STRUCTURAL MODEL OF ENABLERS FOR GREEN LEAN SIX SIGMA IMPLEMENTATION IN MALAYSIAN MANUFACTURING INDUSTRIES

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ABSTRACT

Green Lean Six Sigma (GLSS) has been recently clarified as a business strategy contributing to improving the environmental sustainability performance of operations through adopting the 3R concept, i.e., reduce, reuse, and recycle. Despite its broadly acknowledged benefits and capabilities, practitioners in the manufacturing industry continue to remain cautious of its application due to having insufficient knowledge and culture. This indicates that there is a necessity for recognizing key factors enabling its implementation. In the Malaysian manufacturing context, the enabling factors have yet to be identified and evaluated. Thus, this study aimed to identify and analyse key enablers facilitating the GLSS implementation in the Malaysian manufacturing sector and to develop a structural model for the identified enablers towards the implementation of GLSS. The implemented methodological approach included two steps. Firstly, it performed a systematic review of leading studies on the topic which are rather scarce in the current context. The second step entailed the Factor Analysis (FA) method and the application of Interpretive Structural Modelling (ISM) mixed with Matriced' Impacts Croises-Multiplication Applique' and Classment (MICMAC), for analysing and finalizing the findings. The findings from the literature review revealed that publication growth has been rapid in the last ten years. It is expected to continue to rise due to its intellectual contribution to the environmentally-sustainable (green) manufacturing paradigm, which is regarded as an application of the emerging concept of circular economy. It is also discovered that India, the United Kingdom, and the United States have a massive number of publications and strong international collaborations, respectively. The empirical results obtained by the multiple methods indicated an interpretive structural model with five factors including Strategic Integrity, Human Resource Management, Eco-production, Eco-network, and Technologies and Tools. It was exposed as a result that there is a high correlation between Strategic Integrity and Human Resource Management, both possessing significant driving power. Strategic Integrity was found to be a major factor in the internal consistency of the GLSS factorial structure. Implications wise, this thesis detailed a contemporary study in the field and delivers valuable insights both theoretically and practically.

ABSTRAK

Green Lean Six Sigma (GLSS) baru-baru ini diperjelaskan sebagai satu strategi perniagaan yang menyumbang kepada peningkatan prestasi kelestarian alam sekitar dalam operasi perniagaan dengan mengamalkan konsep 3R, iaitu pengurangan, guna semula, dan kitar semula. Walaupun manfaat dan keupayaannya diakui secara meluas, pengamal dalam industri pembuatan masih berhati-hati dari segi mengaplikasinya disebabkan oleh ketidakcukupan pengetahuan dan budaya. Hal ini menandakan bahawa terdapat keperluan untuk mengenali faktor-faktor utama yang membolehkan pelaksanaannya. Dalam konteks sektor pembuatan di Malaysia, faktor-faktor pemboleh masih belum dikenal pasti dan dinilai. Oleh itu, kajian ini bertujuan untuk mengenal pasti dan menganalisis pemboleh utama yang melancarkan pelaksanaan GLSS dalam sektor pembuatan di Malaysia dan untuk membangunkan model struktur bagi pemboleh utama yang dikenal pasti ke arah pelaksanaan GLSS. Pendekatan kaedah yang dilaksanakan merangkumi dua langkah. Pertama, semakan sistematik terhadap kajian terkemuka berhubung dengan topik tersebut yang agak terhad dalam konteks semasa telah dijalankan. Langkah kedua melibatkan kaedah Analisis Faktor (FA) dan metodologi Pemodelan Struktur Interpretif (ISM) yang digabungkan dengan *Matriced' Impacts Croises-Multiplication Applique' and Classment* (MICMAC) untuk menganalisis dan memuktamadkan dapatan kajian. Dapatan daripada kajian literatur telah mendedahkan perkembangan penerbitan yang pesat dalam tempoh sepuluh tahun kebelakangan ini. Hal ini dijangka akan terus meningkat disebabkan oleh penyumbangan inteleknya dalam paradigma pembuatan yang mesra alam (hijau), yang dianggap sebagai aplikasi konsep ekonomi kitaran yang baru muncul. Kajian juga mendapati bahawa India, United Kingdom, dan Amerika Syarikat masing-masing memiliki sejumlah besar penerbitan dan kerjasama antarabangsa yang kukuh. Hasil empirikal yang diperoleh melalui kaedah pelbagai menunjukkan satu model struktur tafsiran dengan lima faktor termasuk Integriti Strategik, Pengurusan Sumber Manusia, Pengeluaran Eko, Rangkaian Eko, dan Teknologi dan Alat. Hasilnya, terdapat korelasi yang tinggi antara Integriti Strategik dengan Pengurusan Sumber Manusia, dengan kedua-duanya memiliki kuasa memacu yang penting. Integriti Strategik didapati menjadi faktor utama dalam ketekalan dalaman bagi struktur faktorial GLSS. Dari segi implikasi, tesis ini memperincikan kajian kontemporari bidang dan mengenengahkan pandangan yang berharga dari segi teori dan praktikal.

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V	-	Enabler i will influence enabler j
A	-	Enabler i will be influenced by enabler j
X	-	Enabler i and j influence each other
O	-	Enabler i and j are unrelated

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter is opened with the background of the research, which further describes an emergent field, i.e. “Green Lean Six Sigma”, and the existing opportunities for its advancement. Following, the research objectives, questions, scope, and the importance of this study are presented.

1.2 Research Background

Research has demonstrated the effectiveness of the “Green and Lean” integration in boosting operational and environmental performance (Dues et al., 2013; Garza-Reyes, 2015a) as well as “Lean and Six Sigma” integration in enhancing business profits and competitiveness (Salah et al., 2010; Lee et al., 2013). This current study extends the existing frameworks by proposing the unification of both hybrid applications thus forming the “Green Lean Six Sigma (GLSS)” model; advanced studies are needed to investigate the implementation of GLSS in multiple contexts as highlighted by Kaswan and Rathi (2020). According to Gholami et al. (2021), this enhanced integration is driven not only by the proven cohesiveness of the lean principles and tools apparent in both approaches, but also by ostensibly shared attributes of the concepts. Therefore, this section aims to present the background of these specific domains.

Many organizations have taken environmentally-driven proactive steps to develop cleaner and more eco-friendly manufacturing processes as well as produce greener products. Therefore, green practice 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 (Garza-Reyes, 2015a,b). The green notion generally covers numerous environmental management ingenuities including green SCM, green HRM, and *green manufacturing* driven by the 3R initiatives namely reduce, reuse and recycle (Deif, 2011; Digalwar et al., 2013). Based on Rao (2004) and Galeazzo et al. (2013), the green concept basically involves the application of green methods to reduce negative environmental effects and ultimately lessen the environmental footprint created by organizations.

The groundbreaking work "The Machine that Changed the World" had paved the way for significant and unprecedented transformations to *lean philosophy* leading to the unanimous acknowledgment of the prominent value of being lean (Womack et al., 1990). It was in the 1950s that the Toyota Production System (TPS) in Japan first introduced the lean concept (Herron and Hicks, 2008). From then on, the concept grew in repute and utilized broadly in numerous industries worldwide, further driving the prominence of waste reduction (Muda). At present, according to Abdul Wahab et al. (2013), the lean concept is the main global manufacturing standard due to its proven role in improving organizational competitiveness via the reduction of lead times and inventories as well as the reinforcement of overall productivity and quality.

The green movement has motivated organizations to devise new ways of incorporating traditional performance measurements to attain profit and other business objectives via environmentally-friendly measures (Kaswan and Rathi, 2020). Simpson and Power (2005) highlighted the existence of comparable lean and green concepts and practices that contribute to the creation of an improvement-oriented system that is highly effective and well-organized. With its emphasis on waste elimination at all production stages, the applicability of lean manufacturing has been extended to include environmental aspects. Drawing from the TPS concept, the

US EPA (2007) described the objective of 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. Lean initiatives are indicated to result in considerable environmental benefits i.e. a major ground for companies to consider taking up environmentally-oriented innovations (Vinodh et al., 2016). Dues et al. (2013) demonstrated the positive impacts of "*green lean*" on green initiatives and ultimately on lean practices. In 2013, Duarte and Machado developed a standard for green lean organization modeling based on their examination on the impacts resulting from numerous frameworks and the awards to this end. Verrier et al. (2014) measured lean-based profit performances by adding environmental and social features. An approach integrating the lean and green concepts was proposed by Pampanelli et al. (2014) with the aim of not only minimizing waste production, but more importantly reducing environmental/green wastes. The US EPA (2007) defined 'green waste' as all needless or unwarranted forms of resource consumption or the release of substances due to such consumptions which are detrimental to humans and/or the environment. Based on their review of key pieces of literature in the field, Garza-Reyes et al. (2018) identified "energy, water, materials, garbage, transportation, emissions, and biodiversity" as the most prominent green wastes.

Other than the powerful Muda-based (i.e. waste elimination) lean approach, the Mura-based (i.e. inconsistency elimination) Six Sigma approach is another equally powerful mechanism (Miguelez et al., 2014). *Six Sigma* was first outlined in the 1980s as a quality enhancement approach with origins tracing back to the US-based electronics company, Motorola (Soti et al., 2010). According to Matthew et al. (2005), 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 (Maleyeff and Kaminssky, 2002). As pointed out by Linderman et al. (2003), the Six Sigma approach is applicable for both the manufacturing and service industries. Most studies had revealed that Six Sigma is capable of promoting organizational competitiveness and enhancing product or service quality (Banuelas et al., 2005).

Literature has demonstrated the compatibility between Six Sigma and the Lean philosophy due to the former's problem management tools and capability of identifying lean issues. Many studies have proven the effectiveness of the "*Lean Six Sigma (LSS)*" integration (Salah et al., 2010; Lee et al., 2013). According to Salah et al. (2010), LSS expedites processes by reducing wastages and improves quality via minimizing process variability. The study of Shah et al. (2008) on 2215 companies implementing LSS-oriented projects revealed that LSS is a highly powerful hybrid model. Six Sigma supports the lean philosophy by providing issue-oriented tools and expertise that are identified during the course of the process. However, selection of the best approach for implementing LSS greatly contributes to its success (Lee et al., 2013; Powell et., 2017).

1.3 Problem Statement

Despite being recognized as a highly effective approach for making operations more eco-friendly via the reduction of wastes, emissions and reworking, the integrated green lean approach still suffers from several drawbacks that impede its successful implementation. A 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 matter. And, for that reason, this approach may not be helpful to achieve the 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 'other tools' for reducing or eliminating the said drawbacks. Owing to the drawbacks of green and lean as separate approaches and as an integrated model, as elaborated by Gholami et al. (2021), Sagnak & Kazancoglu (2016) and Garza-Reyes (2015a), it seems that GLSS serves as a novel environmental developmental agenda for overcoming the aforementioned limitations and boosting the performance of green lean ingenuities.

Due to very limited studies on GLSS, further state-of-the-art research on the subject is called for (Garza-Reyes, 2015a; Cherrafi et al., 2017; Caiado et al., 2018; Sony and Naik, 2019) particularly empirical investigations that offer systematic guidelines for the implementation of GLSS in numerous sectors (Kaswan and Rathi, 2020a). The concept, however, has not been well-defined both empirically and theoretically. Although the capabilities and benefits of GLSS have been documented, practitioners remain cautious of its application. Due to this, there are research demands to recognize the factors that enable successfully implementing GLSS (Gholami et al., 2021). In this regard, Kaswan and Rathi (2019) identified and prioritized only 12 main enablers of GLSS using the ISM method in the Indian context, in eight hierarchical 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". Kaswan and Rathi (2020a) depicted 11 GLSS enablers for future research; however, the proposed enablers were just slightly renamed from their former paper. Kaswan and Rathi (2020b) used different multi-criteria decision-making methods to rank the same enablers. There are also several studies investigating enablers, as systematically reviewed in the next chapter.

Based on Pandey et al. (2018) and Kaswan & Rathi (2020a), enablers are regarded as the prerequisites providing a stimulus to organizations to incorporate a new approach. Enablers for the implementation of 'Lean' or 'Six Sigma' or 'Lean and Six Sigma' have been identified in many past studies (e.g., Soti et al., 2010; Yadav and Desai., 2017), but none had identified and analyzed the enablers for 'GLSS' specifically in the Malaysian manufacturing sector which is a key economic contributor as well as a generator of adverse environmental and social impacts as it consumes excessive scarce resources and produces dangerous wastes and emissions. To narrow this gap, this study considers all the research that investigated 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). In this regard, qualitative and quantitative methods will be taken into consideration as they are capable to provide its users with thorough and systematic techniques for incorporating group judgements in developing structural models. According to Shahabadkar et al. (2012), the benefits of such models can be enumerated as: 1) ability to manage excessive variable communication in complex systems, 2) provision of a broad system view, 3) easy utilization by multiple and interdisciplinary users, and 4) integration of various perceptions.

Consequently, with the recent development of GLSS, innovative studies are needed for the purpose of identifying, analyzing and modeling the key enablers of GLSS implementation in the Malaysian manufacturing sector. To the best of the author knowledge, only a paper, which was published by Gholami et al. (2021), 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. It is also highlighted by them that "it is essential to identify and analyze key enablers to the clearer implementation of the application (p.1927)".

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, which were discussed, it is evident that GLSS serves as a novel environmental developmental agenda for overcoming the aforementioned limitations and boosting the performance of green lean ingenuities. 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 ostensibly shared attributes of the concepts. Delving into the effectiveness of such an integration, which was demonstrated by many scholarships (reviewed in Chapter 2), more cutting-edge studies on the topic are required, particularly empirical investigations that offer systematic guidelines for the application of GLSS in a variety of areas. The concept, however, has yet to be precisely defined, requiring systematizing 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 the GLSS implementation. Thus, this study aims to enrich the current body of knowledge and propel the implementation of GLSS via addressing the research questions formulated.

1.4 Research Questions

The questions of the research are:

(a) How has research on Green Lean Six Sigma (GLSS) evolved in recent years?

(b) What are the key enablers facilitating the GLSS implementation in Malaysian manufacturing sector?

(c) How should key enablers of GLSS be structured towards the implementation?

1.5 Research Objectives

The objectives of the research are:

(a) To analyze key enablers facilitating the GLSS implementation in Malaysian manufacturing sector using the FA method.

(b) To propose a structural model of identified enablers towards the implementation of GLSS using the ISM-MICMAC application.

1.6 Research Scope

The study falls into the scope of the Malaysian manufacturing industries, as shown in Figure 1.1, investigating key enablers facilitating the GLSS implementation in this sector to reach a more sustainable-based state. Thus, the scope of this research entails: (1) theoretical domains including Green, Lean, and Six Sigma, (2) the Scopus database since it compiles the largest reliable data of the leading literature, (3) methodological domains including Factor Analysis (FA), Interpretive Structural Modeling (ISM) and MICMAC application, which are recognized as the multi-criteria-decision-making techniques and are capable of developing structural models, and (4) the engagement of qualified experts who are registered as P.Eng. or C.Eng.

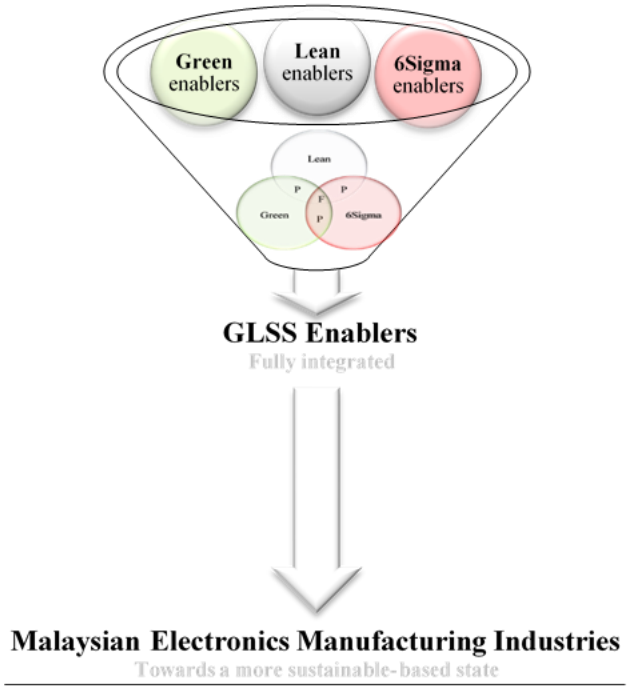

Figure 1.1 Scope of the study

1.7 Research Significance

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. (2019) 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 (Mani et al., 2014). 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 (GTMPM, 2017). These green issues and other environmental compliance and societal regulations issues as emphasized under the "Malaysian Environmental Quality Act" (Aja et al., 2016) signal the critical requirement for strategic approaches for assessing and developing environmental sustainability in the manufacturing sector, as illustrated in Figure 1.2, where a need to adopting Green Initiatives to reach the aspirational target, which is up to 50% by 2030, has been highlighted in Malaysian Green Technology Master Plan (GTMPM, 2017).

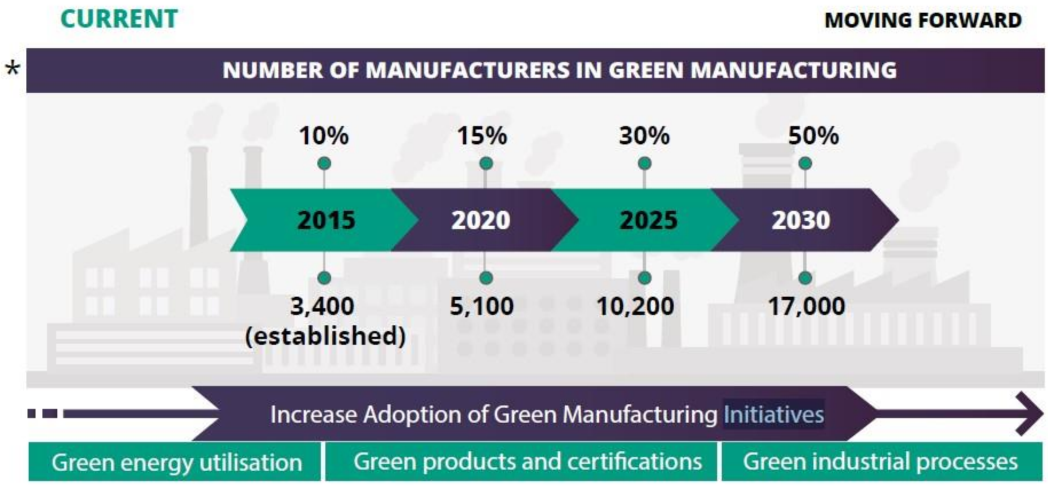

Figure 1.2 Aspirational target for the manufacturing sector in Malaysia (GTMPM, 2017)

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 environmental-related issues. A more effective solution is via a unified approach that minimizes waste and variability as well as mitigates adverse environmental impacts (Kaswan and Rathi, 2020a). The integration of Green production, Lean manufacturing, 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 (Gholami et al., 2021).

The green concerns and other environmental compliance and societal regulation issues, as underlined by the Malaysian Environmental Quality Act, 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 (Figure 1.2), there is a need to adopt green initiatives to meet the aspirational goal of up to 50% by 2030. Yet, with the new industrial technology invasion and shockwaves caused across global markets and emerging green trends, Malaysian industries are projected to enter a challenging phase to achieve. This study enriches the current body of knowledge and propels the implementation of GLSS via the analysis and modeling of its enablers specifically in the context of the Malaysian manufacturing sector. The main expected outcome of this project is a structural model that allows evaluating the mutual impacts of key enablers and also their explicit interactions made. It will offer a comprehensive view of key enablers to the successful implementation of GLSS. The effective adoption of GLSS in companies may help reduce negative environmental effects and, ultimately, to lessen the environmental footprint of manufacturers since 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.

1.8 Structure of the Thesis

To meet the research objectives, this thesis is organized as follows: Chapter 2 provides insights into the theoretical domains, systematically reviewing the literature to move towards furthering the research purpose. Chapter 3 presents the research methodology to clarify the procedures and methods utilized. Chapter 4 discusses theoretical results contributed by a systematic review as well as empirical findings contributed by the analyses in the understudied scope. Finally, Chapter 5 covers the conclusions as well as future directions for the research.

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LIST OF PUBLICATIONS

1. Letchumanan, L.T., Yusof, N.M., Gholami, H., & Ngadiman, N.H.A.B. (2021). Green Lean Six Sigma: A Review. *Journal of Advanced Research in Technology and Innovation Management*, *1*(1), 33-40.

2. Letchumanan, L.T., Gholami, H., Yusof, N.M., Ngadiman, N.H.A.B., Salameh, A. A., Štreimikienė, D., & Cavallaro, F. (2022). Analyzing the Factors Enabling Green Lean Six Sigma Implementation in the Industry 4.0 Era. *Sustainability*, *14*(6), 3450.

List of Conference Presentations

1. The conference "INTERNATIONAL PROFESSIONAL DOCTORATE & POSTGRADUATE SYMPOSIUM 2021 (iPDOCs'21)".