analyses revealed that there were strong relationships between these key factors throughout the model. Strategic Integrity was found to be a major factor in the internal consistency of the GLSS factorial structure, with 44.246% of the total variance explained.

Implication-wise, this article details a contemporary study in the field and delivers valuable insights both theoretically and practically. Despite the fact that the relevance and capabilities of GLSS have been studied, there is still work to be done to establish a definition or a commonly accepted conceptual model, to develop valid and reliable scales to investigate the degree of implementation, to analyze its main factors and impacts on business results and to conduct rigorous empirical studies on the topic. This study, as one of the preliminary investigations carried out to this end, indicates GLSS is a business strategy with five key dimensions that can be applied to investigate its degree of implementation. The developed structural model has the potential to facilitate new studies in the development of an effective GLSS system. It may also serve as a guide for decision-makers towards its implementation in manufacturing systems, particularly in electronics manufacturing industries. Furthermore, it may support studies on developing industrial sustainability, a topic which is gaining traction in a variety of manufacturing sectors.

Nevertheless, the empirical findings, which are suggestive rather than definitive, have some limitations that may suggest future research directions. Although every effort was made to include all essential enablers of GLSS by extensively studying the most up-to-date literature on the subject (see Table 1), there may be more critical factors that should be considered. Additionally, some mediators may need to be investigated further. It may be necessary to include new enablers and/or to exclude the original ones in some scenarios. However, the primary recommendation for future research is to investigate the generalizability of the discovered factors across multiple contexts (various countries, firms, and ethnic groupings) by testing the validity and reliability of the factors and by developing factorial structures using new, larger datasets.

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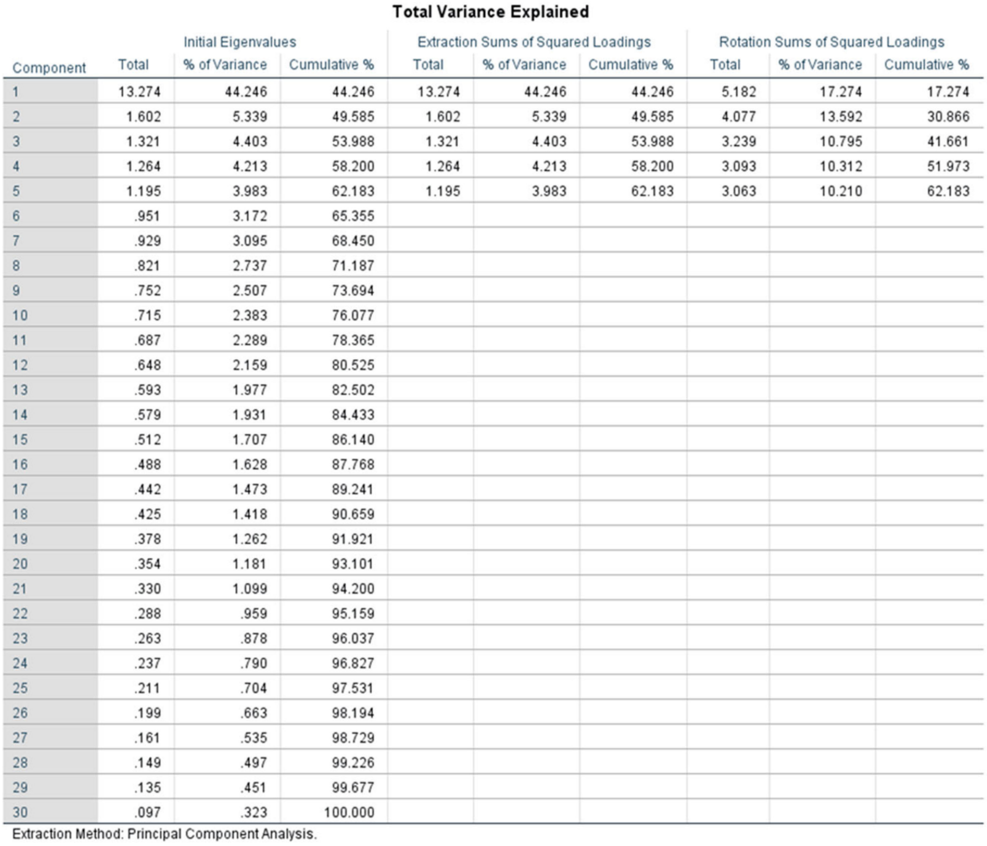
Appendix A



Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	13.274	44.246	44.246	13.274	44.246	44.246	5.182	17.274	17.274
2	1.602	5.339	49.585	1.602	5.339	49.585	4.077	13.592	30.866
3	1.321	4.403	53.988	1.321	4.403	53.988	3.239	10.795	41.661
4	1.264	4.213	58.200	1.264	4.213	58.200	3.093	10.312	51.973
5	1.195	3.983	62.183	1.195	3.983	62.183	3.063	10.210	62.183
6	.951	3.172	65.355						
7	.929	3.095	68.450						
8	.821	2.737	71.187						
9	.752	2.507	73.694						
10	.715	2.383	76.077						
11	.687	2.289	78.365						
12	.648	2.159	80.525						
13	.593	1.977	82.502						
14	.579	1.931	84.433						
15	.512	1.707	86.140						
16	.488	1.628	87.768						
17	.442	1.473	89.241						
18	.425	1.418	90.659						
19	.378	1.262	91.921						
20	.354	1.181	93.101						
21	.330	1.099	94.200						
22	.288	.959	95.159						
23	.263	.878	96.037						
24	.237	.790	96.827						
25	.211	.704	97.531						
26	.199	.663	98.194						
27	.161	.535	98.729						
28	.149	.497	99.226						
29	.135	.451	99.677						
30	.097	.323	100.000						

Extraction Method: Principal Component Analysis.

Figure A1. Total variance explained using IBM SPSS 26.

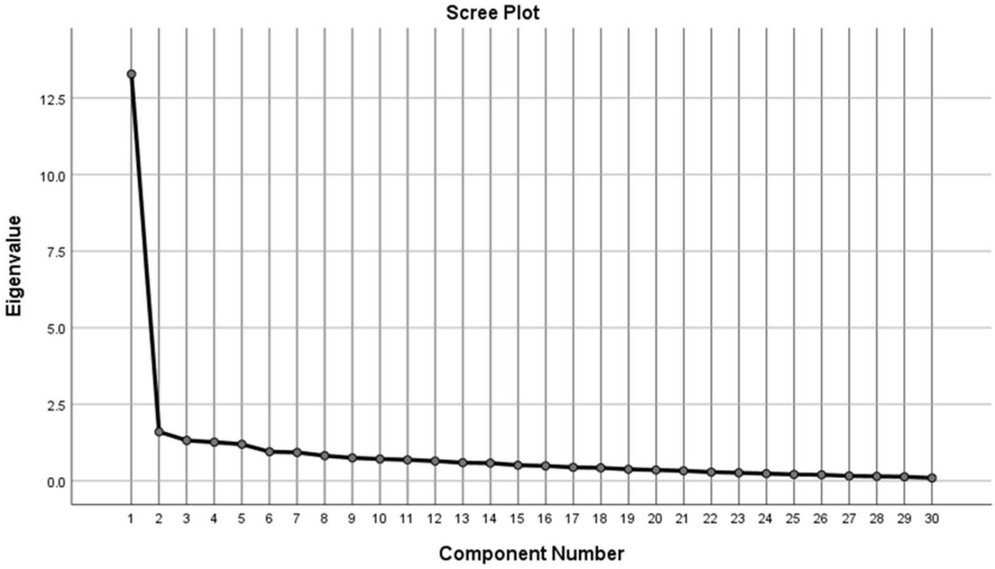


Figure A2. Scree plot test.

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