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Green Lean Six Sigma: A Review

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ABSTRACT

Although the capabilities and benefits of Green Lean Six Sigma (GLSS) have been well-documented towards developing sustainability in the manufacturing industry, practitioners remain cautious of its application. Due to this, there are research demands to systematize the available knowledge on this green initiative as well as to recognize the factors that enable the successful implementation of GLSS. Enablers are regarded as the prerequisites providing a stimulus to organizations to incorporate a new approach, but none had identified and analyzed the enablers for GLSS implementation in the Malaysian manufacturing sector. Thus, the objectives of this study are to review the leading-edge GLSS studies as well as to investigate its key enablers for positioning this green initiative at an operational level, particularly in the Malaysian manufacturing sector. The results revealed that the growth of research in this area has progressively evolved over the years and it is expected to continue to rise due to its importance and capability towards greening manufacturing industries. India, the UK, and the US had a large number of publications and strong international collaborations, respectively. This ongoing study also contributes leading references that can be fruitfully exploited in the enablers' assessment process and subsequently the GLSS success.

Keywords:
Green production; lean manufacturing;
six sigma; enablers; literature review

1. Introduction

The manufacturing sector is identified as the main enabler of sustainable development (SD), prominently conceptualized by [1] as "the development that meets the needs of the present without compromising the ability of future generations to meet their needs". However, a majority of manufacturing processes have negative environmental and social impacts resulting from the excessive usage of limited resources and the release of harmful wastes and emissions. Saad *et al*., [2] revealed that the manufacturing industry is accountable for 19% of greenhouse gas (GHG) emissions including CO2 due to various economic activities conducted by European Union nations. Based on the Manufacturers National Association, the sector contributes 31% to the United States' overall energy consumption whereby 65% of it is attributable to the manufacturing industry. This sector is the key economic driver for Malaysia, but its industrial processes had contributed to the 46% hike in GHG emissions from 2000 to 2011 based on the 2016 Malaysian Biennial Update Report [3,4]. These green issues and other environmental compliance and societal regulations issues as emphasized under the "Malaysian Environmental Quality Act" [5,6] signal the critical requirement for strategic

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approaches for assessing and developing environmental sustainability in the manufacturing sector, as illustrated in Fig. 1, where a need to adopting Green Manufacturing Initiatives to reach the aspirational target, which is up to 50% by 2030, has been highlighted in Malaysian Green Technology Master Plan [3].

Hence, manufacturing industries need to incorporate green initiatives in their operations to safeguard societal welfare and to protect the environment. Innovations such as lean, green, six sigma and others were developed in the past decades to generate high-quality products, but a single methodology alone cannot solve all the SD-related issues. A more effective solution is via a unified approach that minimizes waste and variability as well as mitigates adverse environmental impacts [7]. The integration of Lean manufacturing, Green production, and Six Sigma led to the development of Green Lean Six Sigma (GLSS), i.e., a tactical, systematic and incessant approach for producing high-quality products and services and reducing environmental emissions using the 3Rs – reduce, reuse, and recycle [8]. Due to very limited studies on GLSS compared to the individual approaches, further state-of-the-art research on the subject is called for [9,10] particularly empirical investigations that offer systematic guidelines for the implementation of GLSS in numerous sectors [7,8,11]. However, the concept has yet been well-defined both empirically and theoretically. Although the capabilities and benefits of GLSS have been documented, practitioners remain cautious of its application [8,10,11]. Due to this, there are also research demands to recognize the factors that enable successfully implementing GLSS [8]. Enablers are regarded as the prerequisites providing a stimulus to organizations to incorporate a new approach [7,11,12], but none had identified and analyzed the enablers for GLSS implementation in the Malaysian manufacturing sector. To narrow this gap, this paper is aimed at addressing the following research questions:

1. How has research on Green Lean Six Sigma (GLSS) evolved in recent years?
2. What are the main enablers facilitating the GLSS implementation in the manufacturing sector?

Fig. 1. Aspirational target for the manufacturing sector in Malaysia [3].

2. Methodology

To address the research questions, this study applied a methodological approach based on the Bibliometric analysis, in pursuit of [13-15], including main steps, as depicted in Fig. 2. According to [13], this Bibliometric analysis-based review is employed to scrutinize research trends in specific areas and to recognize the impacts of such research on individuals, groups or organizations by looking

at the literature database outputs. Thus, this method is carried out to investigate trends of research in GLSS.

The data for this study was extracted from Scopus within May 2021. However, based on Lee et al. [15], the Scopus database is the largest indexer of global research content and includes titles from more than 5,000 publishers worldwide including Springer, ScienceDirect, Emerald, Taylor & Francis, Wiley, etc. The central theme in this research was the scientific documents containing theoretical domains – Green Manufacturing, Lean Manufacturing, and Six Sigma – and also the interchangeable terms – Green Production, Lean Production, and 6Sigma – in the title and abstract. Hence, the query string used for the search was: TITLE-ABS (("Green") AND ("Lean") AND ("Six Sigma" OR "6Sigma")). This query string resulted in 106 articles after screening documents (Fig. 2). Next, manual article selection by reading abstracts and full-texts was conducted to discard any duplications and to exclude irrelevant articles. 66 remaining articles were resultantly considered for the review, where the oldest publication was produced in 2011, with the aim of demonstrating "how process efficiency and environmental Muda may be dealt with simultaneously in a lean-and-green project driven by hardcore Six Sigma tools" [16].

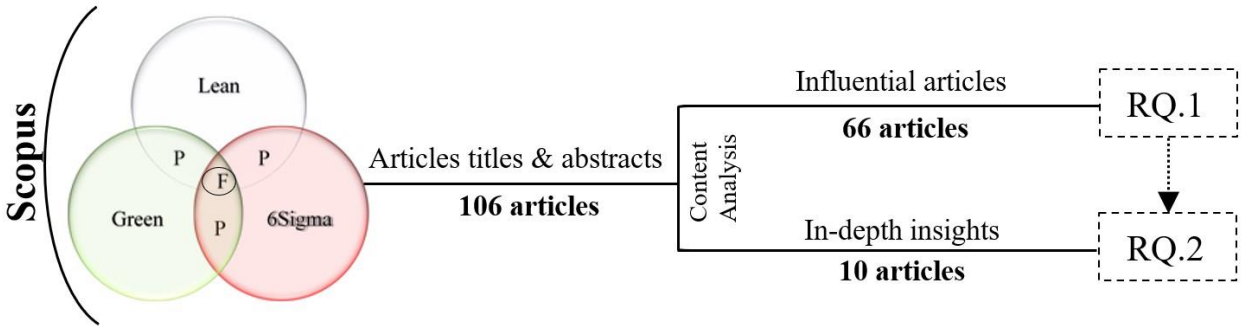

Fig. 2. Research framework.

3. Results and Discussion

Findings on the distribution of influential articles based on publication year indicate that the growth of research in GLSS has progressively evolved over the years; applying this green initiative in 2011 was found in only one article, i.e. [16], and this number was significantly increased to twenty articles in 2020, as illustrated in Fig. 3. It is expected to continue to rise due to the importance and capability of GLSS in the context of environmentally-sustainable manufacturing.

The top-three international journals for the field were: (1) International Journal of Lean Six Sigma, with six articles (CiteScore 2020: 5.2), highlighting that this journal has the most significant role in the GLSS area; (2) TQM Journal, with five articles (CiteScore 2020: 4.3); and (3) Journal of Cleaner Production, with four articles (CiteScore 2020: 13.1).

Three prolific authors have more than five publications on the subject. The leading author is Garza-Reyes, J.A., who explained "Green lean and the need for Six Sigma [9]", with a maximum number of seven publications followed by Rathi, R. (7 articles), and Kaswan, M.S. (6 articles). Fig. 4 shows the distribution of the authors' affiliations from 20 countries. India, the UK, and the US as the three most dominant countries have the greatest number of affiliations, with 24, 15, and 6 documents, respectively.

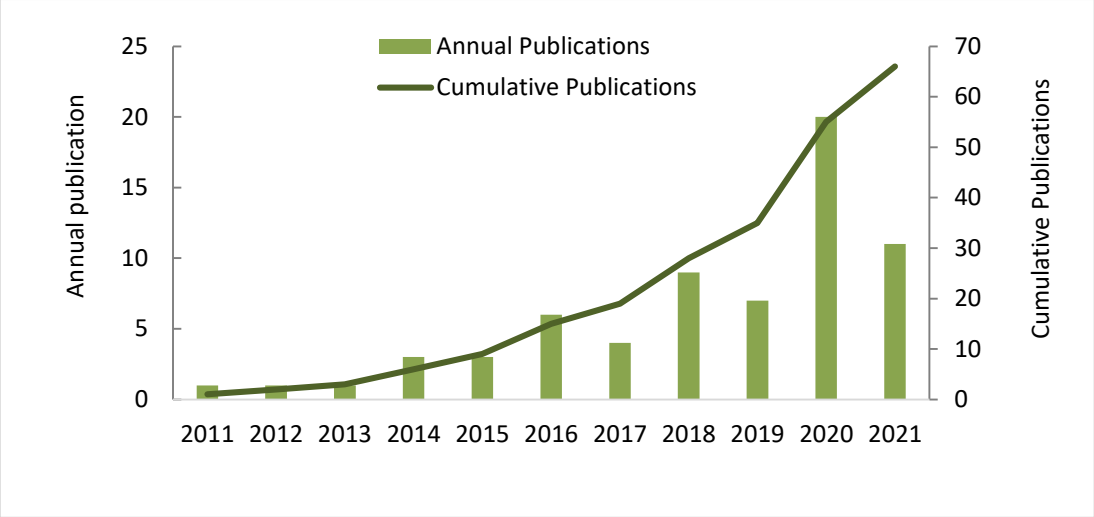

Fig. 3. The annual and cumulative publications on GLSS.

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Fig. 4. Distribution of GLSS documents across the world.

The most influential articles, among others, are those published by Kumar *et al*., [17], Cherrafi *et al*., [10], and Garza-Reyes [9], with 120, 119, and 109 citations, respectively, as presented in Table 1. Interestingly, only one of the papers, which was published by Gholami *et al*., [8], applied GLSS in the Malaysian manufacturing context. This study revealed that the GLSS application can significantly lessen the consumption of chemicals and energy in the system by 28% and 21%, respectively. [8] also highlighted that "it is essential to identify and analyze key enablers to the clearer implementation of

the application (p.1927)". This affirms that no previous studies have discussed this issue in the Malaysian manufacturing industry.

Table 1
Top 10 most influential articles on GLSS in Scopus.

No.	Authors	Year	Document title	Source title	Total citations	Document type
1	Kumar *et al.*, [17]	2016	Barriers in green lean six sigma product development process: An ISM approach	Production Planning and Control	120	Article
2	Cherrafi *et al.*, [10]	2017	A framework for the integration of Green and Lean Six Sigma for superior sustainability performance	International Journal of Production Research	119	Article
3	Garza-Reyes [9]	2015	Green lean and the need for Six Sigma	International Journal of Lean Six Sigma	109	Article
4	Banawi and Bilec [18]	2014	A framework to improve construction processes: Integrating lean, green and six sigma	International Journal of Construction Management	90	Article
5	Chugani *et al.*, [19]	2017	Investigating the green impact of Lean, Six Sigma and Lean Six Sigma: A systematic literature review	International Journal of Lean Six Sigma	80	Review
6	Sagnak and Kazancoglu [20]	2016	Integration of green lean approach with six sigma: an application for flue gas emissions	Journal of Cleaner Production	50	Article
7	Kaswan and Rathi [21]	2019	Analysis and modeling the enablers of Green Lean Six Sigma implementation using Interpretive Structural Modeling	Journal of Cleaner Production	49	Article
8	Kumar *et al.*, [22]	2015	Conceptualisation of Sustainable Green Lean Six Sigma: An empirical analysis	International Journal of Business Excellence	39	Article
9	Hussain *et al.*, [23]	2019	Green, lean, Six Sigma barriers at a glance: A case from the construction sector of Pakistan	Building and Environment	38	Article
10	Belhadi *et al.*, [24]	2020	The integrated effect of Big Data Analytics, Lean Six Sigma and Green Manufacturing on the environmental performance of manufacturing companies: The case of North Africa	Journal of Cleaner Production	31	Article

To contribute to narrowing the aforementioned gap, we also analyzed in-depth insights into the factors that enable the successful implementation of GLSS; however, enablers are regarded as the prerequisites providing a stimulus to organizations to incorporate a new strategy [7,11,12] – they are strategy-driven. Thus, the analysis for the sub-research field was to identify key enablers, so as to

address the second research question raised (Figure 2). Accordingly, the screening of the articles was resulted in identifying ten articles – [7,11,12,21,22,25-29] – as systematically reviewed and described in Table 2. These leading-edge studies, which revealed the importance of enablers to the GLSS success, propose criteria and sub-criteria that can be considered as starting points for further research in various contexts. In other words, it can help the researchers and practitioners to develop the measurement scale for the implementation of the application. As presented in Table 2, the contribution of this ongoing study also entails the leading references regarding the key enablers-based checklists, which would be useful in the enablers' assessment process and subsequently implementing the GLSS initiative.

Table 2
Contemporary studies on the enablers that facilitate GLSS implementation.

Year	Authors	Description	Number of identified enablers
2015	Kumar *et al.*, [22]	This study, which was carried out by a multi-method approach to conceptualize sustainable GLSS in India, outlines the top five enablers, among 44 enablers, including (1) "Training, rewarding and recognition of team members"; (2) "top management commitment, leadership and support"; (3) "effective scheduling"; (4) "continuous improvement and KAIZEN environment"; and (5) "quality of human resources", respectively.	44
2018	Gandhi *et al.*, [25]	This research used fuzzy multi-criteria decision-making methods to rank GL enablers in the Indian manufacturing context, resulting in the five most important enablers among 15 other ones – (1) Top management commitment, (2) Technology up-gradation, (3) Current legislation, (4) Future legislation, and (5) Green brand image, respectively.	15
2018	Pandey *et al.*, [12]	This investigation applied the AHP method in the Indian manufacturing industry to rank 18 GLSS enablers in five main categories, which respectively are (1) Top management, (2) Quality, (3) Internal factors, (4) Supplier and customer, and (5) Green practices.	18
2019	Kaswan and Rathi [21]	This paper prioritized 12 main enablers of GLSS using the ISM method in the Indian context, in eight levels which respectively were (1) "Organizational readiness for GLS measures together with competence for green product and process", (2) "Top management commitment toward sustainable performance improvement" & "Thorough understanding of green technology and statistical tools", (3) "Linking of GLS to business objectives", (4) "Team effort", (5) "Expertise training in GLS" & "Availability of funds with the organization", (6) "Organizational ambience" & "Effective performance and feedback measure both at upstream and downstream", (7) "Integration of Green, Lean and Six Sigma across all the stages of product development cycle" & "Organizational learning through human resource development", and (8) "Effective data assimilation and Lean Green matrices identification".	12
2020	Kaswan and Rathi [11]	This research used different multi-criteria decision-making methods to rank 12 GLSS enablers, similar to their previous paper.	12
2020	Kaswan and Rathi [7]	In this review paper, authors depicted 11 GLSS enablers for future research; however, the proposed enablers were slightly different from their former papers.	11
2020	Parmar *et al.*, [26]	This study evaluated sustainable GLSS enablers in Indian manufacturing organizations and found "top management commitment and involvement" as the most important enabler among 26 key enablers, which was followed by "organizational readiness".	26
2020	Farrukh *et al.*, [27]	This review paper presented 35 critical factors which enable organizations to successful implementation of GLSS. However, in this study, GLSS	35

		enablers have been addressed via GLSS tools such as DMAIC, VSM, LCA, 5S, etc.	
2021	Singh et *al*.,[28]	This research analyzed and finalized 22 out of 30 identified GLSS enablers in Indian MSMEs, categorizing enablers into five groups: (1) environmental based, (2) strategic based, (3) culture based, (4) resources based, and (5) linkage based.	30
2021	Ershadi *et al*., [29]	This instigation was elaborated on “technology readiness level”, taking it into account as a key enabler since it plays a meaningful role in implementing GLSS projects.	28

4. Conclusion

As GLSS has been receiving considerable attention from practitioners and researchers and its adoption towards improving environmental sustainability performance in manufacturing industries is slowly progressing, the purpose of this research was to present an overview of a literature review on the GLSS initiative. To do so, the fundamental studies in this area were analyzed using a methodological approach.

Findings revealed that publication growth has been rapid since the last 10 years, and it is expected to continue to rise. It is also discovered that India, the UK, and the US have a massive number of publications and strong international collaborations as such. These entities can be an opportunity for researchers from other countries to broaden their research collaborations. This review can significantly contribute to the existing body of knowledge as there is a lack of research on the integration and systematization of the available knowledge on GLSS. Particularly, it offered a set of leading references that can be fruitfully applied to position this green initiative at an operational level.

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