CRITICAL SUCCESS FACTOR OF LEAN SIX SIGMA DEPLOYMENT IN A SEMICONDUCTOR MANUFACTURING FIRM: A CASE STUDY

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DOCTOR OF BUSINESS ADMINISTRATION
UNIVERSITI UTARA MALAYSIA
Aug 2021

Critical Success Factors of Lean Six Sigma Deployment in a Semiconductor Manufacturing Firm: A Case Study

By

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Thesis Submitted to Othman Yeop Abdullah Graduate School of Business, Universiti Utara Malaysia, in Partial Fulfillment of the Requirement for the Doctor of Business Administration

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ABSTRACT

The research is to study what is the Critical Success Factor (CSF) that makes a Multinational Company (MNC) in Malaysia successfully deploys Lean Six Sigma 4.0 (LSS 4.0) for its business excellence. The study examines the three major categories and their CSFs to assess what are the most important factors that succeed in the deployment. The CSFs are grouped into three major categories and apply the Fuzzy Analytic hierarchy process (AHP) to analyze the collected data from 30 internal practitioners and consultants. This research revealed that the management initiative category is important in the LSS deployment, followed by involvement and engagement, which involves various parties in the transformation process. In contrast, technology and knowledge are the least critical category. The important CSFs are customer focus, communication, and understanding of the tools and techniques. This research further explores the adoption of IR4.0 in the LSS framework, which is named LSS 4.0, though the result shows it is the least important factor. The study disclosed that CSF prioritization varies by job function; it might depend on the subject's job requirements and working environment. This research guides managers in semiconductor industries on continuous improvement deployment and transformation by integrating LSS and IR4.0 to plan and design the framework with the important CSFs. It shares the deployment strategy of respective important CSFs in the company as a reference and proposed a guideline for the execution of different CSFs.

Keyword: lean six sigma, industry revolution 4.0, fuzzy ahp, critical success factor

ABSTRAK

Penyelidikan ini adalah untuk mengkaji apakah Faktor Kejayaan Kritikal (CSF) yang menjadikan Syarikat Multinasional (MNC) di Malaysia berjaya menggunakan Lean Six Sigma 4.0 (LSS 4.0) untuk kecemerlangan perniagaannya. Kajian ini mengkaji tiga kategori utama dan CSF mereka untuk menilai apakah faktor terpenting yang berjaya dalam penggunaan. CSF dikategorikan kepada tiga kategori utama dan menggunakan proses hierarki Fuzzy Analytic (AHP) untuk menganalisis data yang dikumpul daripada 30 pengamal dan perunding dalaman. Kajian ini mendedahkan bahawa kategori inisiatif pengurusan adalah penting dalam penggunaan LSS, diikuti dengan penglibatan dan penyertaan, yang melibatkan pelbagai pihak dalam proses transformasi. Sebaliknya, teknologi dan pengetahuan adalah kategori paling tidak kritikal. Hasilnya menunjukkan bahawa CSF yang penting ialah tumpuan pelanggan, komunikasi dan pemahaman alat dan teknik. Penyelidikan ini turut meneroka penggunaan IR4.0 dalam rangka kerja LSS, yang dinamakan LSS 4.0, namun dapatan menunjukkan ia adalah faktor paling tidak penting. Kajian itu mendedahkan bahawa keutamaan CSF berbeza mengikut fungsi pekerjaan; ia mungkin bergantung pada keperluan pekerjaan subjek dan persekitaran pekerjaan. Penyelidikan ini membimbing pengurus dalam industri semikonduktor mengenai penggunaan dan transformasi penambahbaikan berterusan dengan menyepadukan LSS dan IR4.0 untuk merancang dan mereka bentuk rangka kerja dengan CSF yang penting. Ia berkongsi strategi penggunaan CSF tertentu yang penting dalam syarikat sebagai rujukan dan mencadangkan garis panduan untuk pelaksanaan CSF yang berbeza.

Kata kunci: lean six sigma, revolusi industri 4.0, fuzzy ahp, faktor kejayaan kritikal

ACKNOWLEDGEMENT

Foremost, I would like to express my sincere gratitude to my supervisor Dr. Gunalan Nadarajah for the continuous support of my doctorate study and research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my doctorate study.

I am extending my thanks to management and administration of Othman Yeop Abdullah Graduate School of Business (OYA), Universiti Utara Malaysi (UUM), Sintok, and their staff to do this work and genuine support to complete this dissertation successfully.

I am extremely grateful to my mother for her love, prayers, caring and sacrifices for educating and preparing me for my future. I am very much thankful to my wife and my sons for their love, understanding, prayers and continuing support to complete this research work.

I am are over helmed in all humbleness and gratefulness to acknowledge my depth to all those who have helped me to put these ideas and helped me a lot in gathering different information, and guiding me from time to time in making this project , despite of their busy schedules ,they gave me different ideas in making this project unique.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AM	Autonomous Maintenance
APIC	Annual Productivity & Innovation Conference and Exposition
CCM	Crisp pairwise comparison matrix
CI	Consistency Index
CR	Consistency Ratio
CSF	Critical Success Factor
DRAM	Dynamic Random Access Memory
FCM	Fuzzy pairwise Comparison Matrix
HDD	Hard Disk Drive
IT	Information Technology
IIoT	Industry Internet of Things
IMS	Integrated Mananagemet System
IR 4.0	Industry Revolution 4.0
KPI	Key Performance Index
LSS	Lean Six Sigma
MITI	Ministry of International Trade and Industry
MNC	Multinational Company
MPC	Malaysia Productivity Corporation
PM	Preventive Maintenance
RAM	Random Access Memory
RI	Random Consistency Index
RISTEx	Regional Showcase on Team Excellence
RPA	Robotic Process Automation
SSD	Solid State Drive
TFN	Triangular Fuzzy Number
TPM	Total Productive Management
TPS	Toyota Production System

TQM	Total Quality Management
QM	Quality Management
WEF	World Trade Forum

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION

This chapter presents the importance of Lean Six Sigma (LSS) deployment in a highly competitive market, especially when LSS integrated with Industrial Revolution 4.0 (IR 4.0) to form a new trend in the LSS deployment. Subsequently, the chapter covers the problem statements on two aspects, one from the LSS implementation framework in the company, which can be a reference in the semiconductor industry and follows by the academic element to fill up the research gaps and enrich the current research. The final portion of the chapter gives a basic introduction to the key industrial terminology used in the chapter.

1.2 BACKGROUND OF THE STUDY

Integrating Lean and Six Sigma is a ubiquitous management philosophy, especially in western countries. The combination of Lean and Six Sigma is very flexible to the companies involved in quality improvement, and it applies to various industries (Chakraborty et al., 2013). The integration, known as Lean Six Sigma (LSS), creates flexibility, attributed to the broader use of the tools in different business problems. Many companies deploy the LSS because it is a survival tool to improve productivity, waste reduction, and improved quality, strengthening competitive advantages (Chaurasia et. al., 2016). Thus, management is a great motivation to start a transformation program when the industry is in a very competitive environment, such as the semiconductor industry in the memory sector.

Nevertheless, deployment and sustaining in an organization are a challenge to succeed. LSS is a management strategy to reduce the constraints that prohibit value creation for the customer (Murmura,F., et. al., 2021). Therefore, the conceptual framework plays a crucial role in strategic planning (Sim, C.L., et. al., 2021) to ensure deployment success.

Snee., R.D. (2010) comments LSS applies the proven tools, proven via research, and its theory and methodology were an evolution from time to time. The latest development in the LSS is integrating with the IR4.0 elements. The popularity of Industry IR 4.0 elements in LSS is improving and gradually being combined with LSS activities. In the study by Rodgers et al. (2019), some of the respondents commented that the LSS should evolve and improve with the advancement in data science, Artificial Intelligence (AI), and Robotic Process Automation (RPA) technologies. Therefore, the technology and knowledge on IR4.0 have now become critical in LSS implementation.

Arcidiacono et al. (2018) claimed that the integration of LSS and IR4.0 is a critical research area being explored extensively. The IR4.0 elements become essential factors of the LSS implementation in a modern manufacturing facility. IR4.0 was introduced in 2011 in German as "Industrie 4.0," and its influence on design principles and technologies has been dominant and extensive as a technological phenomenon (Ghobakhloo, 2018). Cifone, F.D.C. et. al. (2022) also cites that integration with IR4.0 elements brings much more significant improvement, but the application seems like a traditional way.

Although different parties categorize the elements with different pillars, the autonomous robot, the Industrial Internet of Things (IIoT), and big data are the most common pillars of the IR4.0 pillars. Recently there have been few research studies conducted on the linkage or the influence of the pillars in LSS deployment (Laux et al. (2017), such as Arcidiacono et al. (2018), Gupta et al. (2019) and Ghobakhloo et al. (2019). As autonomous plays an essential role in production to reduce waste (Theuer H., et. a., 2013), it allows the LSS implementation to reach another milestone in conjunction with IR4.0 implementation. Yadav, N. et. al. (2020) study on LSS and QMS with integrated manufacturing improvement technologies like IIoT, IR4.0, and so forth shows synergy and ensures better results. The similar conclusion from Jayaram, A. (2016), the author cites the integration eliminates the wastes.

Bessant et al. (1999) defined continuous improvement as a process that required organization-wide focus to sustain incremental innovation, representing an essential element in such dynamic capability. A high proportion of the organization involved its creation and learning process. Therefore, the new evolution is expanding the current capabilities with the latest integrated continuous improvement methodology recommended by Arcidiacono et al. (2018). The author named the latest technological trend of LSS integration as Lean Six Sigma 4.0, LSS 4.0. As Snee., R.D. (2010) quoted, the development could be a new milestone for a new evolution in LSS. However, the framework with identified CSF for LSS4.0 is coming into the picture.

Sorokhaibam et al. (2018) commented that the ranking of the CSFs could facilitate the effort of embarking on the methodology. He has recommended studying and analyzing the degree to which the decision-makers, researchers, and practitioners could reduce or eliminate the identified barriers. Silva et al. (2018) support that the CSFs had been well-studied in identifying the CSFs, and its smart deployment can reduce the chances of failure during the implementation stage. Yadav et al. (2018) also support the statements from these two authors on studying the CSF ranking to facilitate the implementation of LSS.

The motive of the research is to examine the CSFs that lead to the success of the LSS 4.0. The integration with the IR 4.0 elements in the targeted company is the greater interest in the study to examine a new form of a framework. The survey would prioritize the CSF with the degree of importance by referring to the survey result from internal practitioners and internal/external experts. Flor Vallejo et al. (2020) cited a framework for developing a roadmap for LSS deployment, which is adaptable to any organization's conditions and cultures, with size and type variances. The author also cited that identifying and developing a CSF framework is vital for an organization to implement successfully. The CSF roadmap is used to create an effective and efficient deployment plan and implementation framework (Patel et al., 2018). From the academic perspective, Chen, C.K., et. al. (2021) found that the related framework and the enabler are the most focus areas. Thus, it is worth conducting the study to explore the framework that makes integration successful in the company.

The targeted company in the study fulfilled all the requirements needed to meet the research objectives. The company embarks the IR4.0 and integrates it with LSS to form the LSS4.0. The government agency recognized the company as “The Most Productive Organization” in 2020 and “The Lean Manufacturer” certification for 2021 to 2022. Besides, the company successfully earned and became one of the Lighthouse members from the World Trade Forum (WEF) with proven achievement in IR4.0 in 2021. LSS4.0 is one of the success stories in workforce transformation, which is under IIoT Academy to demonstrate the company‟s effort in adopting the IR4.0 in continuous improvement.

1.3 INTRODUCTION TO THE TARGETED COMPANY

This session provides detailed information on the selected company and the contributions of the memory business in the global semiconductor market. This information could explain the reason and the appropriateness of choosing the company in the study.

1.3.1 Company Background

The company used in this study is a multinational company with its headquarters in the United States and among the leading global NAND flash memory semiconductor manufacturers in Malaysia. However, considering the company's confidentiality and market branding, the company name is not disclosed. However, the alternative wordings "the company" or „the targeted company” are used to address the company in all related discussions. This company has set up a few overseas facilities for operational cost optimization and to remain competitive in the Asian market.

The company"s management had decided to embark on LSS to drive its cultural change. According to the company LSS expert, the company is linking to fudging cost by improving the overall equipment efficiency (OEE) with Total Productive Maintenance (TPM) as part of the LSS effort to improve productivity, quality, delivery, safety, and operator morale on the production floor (Kumar et al., 2014).

The management form transformational teams to execute the cultural change plan and embark on the LSS journey to be part of the plant-wide Key Performance Index (KPI) and reviewed every quarter. The company embraces IR4.0, the latest trend in the global industry. It integrated the components of LSS and IR4.0 and named it LSS 4.0.

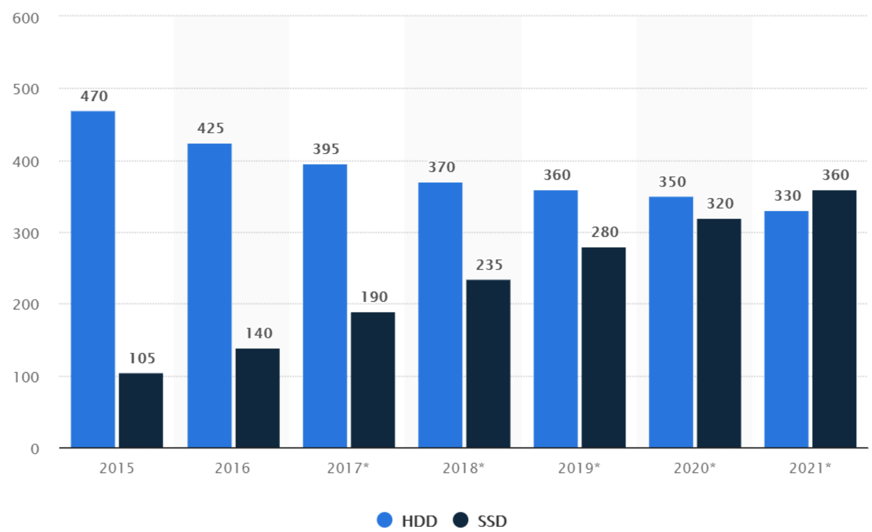
The company received numerous awards from Regional Showcase on Team Excellence (RISTEx) and Annual Productivity & Innovation Conference and Exposition (APIC) on continuous improvement projects and IR4.0 awards for successfully adopting the IR4.0 elements into the projects. The company also received recognition as "The Most Productive Organization" and "Lean Manufacturer" from Malaysia Productivity Corporation (MPC), one of the government agencies under the Ministry of International Trade and Industry (MITI). It is to recognize the company's success on the LSS4.0 implementation, resulting in a proven record of operational excellence. The company successfully earned an honor as one of the Global

Lighthouse Network in 2021. One of the efforts is embracing the LSS4.0 in the workforce transformation. The concept of LSS4.0 is the first time introduced in one of the Lighthouse pillars at IIoT Academy pillar. It is a key pillar to show the company's effort in adopting the IR4.0 in workforce transformation. It is the key reason of choosing the company as the targeted subject in the research.

1.3.2 Introduction to the Memory market

In 2015, the customer shipment for SSD was 105 million units, which is four times lower than HDD shipments, with 470 million units shipped to customers. However, this trend is increasing and will overtake the HDD in 2020. In this respect, part of the semiconductor sector, the NAND manufacturing process, plays a critical role in the market"s economy. The world's leading market research and advisory company, Garner Incorporation, mentioned that the memory devices revenue occupies 34.8 percent of the total semiconductor revenue of USD 476.7 billion in 2018, which is the largest semiconductor category in the semiconductor sector. On the other hand, NAND manufacturing is a critical industry in the semiconductor industry, whereby 3D NAND manufacturing is distinct from the normal wafer fabrication process compared to other semiconductor sectors.

Figure 1.1: Shipment of HDD and SDD in a million unites

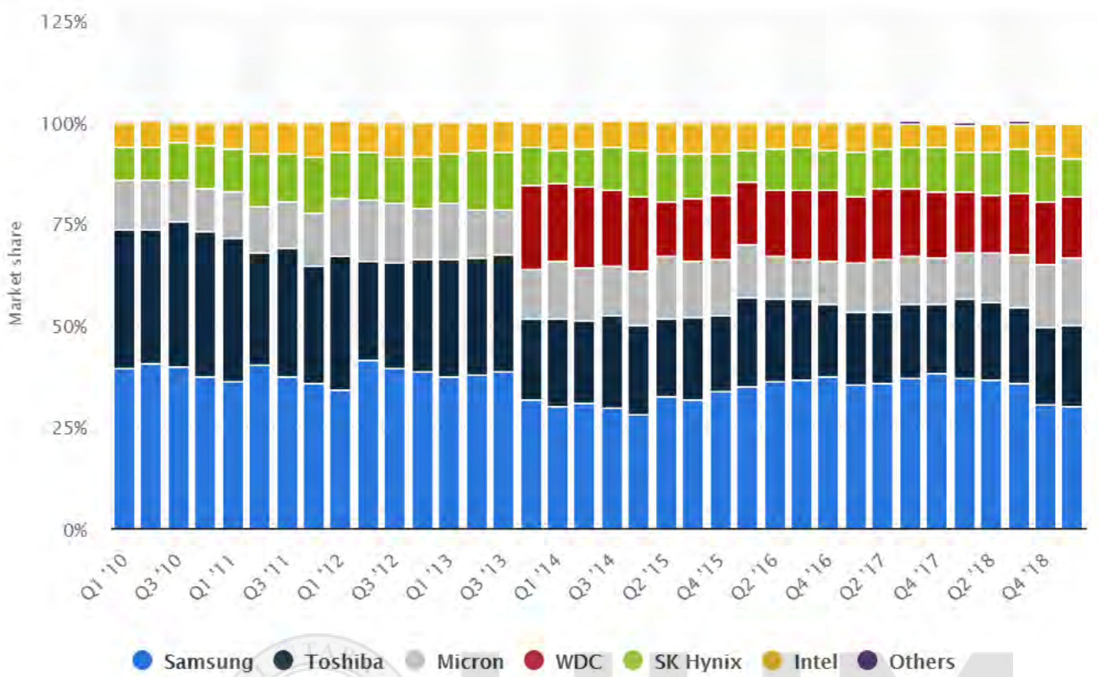


Source: Statista, https://www.statista.com/statistics/285474/hdds-and-ssds-in-pcs-global-shipments-2012-2017/, downloaded on 12 August 2019

As shown in Figure 1.1, the technology shift starts from magnetism to silicon-based manufacturing. SSD and HDD are substituting in different storage devices, with both their advantages and disadvantages. However, the typical application is a bit different. HDD has the most significant advantage as it has a lower price per gigabyte than SSD, which has better energy-saving, is smaller in size, and performs at higher transaction speed.

SSD is gradually replacing HDD in mobile devices applications, considering its price is close to the HDD price, or the price gap is reducing to an acceptable level. Currently, both SSD and HDD are integrated to provide a more cost-efficient and minimized data latency memory solution, such as cloud based applications.

Figure 1.2: Key NAND producers market



Source: Statista, https://www.statista.com/statistics/275886/market-share-held-by-leading-nand-flash-memory-manufacturers-worldwide/, downloaded on 12 August 2019.

There are a few key players in the NAND flash industry, as shown in Figure 1.2. Samsung is leading the market, followed by Toshiba, Western Digital, Micron, SK Hynix, and Intel. The NAND flash manufacturers compete on the cutting edge 3D technology to reduce prices, gain the market niche from other NAND flash manufacturers and grasp the market share from HDD.

1.4 PROBLEM STATEMENT

The study examines the priority of the success factors that lead the company to gain recognition in the LSS implementation, especially integrating with the IR4.0 elements. It is crucial to the LSS4.0 deployment framework formation in a semiconductor and fills up the academic research and execution gaps that lead to success. The study examines main categories and their sub-groups or the CSF in the success of the deployment. Finally, rank the CSF according to its importance in the success of the deployment.

Alblooshi et al. (2020) commented it is important to explore the roadmap and framework involved in preparing and implementing LSS. The study will assist the organization‟s management meet the different requirements and overcoming implementation challenges. Silva et al. (2018) commented that LSS deployment guidelines are vague in different situations, where most companies use the LSS as a tool rather than a technique. Therefore, from a practical perspective, it is necessary to understand the framework facilitating the LSS4.0 deployment in the company.

Besides, the study also examine the importance of the IR4.0 in the LSS framework, which one of the subgroup in the third major group. Anthony et al. (2018) point out there is lacking exploitation of IR4.0 with Six Sigma (Antony et al., 2019). Gaikwad et al. (2020) also suggested using the IR4.0 technologies in LSS deployment. It could be an essential enabler in the LSS implementation (Panayiotou et al., 2020). These auditors comment IR4.0 is potentially a new vital success factor in LSS deployment. Therefore, it is good to explore the importance of the

IR4.0 infrastructure in the success of the deployment. Thus, the authors claim that the study in this field is still lacking even though few pieces of research are being conducted (Fogarty, 2015 & Anthony et al., 2020).

While from the academic perspective, as commented by Yadav et al. (2015), the author pointed out most of the papers are theoretical and application-oriented, where they were written by academicians (Raval et. al., 2018, & Ravi et. al., 2014) instead of practitioner and consultant in the framework study (Raval et. al., 2017). Based on Vijaya et al. (2018), researchers and practitioners of LSS have a deeper understanding of LSS practices within an organization, while Shokri (2017) suggested that collaboration of a broader perspective in LSS is needed between the academia and the enterprise.

Another aspect from the academic perspective is more related to the coverage of the past research in the scope of different sectors or industries. As Shokri (2017) commented, there is still a significant disparity in research related to continuous improvement practices as most of the studies are limited to a few industries only. The author pointed out a few common sectors in this research area, including general manufacturing, healthcare, automotive and electronic industries. Prakash, S. et. al. (2021) also concludes an almost similar result with Shokri (2017) that general manufacturing and automotive are the highest focus area, but it follows with electronics part manufacturing. Sreedharan et al. (2016) also gave a close result, and the author found most manufacturing LSS research is done in the automotive and non-electronic manufacturing segment. Mahipal et. al. (2019) show that most LSS researchers are working on the nonmanufacturing sector, resulting in the manufacturing environment lag, which contradicts Prakash, S. et. al. (2021) result; the author concludes most of the LSS study happens on manufacturing.

Nevertheless, Endrigo et. al. (2020) suggest that future studies should extend to other areas and focus on various sectors. In a study, Walter et al. (2019) also support it; he commented it is essential to conduct research on LSS integration in different segments and sectors and analyze the results of a particular company that replicated in the same way but with different characteristics. The author also suggests that LSS implementation parameters could differ from other industrial sectors (Muganyi et al., 2019 & Scheller et al., 2018 & Sreedharan et al., 2016). The differences might be attributed to the different perceptions of the factors in various sectors and scales of the industries (Desai et al., 2012).

Another scope or coverage in the research is the location, as Raval et al. (2018) found that most LSS researches happen in developed countries, such as America and United Kingdom, compared to developing and underdeveloped countries (Sordan et al., 2020; Raval et. al., 2018). Silva et. al., 2018 cite even several research papers are being published, such as Jayaraman et al. (2012) and Habidin (2013). However, in the study of the Prakash, S. et. al. (2021), the recent publication is increasing in developing countries including Malaysia, one of the Malaysia universities is even given a more outstanding contribution in LSS study. Nevertheless, it is essential to have the same research conducted in different countries to identify the differences, especially in Malaysia's manufacturing industry, as suggested by Jesus et al. (2016). Moya et al. (2019) cited that each country has its own business culture that acts as a critical factor in influencing a company in its management and organization. Therefore, more studies conducted in the Malaysian context will provide more information to academic researchers and managers on the practical adoption of LSS in the country. Gandhi et. al. (2017) cited that prioritization could differ from nation to nation because every country has a different approach and working culture. His comment is also supported by Mehralian et al. (2016); the author pointed out the differences are attributed to the distinct operation environment.

Last but not least, from the research methodology perspective, the study used the Fuzzy AHP. Raval et al. (2018) cited that most CSF studies use traditional data analysis techniques. The author commented that there are very few fuzzy set theory and mathematical modeling uses. The author encourages future research should focus on CSFs and mathematical modeling methods usages. The claim is also supported by Prakash, S. et. al. (2021); the author points out most of the analysis approaches are using descriptive statistics, such as frequency distribution. Therefore, Gurwinder et. al. (2020) proposed a future study to apply Fuzzy AHP to rank CSFs and identify the most important CSFs and implementation models developed for the manufacturing industries.

1.5 RESEARCH QUESTIONS

This research refers to the study conducted by Sreedharan et al. (2018) on the CSFs in the LSS implementation, which serves as the guideline. The author studied the various CSFs for TQM, Lean, Six Sigma, and LSS and listed ten common factors. Sreedharan had published 15 journals on LSS, out of which 154 are of global citation. Hence, the author is very famous for LSS research. However, the study accommodates the IR4.0 element and does minor modifications to meet the research objective.

The ten common factors are further filtered by reviewing the latest journals and input from the experts in this field. As the outcome, only nine factors will be focused on in this study to rank the essential CSFs in a memory-based semiconductor manufacturing facility. The research questions will go with three levels.

In this study, three research questions are proposed based on the nine factors, as the following:-

Question 1:

Does the management initiative and its elements play a critical role in successfully implementing LSS in a semiconductor manufacturing facility in Malaysia?

Question 2:

Does the Involvement and engagement of different parties, such as employees, suppliers, and customers, play a critical role in successfully implementing LSS in a semiconductor manufacturing facility in Malaysia?

Question 3:

Does the IR4.0 technology, training, and understanding of the LSS tools critical in successfully implementing LSS in a semiconductor manufacturing facility in Malaysia?

1.6 RESEARCH OBJECTIVES

The study's primary objective is to prioritize the CSFs, which may be the crucial determinant of LSS4.0 deployment's success in the company. The study has a similar purpose to Garg et. al. (2012) in prioritizing the critical success factor. The author uses a fuzzy hierarchical structure to examine the CSF.

The final research will conclude the key CSF in the LSS4.0 framework when all these three objectives have been fulfilled, including examining the importance of the IR4.0 in the deployment framework.

Objective 1:

To examine the Management Initiative and its component that influences the success of LSS implementation in semiconductor manufacturing.

Objective 2:

To examine the Involvement and engagement of different parties such as employee, supplier, and customer influences the success of LSS implementation in semiconductor manufacturing.

Objective 3:

To examine the IR4.0 elements, relevant training, and understanding of LSS 4.0 tools influences the success of LSS implementation in semiconductor manufacturing.

1.7 SIGNIFICANCE OF THE STUDY

Some studies in semiconductors under the Malaysia context, such as Ng, K.C. et. al. (2014) on OEE improvement and Ahmad, R., et. al. (2019) on the Bill of Material improvement with DMAIC methodology. These studies focus on the tools and techniques application; Ben et al. (2018) and Yadav et al. (2017) study on LSS adoption techniques, which is critical to ensure the success of the deployment. The authors cite that identifying and prioritizing the critical factors affecting LSS adoption is vital. The study focuses on the LSS framework to generalize a guideline for the Malaysia Semiconductor industry. It is incredibly essential to identify the depth of influence of each CSF in LSS deployment (Lande et al., 2015). The CSFs are crucial in the LSS structure because the manager needs to integrate the elements into the whole framework (Brotherto, 1996; Jesus et al.,2016 & Netland, 2016). Many companies are often confronted with failure when applying for a respective improvement program. Many factors determine success; therefore, it is essential to identify the critical factors in the organization (Yazdi, A.K., et. al., 2021). The result could help the practitioners from the semiconductor sector because the approach contents vary based on companies, consultants, and authors, with some commonalities (Klefsjö et al., 2001). Karunakaran et al. (2016) commented that it is necessary to have a series of activities to transform the organization into an LSS framework or LSS architecture.

As suggested by Anthony et al. (2020) and Arcidiacono et al. (2018), the integration of LSS with IR4.0 is a new trend. While Malaysia aspires to uplift the bottom household income in the shared prosperity vision 2030, IR4.0 is one of the focused areas (Darmalinggam D., et. al. 2021). Therefore study will contribute to the semiconductor under Malaysia context on the LSS4.0

framework, which carries additional weight with taking the latest IR4.0 development in the study. The study will provide the guidelines to integrate the LSS with IR4.0 for a more productive organization and meeting the Malaysia vision. The framework is valuable guidance to the manager to have more effective resource allocation because of the limited resources (Hopland, 2018 & Pathiratne et al., 2018). It is a valuable guideline or information to any other firm if it intends to explore the LSS4.0 as the organization's TQM framework or apply LSS4.0 as part of the digitalization workforce transformation in their organization.

This study targeted the practitioners, the pioneer in starting a new TQM deployment in a semiconductor manufacturer. From an academic perspective, the study is enriching the research in the field and filling up the gap in the practitioner‟s perspectives who has a direct interest in the success of the deployment (Raval et al., 2018, Yadav et al., 2015, Yadav et al., 2018 and Ravi et al., 2014). The final result gives a thought comparison between the academic and practitioner on the LSS deployment framework.

Last but not least, the paper applies the Fuzzy AHP in the data analysis. However, the methodology is not new in the CSF ranking research. Many types of research use the method in the CSF ranking and prioritization. Therefore, the study provides an additional reference to other upcoming research to explore the analytic approach, especially the study exploring the clustering on the priority vector for grouping study. It offers more information on the result interpretation.

1.8 DEFINITION OF INDUSTRIAL TERMINOLOGY

This section provides information on some key terms commonly used in the industry, such as the Lighthouse Network Community. It also gives a short explanation of the memory product in semiconductor. It helps the reader better understand the memory technology to avoid confusion due to the different types of the product, especially the semiconductor and non-semiconductor memory products.

1.8.1 **Global Lighthouse Network**

World Trade Forum"s Global Lighthouse Network is a community of manufacturers leading in the respective industry by deploying the IR4.0 technologies to transform the factories to be more productive and benefit the company with financial gains. There are 90 members in the networks as listed on the website on 14 Nov 2021. Its official website is https://www.weforum.org/projects/global_lighthouse_network. The application has to go through an audit and provide all shreds of evidence to prove the company is creating a good environment of workforce transformation. The company has to have innovative and creative projects that are not duplicating with other companies in the community. It is an excellent reference to others in the industry.

1.8.2 Memory Products

There are two types of memory devices resulting from different recording media: magnetic disk and silicon-based wafer. For both recording media, physical hardware is storing the digital data in binary codes such as Random Access Memory (RAM), Hard Disk Drive (HDD), Solid State Drive (SSD), and Dynamic Random Access Memory (DRAM). SSD is the long-term memory storage device in the semiconductor sector, while DRAM is a temporary storage device. DRAM is a fast-speed component used as temporary storage to support processors on logical computing. The memory content is not lasting after switching off the power supply. All types of processors need DRAM to support the operation; thus, all processor"s devices must have DRAM installed.

Reversely, long-term storage would keep the memory even with no power supply. The applications like personal computers and cloud storage, HDD, and SSD are widely used.

SSD, a silicon-based memory device, is commonly used in mobile devices such as smartphones and notebooks because of its small size and low energy consumption. It does not generate significant heat and lower the chances of mechanical damage due to shock or vibration. It is non-volatile logical gate storage made from the wafer with the current technology known as NAND flash memory.

Unlike SSD and DRAM, HDD is not a semiconductor product, but a magnetic disk-based uses a magnetic field to read and write the memory on a disk. The sputtering process deposits a layer of magnetic material on the aluminum disk instead of a silicon wafer. The sputtering method is an atomic disposition technique to arrange the atoms on a substrate with a very tiny layer in nanometer thick. Most large storage devices use HDD because of the lowest cost per Gigabytes, such as servers and cloud storage.

1.9 ORGANIZATION OF THE DISSERTATION

This paper consists of five chapters. Chapter 1 highlights the background of the study and the motive. It explains why the company embraces the LSS and adopts IR4.0 to create competitive advantages. The paper studied the critical success factors with the research problem statement and questions and derived the research objectives. This topic also narrated the significance of the research from the industry implication and academic perspective .

Chapter 2 reviewed the relevant research on the LSS CSF in the literature review, including the Fuzzy AHP application, Lean, Six Sigma, integration of Lean Six Sigma, and in-depth review on the respective critical factors. Last but not least, intensively look at the underpinning theory, which is relevant and applicable in the study.

Chapter 3 gives detailed information on the research methodology. It comprised of the research framework, hypotheses development, and research design. This chapter also covers the sampling plan and the target respondents. As the study applied the Fuzzy AHP; thus, the chapter gives the step of the mathematical calculation, which included the method of data validation and assessment for fit-to-use.

Chapter 4 calculated the collected data and converted the raw data into helpful information for ranking prioritization. Used the clustering approach to group the functional groups into clusters to assess the statistical similarity to study the differences of choice from different functional groups. Finally, the calculated priority vector prioritizes the CSF's overall ranking.

Chapter 5 summarized the finding versus the research objectives and further discussed the result by referring to each functional group's role in the company. This chapter outlines the research implication and its limitation and suggests the future potential research direction to enrich and supplement the study in this area.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the relevant published research papers to gather related information, linking with the studied topic from an academic perspective. It helps to understand and connect the past research‟s results with the study and generalize it with past studies. This chapter provides an intensive review on the development of Lean, Six Sigma, Lean Six Sigma, and AHP. It also covers the related CSF and the underlying theories that can explain the phenomenon of the study‟s result.

2.2 LEAN MANUFACTURING

Organizations look for different procedures and practices to improve organizational performance and bolster market equity. Previously, the world attempted to consolidate all the continuous quality improvement tools under a system known as Total Quality Management (TQM). Several tactics, morals, methods, and tools were developed to support the TQM. Lean is part of the methodologies, and it provides valuable tools in eliminating wastes in continuous improvement (Ravindaran et al., 2016).

Lean is part of the company's culture, and it is a higher-level meta-improvement method (Gupta et. al., 2016). Thus, the implementation is most likely to succeed if its culture aligns with the lean principles (Marodin et al., 2017). The lean concept originated from the Toyota Production System (TPS), populated by Womack et al. (1990). Birkinshaw et al. (2008) take TPS as an example of management innovation. It describes a novel change in an organization, or the change is an unprecedented departure from the past. It offers excellent potential competitive advantages over others but depends on the extent of the change, which is valuable, rare, and difficult to imitate. The author identified TPS as a new set of practices and processes to improve efficiency and reduce waste. There are seven wastes in the lean concepts, and Lean practitioners eliminate the wastes to reduce the cost in the organization (Naslund et al., 2008). The wastes are transportation, inventory, motion, waiting, overproduction, overprocessing, and defect; in abbreviation, it is TIMWOOD (Marodin et al., 2017).

However, John Krafcik is the first to use the term "Lean" to address the new production technique and system introduced by Taiichi Ohno at Toyota after World War II. He participated in the MIT International Motor Vehicle Program in his research on developments in the automobile industry. The program is led by Daniel Roos, James Womack, and Daniel Jones. Based on Bendell (2006), Womack authored "The Machine That Changed the World." The book has shared the techniques and concepts pioneered by Toyota and extends their Lean Thinking ideas to the readers. It is a philosophy to eliminate all non-value activities (Upadhye et al., 2010) to drive customer values, including the five basic principles of understanding customer value, value stream analysis, flow, pull, and perfection (Andersson et al., 2006).

Today lean apply to a full range of different manufacturing industries, which extended from the automotive sector (Ghosh, 2013) and bound to manufacturing culture to optimize the processes (Chiarini et al., 2016), productivity improvement (Panwar et al., 2017), quality and cost reduction through continuous improvement activities (Anand et al., 2009). Lean helps to minimize the variability in lead times, unpleasant events, and negative effects in the operating environment, which customers prefer (Mokadem, 2017).

2.3 SIX SIGMA

Majstorovic et al. (2015) cited that the Six Sigma methodology could be the best representative in an integrated management system (IMS) because six Sigma is a data-oriented methodology to reduce variation and eliminate errors or quality improvement (Shokri, 2017 & Thawani, 2004). Black et. al. (2006) mentioned that Six Sigma had repackaged some of the critical TQM principles into its deployment approach, adding its distinct concepts and methodologies, a robust expansion of TQM. Six Sigma refocuses on statistical analysis to expand the original TQM tools and gauge the quality improvement with a metric. As illustrated in Ismyrlis et al. (2013), the application of Six Sigma is a collection of tools, where most of the tools are being used in other management techniques to handle quality-related problems for fostering performance improvement by qualified employees.

Six Sigma was initiated and introduced by Motorola in 1982, where its CEO had set a target to cut the quality cost by half in 1982. Subsequently, Six Sigma had successfully spread among the giant American companies such as Texas Instruments, Allied Signal, Eastman Kodak, Borg-warner Automotive, and others (Henderson, K.M. et. al., 2000). It received further recognition under General Electric (Pepper et al., 2010). Six Sigma effectively reduces defects and improves customer satisfaction because of good perception of quality performance and increased financial benefits, as propounded by Habidin et. al. (2012). The integrated management system focuses on measurable and quantitative results from a customer perspective for a zero-defect paradigm. Therefore, the companies that embarked on Six Sigma are the most traditional in quality improvement, as they had previously embarked on other quality systems such as ISO and TQM (Ozkan et al., 2017).

In Six Sigma, the Sigma refers to the standard deviation with the symbol of "σ." Thus Six Sigma means the defect rate should be 3.4 parts per million or lesser (Fogarty, 2015 & Ingle et. al., 2001). Six Sigma focuses on the defect. Whenever the product or service does not meet the customer‟s expectations, it would be considered a defect (Fogarty, 2015). The need to continuously improve the processing system arises (Ahmed et al., 2019).

Nonthaleerak et. al. (2008) cites that Six Sigma is suitable for high-risk, complicated, large-scale, and cross-functional projects. It has been applied in the service sector to improve quality and customer satisfaction by reducing errors through better processing (Islam, 2016; Chakraborty et al., 2012), yielded a financial return on the investment (Pinto et al., 2008) and improvement in organizational performance (Ingle et al., 2001).

2.4 INTEGRATION OF LEAN SIX SIGMA

According to Arnheiter et al. (2005), implementing only one methodology is insufficient. It becomes a stalemate (Muraliraj et al., 2018), while LSS is an evolution (Shokri, 2017), one of the most influential business transformation initiatives. General Electric and Allied Signal take the initiative on integrating Lean and Six Sigma to create synergy effects in continuous improvement (Henderson, K.M., et al., 2000). It is a useful leadership development tool because it provides the concepts, methods, and tools for process changes. Finally, it advances a cadre of great leaders to shift from one way of working to another (Snee, 2010). Andersson et al. (2014) and Marriott et al. (2013) concluded that the joint-use strategy of Lean Six Sigma improves the flexibility, robustness, cost-efficiency, and agility in an improvement project. As a result, it is improving the company‟s competition (Hilton, 2012 & Abu Bakar et al., 2015) by enhancing customer satisfaction (Lande et al., 2016 & Vijaya, 2016), quality, and productivity (Carvalho et al., 2014; Albiwi et al., 2017). LSS also induces cultural change (Hess et al., 2015), instills process thinking, and cultivates quality excellence as part of the organizational culture (Vijaya, 2016).

Besides, Alblooshi et al. (2020) conclude LSS impacts the individuals in an organization and results in better utilization of staff, high levels of employee empowerment, morale, engagement, motivation, building trust, and job satisfaction. The impacts are positively related to the organizational innovation climate.

According to Antony (2011), Lean and Six Sigma possess similarities and differences. Six Sigma methodology is a structured approach and well-disciplined. It enhances process performance (Salah et al., 2010); while lean focuses on people enablement and the flow of products or services in the whole value stream (Arnheiter et al., 2005). Anthony (2011) concludes that Lean emphasizes speed and waste, while Six Sigma focuses on variation, defects, and process evaluation. Six Sigma is used to fix a complex problem with an unknown solution (Antony et al., 2011); it provides a scientific and quantitative approach to quality (Pacheco et al., 2015). Lean implementation has some weaknesses in its tools, and Six Sigma tools supplement these weaknesses (Pepper et al., 2010). As mentioned in Mahipal et al. (2019), Lean takes care of the material flow and the information transaction between the process steps, while Six Sigma adds values within the process steps. At the same time, Gowen III et al. (2012) mentioned that Six Sigma has managed to eliminate error sources significantly, with waste elimination being the primary function of Lean.

Nevertheless, Chandima et al. (2017) proposed that lean use comes first to clear the waste, followed by Six Sigma tools to reduce the process variation. The same opinion has come from Hilton (2012). The author suggests applying Six Sigma tools after the lean approach with data-driven analysis to deliver precision and accuracy.

Habidin et al. (2012) found that the integration of Lean and Six Sigma became a popular and prevalent combination in improving the company performance (Gutierrez et al., 2016; Hess et al., 2015; Albiwi et al., 2017). Although most LSS research focuses on the manufacturing sector

(Gunjan et al., 2015), the adoption embeds into the organization's way of doing things (Laureani et al., 2017). However, today, it is applying to other industries such as automotive (Swarnakar et al., 2016), education industry (Isa et al., 2015) and medical industry (Sim, C.L., et. al., 2021)..

2.5 FUZZY AHP

The fuzzy set theory to deal with human thought's vagueness was first introduced by Zadeh (1965), whereas AHP was proposed by Saaty (1980). The purpose of deploying the fuzzy AHP is to enable the researchers to deal with vague problems and resolve the bias from human judgment. The method resolves the bias by converting the linguistic terms into fuzzy numbers to reduce the uncertainties from linguistic assessment to achieve a more reliable framework (Hosny et al., 2013). The application of Fuzzy logic is easy to understand; it reduces the complex computation and eliminates the vagueness of human judgment (Sreedharan et al., 2019). Various researchers used Fuzzy AHP in different disciplines to determine the relative importance based on the list of evaluation criteria (Sari, 2013).

Many researchers have deployed the methodology in various fields that prioritize the success factors, such as Amrita et al. (2018) on women entrepreneurial activities in India and Lee et al. (2013) applied the Fuzzy AHP to identify the key factors that influence the sociability. Patil et al. (2014) has also involved a similar methodology in prioritizing knowledge management adoption barriers in the supply chain instead of using a simple method like Pareto (Lande et al., 2016).

Pareto analysis is commonly used in enterprise resources planning, food safety assurance system, and total quality management to prioritize the occurrence frequency in an empirical study (Ab Talib, et. al., 2015). The Pareto analysis uses frequency to evaluate which area causes the most problems and gives priority as a direction (Fotopoulous, C. et. al., 2011). Fotopoulous, C. et. al., (2011) pointed out Pareto has few deficiencies, such as merely depending on frequency. Thus, it estimates the true frequency for a problem occurring in a more extended period. The author also pointed out that another deficiency is the method to suppress the other low-frequency problems, as it follows the 80-20 rules introduced by Italian economist Vilfredo Pareto (Anand. S.P., et al. 2021). According to Davis, T.M., et. al. (1988), the procedure of a ranking task is complex for the respondents when the choices are all roughly equally attractive or equally unpleasant.

Furthermore, an interpretation with averaging the ranking may prove to be quite misleading when the respondents hold broad different views. The author suggested that paired comparisons in a survey instrument are possible for overcoming these difficulties. Therefore, Garg, R., et. al. (2012) comments that Fuzzy AHP can be a formal method to estimate the CSF.

According to Percin, S. (2008), Fuzzy AHP collects the respondent‟s opinions through the questionnaire. The author cited that Fuzzy AHP is a more systematic method than other MCDM methods and more capable of capturing a human‟s appraisal of ambiguity if considering the complexity of the multi-criteria decision-making problem. Compared to other research methods, Fuzzy AHP develops the hierarchical structure by collecting the expert‟s opinion (Garg, R., et. al., 2012) or the decision maker's opinion (Chen, J. et. al., 2015). Multi-criteria decision-making

(MCDM) helps make decisions when the criteria are naturally conflicting, containing various factors and evaluating by linguistic variables. In the Fuzzy AHP technique, the fuzzy numbers evaluate the concern of some deviation among decision-makers in a mathematical calculation (Hota et al., 2013).

A fuzzy question is identical to a Likert option but compares a typical survey question with a single question for each variable. The psychometric theory dictates a series of questions to tap different aspects of a concept when the measurement does not happen directly. Nevertheless, Fuzzy AHP measuring the phenomenon of consistency or reliability invalidity can reduce the items and the scale (Bowling, 2005). Human uses imperfect information and uncertainty to generate decisions with Fuzzy set theory. Many decision-making and problem-solving tasks are neither comfortable nor too complicated to be understood quantitatively (Kahraman et al., 2004. The capability to represent vague data is the significant contribution of the fuzzy set theory through the mathematical operators and programming applied in a fuzzy domain.).

According to Garg et. al. (2012), using AHP in factor ranking study is necessary because of its capability in dealing with tangible and intangible criteria. This method is proven effectively applied in various real-world complex applications. It reveals the transparency in the decision-making by decomposing the complex issues into a simple hierarchical structure. Davinder et. al., (2020) has applied the AHP to analyze the CSFs for Six Sigma implementation. It has included experts from the company who have already implemented or are embarking on it. It is useful for managers, practitioners, and academicians to better understand the Six Sigma adoption. Fuzzy

AHP was also applied in some case studies in an industry or a well-defined scope of sampling to evaluate the CSF (Belhadi, A., et. al., 2018). Görener, A. et. al. (2012) uses the tool to assess the important factors in a manufacturing firm case study. The author cites Fuzzy AHP used to systematically determine priorities among factors, which helps to constitute an appropriate strategy for the organization. In a similar study also conducted by Yadav, G., et. al. (2018), the author applied the approach in his research on evaluating the barrier ranking in a machine‟s tools manufacturing case study.

In summary, Fuzzy AHP prioritizing the CSFs helps the company understand the relative importance and improvement plans that have been devised to deal with several or all factors simultaneously and maximize the limited resources during implementation.

Sari (2013) mentioned that there are three necessary steps for conducting an AHP assessment, which are: -

1) build a hierarchical structure of the decision model,
2) judge the activities or variables comparatively by expert opinions, and
3) generate the priorities

However, Fuzzy AHP is evolving from time to time. In the research by Sari (2013), AHP uses a triangular fuzzy number (TFN). Laarhoven et al. (1983) introduced the hierarchical composition principle that assigns weights to the critical decision criteria and weighs the alternatives under each criterion separately. TFN is the most commonly used in AHP to resolve linguistic assessment vagueness (Sari, 2013). Chang (1996) introduced another approach for a priority vector to obtain a crisp priority vector from a triangular fuzzy comparison matrix. Wang et. al. (2008) extended the logarithmic least squares method to calculate priority vector (Laarhoven, 1983).

Many types of research are related to the AHP approach that prioritizes the CSFs and barriers for Lean and Six Sigma success. The research in prioritizing the CSF has recently pervaded into the continuous improvement methodology, which is useful for research that prioritizes the CSF in LSS, Six Sigma, or Lean (Daniel et. al., 2014; Silva et. al., 2018; Yadav et. al., 2017; Talib et. al.,2015). AHP in CSF prioritization that focuses on different paradigms, Pandey et al. (2018) ranked the enablers in another integration of TQM in green lean six sigma implementation.

It is a potent tool for CSFs prioritization as it provides a selection of proper improvement actions in the Six Sigma deployment. A similar comment from Abrahman Moya et al. (2019). The author stated that the AHP is useful for prioritizing CSF and is generally used in prioritizing the barriers, enablers, or CSFs in LSS related research. According to the author, AHP can combine a hierarchical structure of several levels and the opinions of various experts. Therefore, the research uses the Fuzzy AHP to examin the important CSFs in the successful implementation of LSS in the company.

2.6 CRITICAL SUCCESS FACTORS

Critical Success Factors (CSF) is commonly used in management science and production economics, such as information systems, resource planning, lean manufacturing, and total quality management (Hopland et al., 2018). Aquilani et al. (2017) suggested that managers should work and follow the significant steps on the most important CSFs in their organization at the starting point. CSFs are the essential things that the company must identify and achieve to produce excellent "competitive leverages," where the actions and processes can be controlled by the organization's management and fulfill the CSF's requirements to achieve the organization's goal (Lande et al., 2016 & Raval et al., 2018). Brotherton (1996) defined CSFs as essentially fulfilled, and areas that can produce its most significant competitive leverages that ensure the enterprise‟s success are identified (Pathiratne et al., 2018).

While Krishna et al. (2015) pointed out that the CSFs are vital to ensure the transformation process is smooth and leads the organization to meet its goals. Therefore, the organization should define the CSFs and plan a framework properly for the deployment before working on the activities. Sameh et. al. (2017 concluded that this is necessary to understand the critical factor and the implementation. Else, it will be hard to maintain the deployment sustainability (Yadav et al., 2017).

According to Azyan et al. (2017), the success factor and barrier could be the same, depending on the situation. Each activity block in a deployment process, where the proposed mechanism to achieve an outcome or some negative constraints to implementing those activities, is defined as barriers. On the positive side, they can also be a critical success factor. According to Psychogios et al. (2012), it depends on the research participant"s experiences in the application process, and the factors can be the inhibitors or facilitators in the LSS deployment. Assarlind et. al. (2014) differentiated the converter and inhibitor as two conditions. The converter provides energy to move the maturity to a higher level, while inhibitors are the factors that prevent the adoption process from promoting maturity to a higher level.

Ten CSFs in the research are retrieved from the research element by Sreedharan et al. (2018). The author finalized the factors from an in-depth empirical study. These CSFs are important and applicable in Lean, Six Sigma, and Lean Six Sigma. Table 2.1 shows the other researchers applying the CSFs with the AHP approach to rank the CSF based on its criticality.

Table 2.1: Critical Success Factor's category and literature reviews

	Pandey, H. et.al. (2018)	Belhadi, A., et. al. (2018)	Silva, B.B., et. al. (2018)	Yadav, G., et. al. (2017)	Gandhi, N.S., et. al. (2018)
Main Factor	*Green Lean Six Sigma*	*Lean*	*Lean Six Sigma*	*Lean Six Sigma*	*Green Lean*
Employee involvement	Y	Y	Y		
Supplier focus	Y	Y			
Customer focus	Y	Y	Y		
Top management commitment	Y				Y
Organizational culture		Y	Y		Y
Communication	Y	Y	Y		
Understand tool and technique		Y	Y	Y	
Training and education	Y	Y			Y
Organizational insfrastructure			Y	Y	
Team work					

2.6.1 Employee Engagement

Employee engagement is a critical factor. However, extreme formality in people's involvement could discourage individuals from participating in continuous improvement (Pedro et al., 2011). Employee engagement is crucial to lean, where employees should empower and act independently to handle and resolve customer issues (Gupta et al., 2016). The factor strengthens the organizational working environment and improves the outcomes, influencing employee performance (Nazir et al., 2017). Alnadi, M., et. al. (2021) claims that empowering employees in the decision-making and taking responsibility is critical to success the LSS implementation; otherwise, less authority to the employee is the most critical barrier to LSS implementation (Rathi, R. et. al., 2021).

In the research by Kumar et al. (2018), the author cites that even if employees understand the tool, they will still depend on their willingness and motivation to identify the wastes. The organization should consider the reward system in monetary or non-monetary forms or any other forms of recognition to guide the employees to share the company‟s policy, vision, and mission (Brkic et al., 2016). A Lande et. al. (2016) supports that employee rewards and satisfaction are critical to the deployment. However, Brkic et al. (2016) propounded that the training is also important to encourage employee involvement on top of the reward and communication. Although the reward is one of the ways to engage the employee, it must link to company business objectives that make the company a high-performing organization (Jeyaraman et al., 2010). The reward for the graduated belts on their contribution to the project links to the company's benefit on financial and non-financial gains. The training impacts the financial and non-financial results, as suggested by Oprime et al. (2012), and strengthens employee engagement.

Rymaszewska (2014) cited that an insufficiently qualified workforce may undermine the positive long-term orientation effects. There is a need to have enough space and time to allow the activities to occur (Bessant et al., 1999) for systematic and regular application in strategic problem solving, which is one of the vital features of CI behavior. Jadhave et al. (2014) concluded that almost every organization encounters resource constraints. However, it needs the support of adequate and timely resources to bring a positive change in any system, which includes the dedicated employee's time, allocation of the fund, other resources such as communication to encourage employee involvement.

A study by Brüggen (2015) revealed an inverse-U shape between the relationship of workload and quantitative task performance. The performance is low or decreased when the workload is low or high, while the employee's performance is high if the workload is moderate. Therefore, work leveling is an essential factor in enabling employees to work on continuous improvement activities and stay focused, increasing employee involvement.

On top of the work leveling, time allocation, role conflicts, and participation levels are the other issues impacting the employee's involvement in the changes efforts. It is necessary to allocate human resources to the initiatives. But the company size would influence the allocation (McLean et al., 2014).

2.6.2 Supplier Focus

According to Arcidiacono et al. (2016), the company should share the philosophy and LSS practice with their suppliers, who closely participate in the production performances. Win-win relationships with suppliers are the key to the success of the LSS. In lean practices, the supplier‟s involvement will benefit the supply chain, such as e-Kanban enhancing the company operational tasks in material replenishment and guaranteeing a smooth run (MacKerron et al., 2014). Pepper et al. (2010), where the author has proposed extending the lean training to the primary supplier and ensuring that everyone involved in the deployment knew their responsibilities.

High technology companies face intense competition from their rivals since there are forces to be more agile and have proper supply chain management, including inventory and supplier (Taj, 2008). Sousa Jabbour et al. (2014) pointed out that supplier development is part of lean practices, so working with suppliers along the supply chain means extending lean manufacturing (Yadav et al., 2019). Habidin et al. (2013) commented that supplier integration is one of LSS's continuous improvement concepts, supplier‟s involvement in product development, and quality improvement projects to ensure good quality is received. Rathi, R., et. al. (2021) found that lack of interaction with a supplier is critical failures. However, like the employee's factor, the resistance to change also happens in supplier‟s lean journey (Dora et al., 2014).

Trust is the fundamental element that can build a partnership between the customer and the supplier. Thus, the supplier is willing to share the information, share the vision, and commit to the customer. However, it will not happen if the customer does not help product development at the supplier's side (Li et al., 2015). The bits of help is not limited to the early product development but shared responsibility for quality improvement. Uluskan et al. (2016) mentioned that the small and medium-sized suppliers have difficulties implementing the quality management system such as LSS because of the tool applications sophistication; thus, it is essential to initiate and implement the projects at the supplier side or to provide technical support to the suppliers. The essential help provided to the supplier, especially on the new product qualification and quality improvement, will benefit the two parties. Hoque, I. (2021) suggests enhancing the supplier's understanding, motivating them to realise the significance, and resulting long-term benefits as a return. Sharma et al. (2012) support the point; the author cited that long-term supplier collaboration is necessary. It is a win-win situation by validating and monitoring the supplier's performance.

Andersson et al. (2020) suggested that the organization should collaborate in the LSS training as part of the strategy, as the definition of a supplier can even extend to the service provider. Most companies collaborate with external parties in the LSS training, workshop, or seminar. Upadhye et al. (2010) suggested that the decision-maker focuses on the interaction between industries, academia, research institutes, and professional societies for performance improvement. Boyle et al. (2011) mentioned that the external experts hosting the internal workshops on performance improvement are information sources for the manufacturing manager in exploring the techniques and philosophies, as there will be more exceptional support for lean improvement if there is a greater management exposure.

2.6.3 Customer Focus

Senior management utilizes the LSS methodology to develop a stable management process, guide resource allocation, improve competition and consumer preferences; however, it refers to customer demands to drive strategy changes (Manville et al., 2012). Organizations intend to adopt the methodology to satisfy their customer (Gastelum-Acosta, C., et. al., 2022). Management systematically demonstrates the continuous improvement effort to their customer by solving the problems, providing additional services with no extra cost, and (Braunscheidel et al., 2011). Similar comments from Sony et al. (2020), where LSS is a business strategy to improve process performance and customer satisfaction.

The LSS project should not be limited to internal factors. Still, it should start and end with customers, with a deep understanding of the customer requirements, and applying the methodology to create high-value products or services to their customers (Arcidiacono et al., 2016). Tenera et al. (2014) have suggested having a customer satisfaction survey for every LSS project, which will help detect the customer's main requirements to know the Voice of Customer (VOC) based on the DMAIC approach. This suggestion is in alignment with Elias (2016). The author has also concluded that customer satisfaction is one of the critical factors that facilitate the LSS project's success or drive the continuous improvement activities (McDermott O,et. al., 2022).

The manufacturing organizations can gain advantages over their competitors through the strategic relationships between customers and suppliers. Mutual learning between the strategic relationships can enhance the organization's capacity in continuous learning and improve the organization's effectiveness deploys the TQM practices (Peter et al., 1999). Flynn et al. (2010) cited that the interaction with the customers and suppliers is related to operational performance. However, supplier integration alone is not related to operational and business performance. On the other hand, the organization should go with both integrations concurrently to improve organizational performance. Feng et al. (2013) conducted a similar study and concluded that customer and supplier involvement enhances internal integration, significantly affecting operational performance. However, customer involvement is more significant than supplier involvement, but this is essential for the firm to implement customer and supplier involvement to achieve performance improvement. Many companies extend their deployment to their suppliers and customers as the improvement at supplier's processes inadvertent benefits the company and suppliers (Duarte et al., 2012), while customer focus is related to business results (Lertwattanapongchai et al., 2014), which will return the financial benefit to the company in the end.

The interaction between the supplier and customer may not be limited to information sharing, but it can happen through benchmarking as part of other forms of mutual learning. Chen (2002) commented that benchmarking is one of the main components of modern management practices in total quality management (TQM). Usually, benchmarking is based on a competitive basis, and some parametric values are used as a reference point for comparison. Benchmarking is a widely used technique in lean practices. However, in Six Sigma, benchmarking is the most useful tool in the service industry in an LSS project as part of its methodology (Paulo et al., 2012). In a study conducted in the hospital industry by Sabry (2014), it was evident that benchmarking has weak positive correlations with cost reduction. It hints that benchmarking is one of the tools that can easily be applied to introduce the best practices to improve or optimize the process. Benchmarking is the end product of a close partnership that results from a high-value interaction between the customer and the supplier.

2.6.4 Top Management commitment

As commented by Harrington et al. (2015), an organization needs to gain commitment from its management (Antony et al., 2002), as well as the involvement and participation of leadership are essential in a large scale industry (Desai et al., 2012; Alblooshi et al., 2020).

The support from management in LSS is crucial in an organization to prevent any change program failures from happening and implement the changes (Mclean et al., 2014; Laureani et al., 2012; Sharma et al., 2012). The changes will lose momentum and cannot sustain the change initiative if employees only drive the change without management's participation because of insufficient resources and is not perceived as valuable by others (Johnson et al., 2016).

Jagdish et. al. (2014) cited that poor leadership is the reason for the weak sustainability of change, and lack of committed leadership becomes the barrier to implementing it. Lack of commitment from management would lead to a host of other issues, as the achievement will be limited to resource constraints, lengthy decision-making, and communication breakdown. It will be challenging to nurture a continuous improvement mindset and culture in the organization, as the employee is unconcerned with the transformation (Abu, F., et. al., 2022). Sagar et. al. (2014) cited a prime principle that top management reinforces those significant initiatives in the organization. The top management creates a continuous improvement environment by establishing quality policies and goals and providing training and resources to low-level employees through proper leadership.

As mentioned in the study by Ghobakhloo et. al. (2019), the top management should commit to providing the resources to ensure the successful deployment of Lean Manufacturing with IR 4.0 digitalization projects. Walter et al. (2019) cited that top management's commitment and support are vital to ensure all required resources are available (Singh, M. et.al., 2021) and remove all obstacles. Funding is one of the crucial resources that need support from top management as the determination of any successful project is the financial capacity. Financial allocation adequacy is critical to the adoption and subsequent successful implementation (Achanga et al., 2006). Arcidiacono et al. (2016) mentioned that training for LSS activities needs financial resources. The author also comments commitment also required from the top management on working hours that the staff and professionals are needed to work on the projects, such as overtime on the production floor kaizen are considered human resources incurrences.

Management support and involvement are fundamental requirements in all organizations for a new deployment. Many studies have revealed that the factor has always been a high score in the CSF research. For instance, Sabry (2014) found that appropriate support from management is needed. A similar finding in Upadhye et. al., (2010) and Achanga et al. (2006). Arcidiacono et al. (2016) agreed that the management should provide resources if the management cannot participate in the project. Psychogios et al. (2012) suggested that top management‟s commitment and determination are needed in the optimization process and continuous quality improvement in the organization, including the internal operational improvement and external business development (Lameijer, B.A., et. al., 2021)

Top management's total and visible commitment are essential before seeing tangible and significant results after four to five years (Ray et al., 2010). As it takes years to succeed, the LSS project will fail if there is no commitment from the top of senior management (Raja et al., 2018). However, according to Ahmed et al. (2019), the top management commitment does not improve quality performance if other factors do not accompany it. It should be mediated by workforce management, which offers rewards, recognition, and promotion to the employees to increase their participation in the LSS project.

The program will fail if management lacks involvement and commitment (Albliwi et. al., 2014; Leopoldo et. al. 2016; Achanga et. al., 2006). The executives should directly participate in LSS activities and offer support to encourage, influence, inspire, and motivate all employee layers within an organization (Naslund, 2013). Top management's involvement in the project selection is significant because culture change, expense in training and development aligns with the business objectives with customer requirements, decision-makers on the improvement project, and prioritization (Ray et al., 2010). Most of the companies failed to achieve the desired performance, and a part is due to the management does not make the right strategic decision on the initiatives match the company quality objective, the market wanted, strategic management, company culture, and working environment (Habidin et al., 2016). Coronado et al. (2002) commented that management involvement is a must for successful implementation, which is often regarded as a requirement rather than a commitment of action.

One of the features of LSS is continuous improvement in products and processes, which needs the involvement of all production employees and the support of top management as an improvement team (Sánchez et al., 2001). The improvement has to be materialized to increase the profit or lower the cost. Thus, top management support is necessary (Andersson et al., 2006). Freiesleben (2006) cited that it is easier to promote continuous improvement initiatives to top management by communicating the quality benefits associated with money. The author concluded that quality improvement benefits increased the contribution margin with a higher price but lowered the unit costs, increased sales volume, and reduced fixed costs. Thus, it is easier to convince the management that better quality leads to increased profits.

2.6.5 Organizational Culture

Organizational culture defines as a rule and behavior, and it covers trust, hierarchy, working environment, and feel of the group, which is crucial for implementation (Yadav et al., 2019). It is an assumption or belief shared by the organization members on how it influences the staff to perceive, think, and act (Knabb, 2015). Laureani et al. (2012) concluded that the organizational culture is one of the more fully identified factors in the LSS CSF research; however, measurement is needed in the organizational culture to promote the cultural profile to result in a successful lean (Paro et. al., 2017). Sahoo, S. (2021) cites organizational culture directly affects operational performance; it is one of the essential factors (Jayaraman, K, et. al., 2012) and should be prioritized in lean deployment. Laureani et. al., (2017) cited that leadership is a mechanism for embedding cultural values and norms into an organization. Thus, a reciprocal relationship between leadership and organizational culture is needed to mold into an ethical organizational culture. However, pre and post cultural formation could exist along the deployment process, suggesting some prerequisite culture had existed before building up a new culture in the organization, as suggested by Laurean et al. (2017) and Paro et al. (2017).

Hilton et al. (2012) cited that group culture, development culture, and rational culture within an organization are essential in the LSS deployment (as cited in Sharma et al., 2012). The group culture is a supportive environment in continuous improvement, promoting employee participation, building trust, and taking human development as a core value (Zu et al., 2010). Based on Achanga et al. (2006), a supportive organizational culture should be created for implementation because it is a virtual platform. Douglas (2017) postulated this as a prerequisite for successfully implementing a philosophy.

Companies with a culture of sustainable and proactive improvement are high-performing companies. Consequently, there is a prerequisite for managers to operate in a diverse environment, have a low resistance to change, and focus on their long-term roles. However, possible restrictions to the change efforts are the business's culture, which indicates the employee‟s behavior and strategies that support the organizational goal (Antony et. al., 2017).

The organization should not implement the LSS as a stand-alone activity. In contrast, the management should integrate the LSS into the organizational culture, providing active promotion for LSS through performance assessment, and reward to internalize the new value on the individual level (Arcidiacono et al., 2016). Alidrisi H. (2014) opined that the CSFs are interlinked, whereby management involvement and commitment are linked to cultural change and communication. However, the organizational culture and infrastructure are independent variables that they do not link. Nevertheless, organizational culture is part of the top management influence (Naslund, 2013), and corporate culture is significantly influenced by quality management (Fredendall et al., 2006).

2.6.6 Communication

LSS is a breakthrough innovation in a culture that requires long-term focus and some infrastructural characteristics to be in place with communication skills, which is the fundamental aspect of cultural change implementation.

Resistance to change exists in all functions in a company, from shop floor personnel to senior management. It happens because of lack of clarity and uncertainty of change, pressure, interference with interests, and challenges faced in learning new things (Jagdish et al., 2014).

Management initiatives must have had been effectively communicated between all levels in an organizational hierarchy, including between internal and external stockholders in the implementation (Yadav et al., 2019 & Gastelum-Acosta, C., et. al., 2022). Effective communication engages people and increases their sense of ownership, trust, and teamwork (Arcidiacono et al., 2016). Poor communication will fail to implement continuous improvement initiatives and fail any process improvement initiative (Gastelum-Acosta, C., et. al., 2022). Reversely, the organization can establish a common language for change and improvement through effective communication (Antony et al., 2017).

Snee (2010) cited that the organization should create an overall improvement system to guide and integrate all organizational improvement and support management systems that promote sustainability. One of the essential elements in the improvement management system is communication. The communication should be in the deployment plan and required to administer and monitor the overall improvement program, including poor initiative communication and progress. Sagar et al. (2014) postulated that communication plays a vital role in the organization"s growth and development. Hence, effective communication is a significant factor in top management to ensure the effective implementation of progressive policies and strategies.

2.6.7 Understand Tools and Techniques

Six Sigma provides a new approach for quality improvement. It has a positive relationship with improvement initiatives, where both the statistics and non-statistics methods must be appropriate in usage and program understanding (Silva et al., 2018).

Belhadi et al. (2018) cited that the misapplication of practices or improper methodology due to a lack of understanding causes severe handicaps and damages sustainability. Therefore, Sreedharan et al. (2018) listed the understanding of tools and techniques as part of the top 10 factors in Six Sigma, Lean, and Lean Six Sigma.

The ability to use the toolbox in a systematic and disciplined manner is one of the success factors in Lean and Six Sigma (Anthony et al., 2012). The strategy of LSS is to apply the roadmap of DMAIC to create a robust framework that optimizes resource consumption, speed, and accuracy improvement of the process through tools and techniques application (Bhat et al., 2020).

Tools and techniques are the top focus areas in Shokri‟s (2017) research as they are highly focused on the manufacturing sector and most LSS or Six sigma research papers. Kumar et al. (2014) concluded that one of the significant difficulties in companies is the lack of knowledge of particular tools and techniques. The managers lack comprehensive and suitable knowledge in the organization's related culture, planning, and LSS approach, causing failure in the implementation.

2.6.8 Training and Education

Amorim et al. (2018) cited that an organization should invest in quality training for effective deployment. Goffin et. al. (1996) mention that training shall develop the skills even if it hires the right candidate. The organization's continued success in a competitive market is wildly dependent on the ability to have quick learning from its competitors. According to Lande et al. (2016), in his study on the Indian SME LSS CSF priority using the Pareto Chart approach, he found the training is one of the critical elements (Yazdi, A.K., et. al., 2021). However, he combined employee involvement and practice as one CSF, thus unable to differentiate the importance level for both factors. McLean et al. (2017) cited that training is one of the top five key factors under the manufacturing context. Sreedharan et al. (2018) found that inadequate training will lead to imperfect knowledge of the LSS tools and techniques; it induces employee‟s resistance causes the LSS project to fail because they poorly understand the statistical tool.

In a study by Albliwi et al. (2017), he found that the training is critical to the success of LSS, and there should be over 50% of the company staff being trained to drive the change in the business to improve the company‟s profit. The six Sigma project requires many resources, especially in training. Most organizations have involved employees in the initial training before implementing a comprehensive Six Sigma program (Charkaborty et. al., 2013). Thus, the training is a prerequisite and top management shall provide training and equip the employees (Sim, C.L., et. al., 2021).

In a study by Brkic et al. (2016), it was postulated that training is an independent variable, and it has a higher contribution to the success of LSS. An organization should regularly provide training to all employees, assess the training effectiveness, change, update, and continually improve the training materials. As Amberkar et al. (2017) mentioned, training can significantly remove the obstacles with adequate resources and a well-developed employee attitude. Continuous training is required for project success after the training completion (Hill et al., 2018).

Duarte et al. (2012) quoted the use of top talent in black belt roles to deploy LSS successfully and, as mentioned by Hilton et al. (2012), concluded that the LSS project's success is affected by a black belt or/and master black belt competency. In these researches, it was evident that learning behavior correlates with knowledge, as the latter will improve the team's understanding and capability for successful project quality.

It is a widespread phenomenon that some people cannot adapt to the method of tools application; thus, selecting the right person in training is critical. Both Elias (2016) and Mustapha et al. (2019) established that some employees found the statistical tools and the related concepts complex and challenging. Proper training is needed for employees to use the tools and techniques effectively. It is in line with Hilton et al. (2012) that the LSS training facilitators need to consider academia's involvement in the training or course design in ensuring statistical education is an integral part of the LSS certification curricula.

Naslund (2013) cited that training should be provided to managers and workers, considering its necessity and vitality. Training for managers enables them to generate new ideas and enhance their knowledge of quality and the TQM program (Abu, F., et. al., 2022), as they are both the decision-maker and the change agent who will materialize the organizational change with strategic objectives (Lertwattanapongchai et al., 2014). Attitudes of the managers and knowledge are the key success factors that drive the changes to create a more significant outcome.

Lertwattanapongchai et al. (2014) cited that the leader's competencies are essential to ensure change effectiveness. Therefore, the change agent's quality is paramount despite appropriate training provided to the employees. According to Virmani et. al., (2017), various training programs are organized from time to time to ensure the employees are well acquainted with the latest technologies, quality tools, and techniques. However, project-based training produces immediate financial and business results, and the project pays the training cost (Snee, 2010).

2.6.9 Organizational Infrastructure

In the study of Knapp (2015), he found that the organizational infrastructure refers to the LSS practitioner's structure in leading and implementing the LSS initiative. Maisiri et al."s (2019) study on Africa's IR4.0 readiness revealed organizational infrastructure terms as the equipment functionality and adaptability, digital modeling, systems, and interface to a leading system. In contrast, Reed et al. (2013) described it as a systematic framework comprising specific features and expectations. The conclusion from both these pieces of research is that the organizational infrastructure is a framework that includes all the essential factors towards deployment support and success. Galeazzo, A., et. al. (2017) cite organizational infrastructure as important to sustain continuous improvement, and it can dynamically modify, reconfigure, and expand new knowledge in the organization.

Ben et l., (2018) cite that to support LSS adoption, dedicated technologies are developing, and investment in the infrastructure is vital to building a substantial project scope. Alexander et. al. (2019) comment that the LSS project fails to execute effectively or sustainably if the management cannot create an appropriate infrastructure. Based on Yadav et al. (2017) and Chaple et. al. (2018), lack of financial, technical, and human resources is a prominent barrier to success in the LSS implementation. It is propounded in Yadav et al. (2019) that financial and technical support is essential to build and sustain the infrastructure, whereby human resources is prevalent in the whole process of creating and maintaining. Kumar (2014) cited that today's manufacturer's focus is more on efficient and effective production facilities and information infrastructure, strengthening the notion that companies have to invest in technologies and processes.

The manufacturing sector faces new industrial development, Industry Revolution 4.0 (IR 4.0). According to Lin et al. (2018), IR 4.0 enables the industry to integrate production processes and information technology. He cited that IR4.0 is consists of three streams; the first stream consists of the architecture configuration, system reconstruction, and information provision. Stream two comprises technological innovation and overcoming the technological limitations in a new application, whereas the last stream is the study on the impacts of the communication aspect. Based on these streams, it is apparent that IR 4.0 technology will affect the manufacturing quality and influence the managing framework.

The term or the CSF further extends to the latest development in the manufacturing sector, which is IR4.0. An essential suggestion is that LSS should integrate with IR4.0 elements, especially with big data and IIoT technologies (Antony et al. (2019); Fogarty, 2015). It supports the decision-making and project to achieve the operational goal by obtaining data in real-time and large data sets (Lobo Mesquita, L., et. al., 2021). In nature, it changes, modifies, and extends the existing field of LSS and its associated frameworks (Yadav et. al., 2017). As a result, the new concept of organizational infrastructure is formed to create a new framework of LSS and is known as LSS4.0 (Arcidiacono et al., 2018); as a result, the organizational infrastructure refers to the IR4.0 enablers in the study.

In the study of Yadav et. al. (2020), the study found that combining LSS with IR4.0 and ICT would significantly improve organizational performance. Saxby et al. (2020) found that some of the lean elements positively support the IR4.0, Yazdi, A.K., et. al. (2021) rank supportive IT as a very important factor in the success of the integration. Laux et al. (2017) mentioned that combining six Sigma with big data can create an effective improvement system, with the DMAIC methodology providing more structured problem-solving methods. In the study of Pagliosa, M., et. al. (2021), the author also found some IR4.0 technologies have high integration with Lean tools and techniques from the intercellular level to the supply chain level. Ghobakhloo et. al. (2019) urge to integrate Lean with IT for lean-digitized manufacturing. Other researchers, such as Wahab et al. (2019), also support LSS4.0. The author mentioned that LSS 4.0 automation approach should be applied to reduce the processing, LSS tools and techniques should integrate with IR4.0, and use it as part of the LSS project tools.

Big data could fulfill the requirements as the data was collected in real-time and in raw data format, meaning that the data is available right after generating by the system (Olsson et al., 2015). Big data refers to the data was in high volume, velocity, and variety of information sets. In general, big data has few features; the data is generated digitally, passively produced, collected automatically, geographically, and temporally traceable. They are real-time or timely strategic responses in a short time allowing (Laux et al., 2017). According to the study of Gonzalez-Aleu et al. (2018), data availability and trustworthiness is a CSF in Continuous improvement projects. It is critical in process performance management (Blasini et al., 2013). Allio (2012) found that dashboard deployment improves performance management. The dashboard should be real-time and accurate and serve as a communication tool for different parties (Gröger et al., 2013).

In a smart manufacturing system, daily activities generate vast and complex data, such as control, monitoring, observation, or optimization. It creates new challenges in data analysis. These specific statistical tools cannot handle multiple megabytes or gigabytes of data; thus, big data technology and techniques, such as data mining, simple data analysis, are required (Nagorny et al., 2017). Laux et al. (2017) quoted that big data is applicable in DMAIC phases, such as defining the customer's voice or collecting limited data compared to big data in it‟s phases. The data visualization in DMAIC at Analyze and Control phase has not been used in any standard statistical tools to analyze massive data and timely updates on critical parameters for monitoring, controlling, and improvement (Seetharam et al., 2019). Mrugalska et. al. (2017) called the data collected from machine analysis in the cloud server is a smart machine that provides the mistake-proofing or Poka-yoke solution.

Anthony et al. (2018) recommended using big data in Six Sigma; with the increases of automation demand in manufacturing, advanced analytics, and cyber-physical system, the IIoT supports the big data environment, and it improves efficiency and productivity. Sreedharan et al. (2018) pointed out that it is challenging to understand customer types and demand with limited data. The data has to go through preprocessing with non-traditional statistical tools before being analyzed with traditional Six Sigma tools. Big data is used to define new opportunities and collect innovations. Fogarty (2015) cited that the statistical techniques taught in Six Sigma training programs are exploratory data analysis or descriptive statistics. The application of advanced analytics with big data enables practitioners to take advantage of massive information stores for process improvement and innovation. Gupta et al. (2019) suggested that the big data analysis application is a new methodology in the LSS project.

Arcidiacono et al. (2018) pointed out that the use of IoT in the DMAIC project helps gather input in real-time, which has a profound impact on the real-time adjustment in the production floor and tailoring the product design after-sale feedback. The whole information gathering process will assist by the big data analysis. The author also point out that another pillar of IR4.0 is the automation in the production floor, fulfilling the requirements in the Toyota Production System on Just in Time practices.

IT infrastructure is another technology that needs to focus on the LSS deployment. Under the lean concept, the organization looks for flexible, intelligent automated, and low-cost technologies. The highly automated organization in IT infrastructure for digitalization can be less vulnerable to the typical problems of manual work. Still, overinvestment could worsen the flexibility and ability to respond to the demand changes (Nicoletti, 2013). The IR4.0 requires new technology in IT for data pipeline, IIoT for data collection, and finally uses it for data analysis. These efforts involve plenty of financial investment, various technical support, and human resources (Yadav et al., 2017). These critical factors will guarantee deployment success and become a new organizational infrastructure to the LSS4.0 framework.

Antony et. al. (2017) mentioned that the future for LSS lies in the improvement that should leverage the new technology, such as the Information technology such as software solutions for accounting management, inventory management, production planning. Ghobakhloo et. al., (2019) also comment the Computerized Maintenance Management Software (CMMS), ERP, and other underlying hardware infrastructures support the lean ecosystem.

2.7 ABSORPTIVE CAPACITY

McAdam et al. (2010) stated that many other theories are used in Six Sigma‟s perspective, such as the goal-theoretic approach and the theory of work motivation. However, they are not addressing the knowledge acquisition and the synergies with other change management approach.

According to Cohen et al. (1990), one of the critical components of innovative capabilities is how capable the organization exploits external knowledge. The ability to evaluate and utilize the outside knowledge is an essential function in prior knowledge, known as absorptive capacity. Muraliraj et al. (2018) studied the absorptive capacity of Lean and Six Sigma, and the author defines it as the company's ability to recognize the value of external new information in assimilating, exploiting, and applying the new information in the business needs.

Lin et al. (2002) mentioned that absorptive capacity performs differently in different organizational cultures, and Schofield (2013) revealed that top management support is critical to success in the company absorptive capacity. The deployment of LSS has involved new knowledge acquisition and assimilation as potential absorptive capacity, knowledge transformation, and exploitation in realized absorptive capacity (McAdam et al., 2010; Muraliraj et al., 2018).

The theory of adsorptive capacity is applied to two areas in this research. Firstly, the LSS involves knowledge transfer during startup, which involves four capabilities, namely acquisition, assimilation, transformation, and exploitation (Zahra, 2002). Thus, the result would need the same process and framework of absorptive capacity when adopting similar CSFs in LSS deployment. In the process of CSF adoption, the company must be able to identify an essential CSF to the company (acquisition), analyze and understand the factor (assimilation), able to combine old and new knowledge (transformation), and finally incorporate the new knowledge into its operations (exploitation). Schofield (2013) worked on a similar study and found that the critical factors in knowledge transfer are the company"s absorptive capacity and the ability to integrate new technology into the current value chain.

The second aspect that applies absorptive capacity is the knowledge transfer during implementation. The study from Muraliraj et al. (2018) and McAdam et al. (2010) states that LSS needs knowledge transfer from different parties. Moreover, LSS 4.0 needs to acquire advanced knowledge in different pillars since LSS evolves from time to time based on the latest technology; thus, businesses need to improve productivity to the organization.

Muraliraj et al. (2020) found that different LSS practices such as lean technical practice, lean social practice, role structure, structured improvement procedure, and focus on metrics influence potential and realized absorptive capacity. The LSS is used to develop the absorptive capacity in the organization. The practitioners can explore and exploit the new technology or knowledge along with LSS implementation, especially in the project execution such as exploring the IR4.0

element in the organization using the DMAIC project in root cause analysis. It can yield innovative improvement solutions, automate the system control and monitoring, and shows the LSS approach is proven effective over a couple of decades (Snee, 2010).

2.8 STRUCTURAL CONTINGENCY THEORY

Structural contingency theory defines a condition where the various contextual factors determine the organization's design. Efficiency and strategic choice are the motivational assumptions, and the form and structural dimensions are the typical dependent variables (Narasimhan et al., 2015). It applies to an organization to describe how it adapts to a changing environment by changing a fit organizational environment (Donaldson, 2001).

Netland (2016) cited that CSFs need to be going well to ensure a manager or an organization's success. However, contingency theory suggests different managerial actions are subjected to different environments. The author concluded that the difference in CSFs is significant with four conditions: the corporation, size, the implementation stage, and location. Wadongo et al. (2014) also mentioned that various organizational factors such as size, organizational structure, strategy, technology, culture, and leadership influence the adoption of the performance management system in the organization.

According to Gonzalez-Aleu et al.‟s (2018) research on hospital‟s continuous improvement CSFs, the author found out that the top 10 CSFs have different importance than the top 10 most frequently published CSF in hospitals. The LSS deployment in a company could be different from other companies, including the framework integrating with different CFSs and the control system where the techniques, tools, and methodology are generally similar with minor differences among the companies. Silverstro (2001) revealed significantly different industry types in deploying continuous quality improvement. The author suggested that the managers analyze the appropriateness of specific management practices, tools, and techniques when deciding to embark on any framework as it is very dangerous to adopt any generic model.

The implication of the theory for the company in adopting the LSS framework was to consider the company's crucial factors, such as corporate and local management expectations and available or committed resources. The CSFs ranking should vary according to industry and organization types due to the organizational structure and management interests. As a result, it could be challenging to generalize a rank of essential factors in different companies or sectors. Nevertheless, various studies are needed to understand the differences between the industries from other aspects.

3.1 INTRODUCTION

This chapter narrated how the research has been designed, starting from the research framework, hypotheses setting, instrument design, targeted sample, data collection plan, and applied methodology to evaluate the collected data. As the Fuzzy AHP uses a series of mathematical steps to evaluate the factors in hierarchical manners; thus, this chapter covers every logical calculation step to gain the weight vector from the fuzzy numbers and finally generates the ranking result.

3.2 RESEARCH DESIGN

The CSFs were identified from the literature review and further reviewed by internal and external Lean Six Sigma experts. Four internal Lean and Six Sigma experts are working on the LSS planning and execution in the targeted company. A similar approach is also applied by Singh, D., et. al. (2021), Gandhi et al. (2018), or other research to build the AHP hierarchial structure. However, some researchers like Salmeron, J.L., et. al. (2005) make the hierarchical structure by themselves.

Table 3.1: Demography of the internal and External Experts.

Expert	Category	Gender	Expertise	Year of Experience
A	External Expert	Male	LSS	>20
B	External Expert	Female	Lean	>20
C	Internal Expert	Male	Lean	15
D	Internal Expert	Female	Lean	8
E	Internal Expert	Male	LSS	8
F	Internal Expert	Female	LSS	5

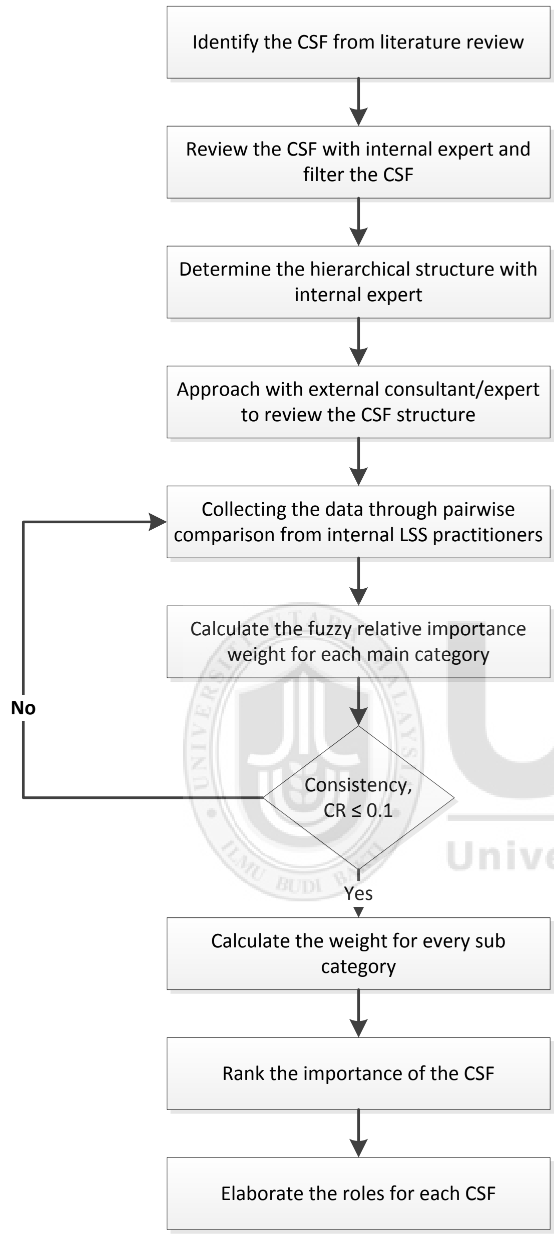
The expert's experience in LSS practice is from 5 to above 20 years, with daily functions in facilitating the training and workshop, project coaching, and mentoring. The internal experts have also organized the CI project contest in the company. They have been dealing with external parties for LSS activities, including the government agents on project showcases or competitions. Another vital role is to cultivate continuous improvement culture in the company.

The CSFs for each subcategory had been identified from the literature review. The internal experts reviewed the selected CSFs, provided input, and commented on the hierarchical structure. It ensures the selected CSF and the questionnaire"s structure are relevant to the company"s deployment. Two external consultants further reviewed the final list of CSFs, one is Lean Master, and the other is a Lean Six Sigma expert. The consultants possessed more than twenty years of experience in consultation in Lean and LSS and provided their service to the company since commencing the LSS; thus, they are familiar with the company"s environment.

The internal experts and consultants answered the questionnaire before releasing it to the targeted subject for data collection as part of expert validation. The subject targets were chosen from an LSS certification list which consists of various departments, ranging from engineers to manager level. They have been practicing and applying the LSS tools and methodologies in their daily function since they are LSS practitioners. The practitioners are respondents who can answer the questions based on their perception and hands-on experience as it will provide reliable data for analysis.

The constructs were developed based on the list of CSFs and followed the Fuzzy AHP matrix to collect opinions from the respondents, where the response of the questionnaires is used to calculate and rank the CSF. Every received response has to pass the validation. The questionnaire will send back to the respondent if they fail the validation. However, the validation is embedded into the questionnaire to increase the usability of the response. The result is further elaborated with actual scenarios in the company to understand the reactions. The overall research plan in the form of process flow is shown in Figure 3.1, as depicted below.

Figure 3.1: Research flow

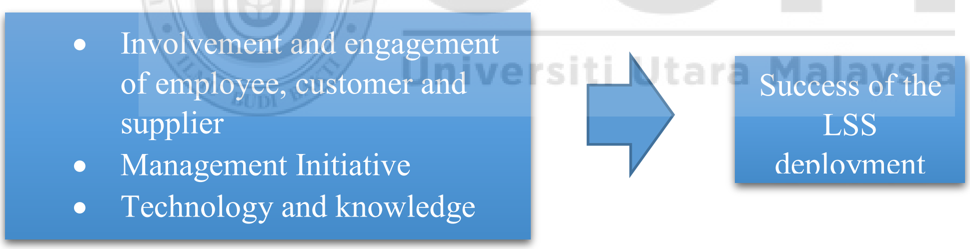


3.3 RESEARCH FRAMEWORK

The Fuzzy AHP framework for this study is split into two layers. The first layer is the main category, it is further categorized into subgroups, as shown in Figure 3.2. It also is known as Fuzzy AHP-based hierarchical structures (Amrita et al., 2018), where the main category consists of 3 major groups. Identify the subgroup's factors for the respective main category through literature review and the recommendation from internal and external Lean Six Sigma experts.

Refer to figure 3.3, research framework, and it shows the internal and external experts categorized the CSFs into three categories, as below

Figure 3.2: Conceptual framework



Vanichchinchai, A. (2012) cites the “total” in the TQM hints the involvement of every department and every person at every level in the organization is required to improve the performance. The author points out TQM only emphasized the intra-connection but supply chain management required integrating internal and external parties. Therefore the first category is Involvement and engagement. It is to consider the importance of the internal involvement of employees (Hoang, D.T., et. al, 2006) and external integration of customer and supplier (Feng, T., et. al., 2013) in the excellent operational performance. Management's involvement in the deployment is critical. It can happen in many aspects. Therefore, this factor is covered in another main category as the management initiative in the LSS deployment's success.

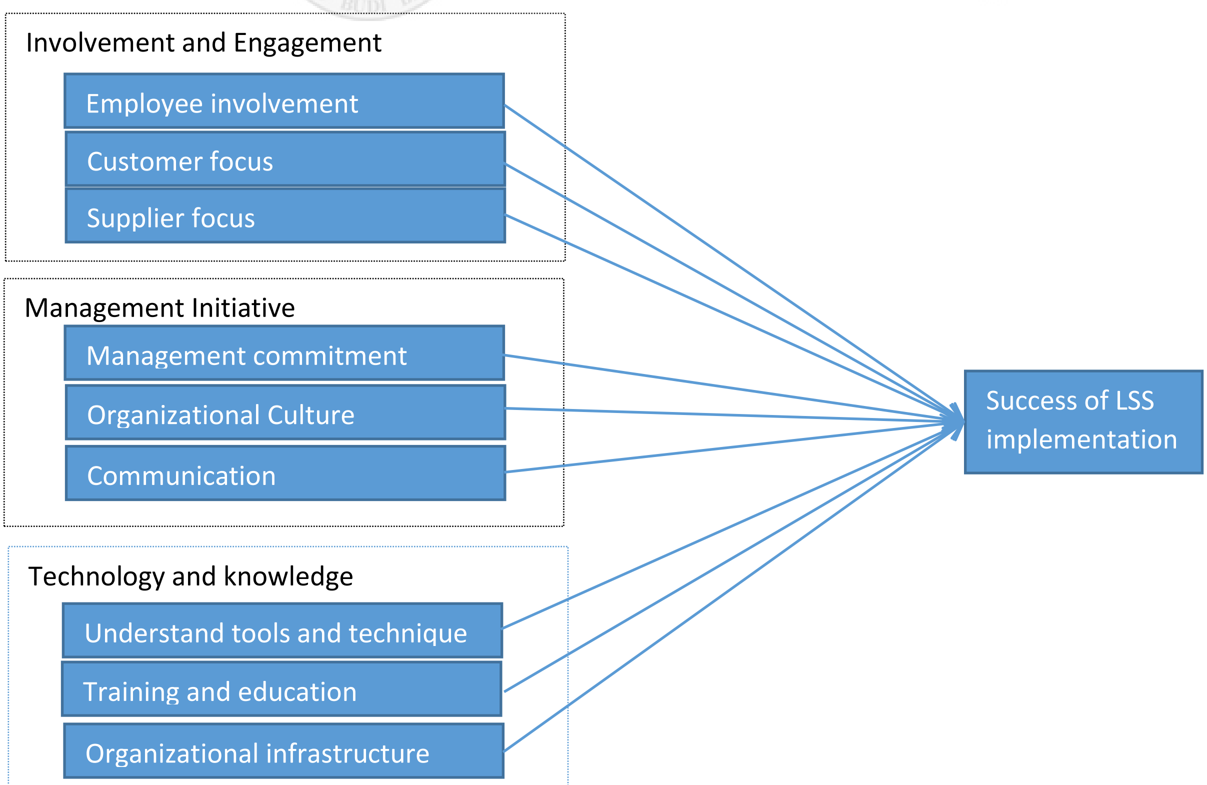
The second category focuses on the key actions from the management‟s perspective and studies the importance of the relevant CSFs in the LSS deployment. In another study of Antony et al. (2012), the failure to institute a culture of using Lean and Six Sigma methodologies is mostly attributed to the upper management not being ready and having no direct involvement in the implementation. Thus, it lacks the commitment from management and communication with employees of the change. In conclusion, the management initiative does not happen when the organization starts embarking on the LSS, resulting in disastrous failure and wasted efforts and resources. Antony et al. (2011) cited the management initiative as a prerequisite for effective implementation, including the management commitment, cultural change, and excellent communication along the company‟s hierarchy. In another study by Alblooshi et al. (2020), this point is supported where the author had found that the management commitment is the most crucial factor, followed by communication, which is the second important factor, and organizational culture as the fourth important factor in LSS implementation.

Lin (2014) mentioned that the top management support and rewards system are significant factors. It further expands the tool‟s application (Abolhassani et al., 2016); therefore, the category is after the management initiative. Carvalho (2014) concluded that the organizational infrastructure encompasses the IT and analytical tools (Hoang D.T., et.al., 2006) that are key

CSFs in Six Sigma deployment and operational excellence. The third category focuses on the CSFs related to knowledge and technology and how important the company's relevant CSFs make the LSS deployment successful. This research includes the LSS tools, methodology, concept, the LSS training, and the diffusion of IR4.0 knowledge to form a new framework or improvement culture in a company. This category could also reflect how the company can absorb and adopt the latest technology and knowledge into the organizational talent pool to form a new CI ecosystem. The knowledge diffusion in the organization significantly depends on its technological, organization, and environmental context.

These CSFs group into the three main categories based on the expert‟s choices and the literature review to develop the Fuzzy hierarchical structure as shown in figure 3.3.

Figure 3.3: *Research framework*



3.4 HYPOTHESES/PROPOSITIONS DEVELOPMENT

Based on the research framework, as shown in figure 3.3, the hypothetic statements are to study the importance of the respective elements from the three key categories. Commonly, Fuzzy AHP research does not produce the research hypothesis as other applied research methods do; some Fuzzy AHP research creates the hypothesis in a series of null hypothesis, such as a study conducted by Garg A. et. al. (2021). The author makes six null hypothesis statements for each main category, similar approach to generate the hypothesis statement was also applied by other Fuzzy AHP ranking research, such as Sam, S. et. al. (2014) and Narges, S. et. al. (2015). The paper applies the same approach but includes the sub-category in each null hypothesis instead of a higher number of hypothesis statements for individual CSF.

The first hypothesis is to evaluate the first main category of Involvement and engagement and its subgroup: Employee Engagement, Supplier Focus, and Customer Focus are the most important CSF compared to the other main category and subgroups. Alternatively, the hypothesis is rejected if the experimental result fails to prove the category is at the top ranking in the first tier in the AHP test and the top CSFs coming from the category at the second tier of the AHP test.

H_a: Involvement and engagement elements and their subcategories are the most important

The second hypothesis also intends to test the importance of the Management initiative and its subgroup as the most important factors in the ranking study.

H_b: Management initiative elements and their subcategories are the most important

The last hypothesis is to assess the importance of the third category with the technology and knowledge bases elements.

H_c: Technology base elements and knowledge its subcategories are the most important

The Fuzzy AHP study goes by hierarchical manners; therefore, the three hypotheses are used to assess the importance of the main category and its CSF. The weight of each category is finally used to evaluate the importance of the individual CSF, which will create the ranking by criticality that the tested subjects perceive. The hypothesis will finally conclude whether the highly weighted main category will also affect the importance of respective subcategorized CSF from the respective main category.

3.5 MEASUREMENT OF VARIABLES/INSTRUMENT

The questionnaire structure used in this research is based on Sahin et al. (2013). It is used to compare the importance of options in the pairwise pattern as it is commonly used in other research. The pairing option A or B is listed on the left and right, as shown in Figure 3.4. The subject or expert rates the importance of either option at two different ends. Hosny et al. (2013) also used the same method, where five scales were used compared to nine by Sahin el. al. (2013) and Lee et al. (2013). According to Rosaria et al. (2015), most AHP researchers have used the five or nine scales to evaluate the crucial factors in solution selection or rank the factors.

Figure 3.4: Example of the Fuzzy logic rating pattern

Criteria option	Choices or rating		Criteria option
A	<- Most important	Most important ->	B

The questionnaire is designed to have a pairwise option with a nine-point Likert option, which is most commonly used to improve the resolution. The rating is then converted to a matrix table, as shown in Figure 3.5. It shows the pairwise comparison structure in the matrix table for the main categories. The arrow indicates the pairwise comparison between the left vertical elements to the top horizontal elements. The three arrows at the top right corner of the table are the corresponding fuzzy number by referring to the respondent‟s rating. Three arrows in the left bottom corner are the reciprocal fuzzy number. It is a mirror image to the top right corner arrows.

Figure 3.5: Matrix for the main category

	Involvement and Engagement	Management Initiative	Technology and knowledge
Involvement and Engagement	-	↑	↑
Management Initiative	↑	-	↑
Technology and knowledge	↑	↑	-

A similar method is also applied to the subcategorized element or the individual CSF. The matrix for respective subcategories or the CSF for each main category as below

Figure 3.6: Matrix for subcategory

	Employee involvement	Customer focus	Supplier focus
Employee involvement	-	↑	↑
Customer focus	↑	-	↑
Supplier focus	↑	↑	-

	Management commitment	Organizational Culture	Communication
Management commitment	-	↑	↑
Organizational Culture	↑	-	↑
Communication	↑	↑	-

	Understand tools and technique	Training and education	Organizational infrastructure
Understand tools and technique	-	↑	↑
Training and education	↑	-	↑
Organizational infrastructure	↑	↑	-

The instrument is not easy to be understood. New structure was developed after the first trial with internal experts, a more comprehensive questioning structure to reduce the confusion. The new structure used the MS Excel function, which creates step-by-step guidance for the respondent to correctly answer the question and summarize their choice in a statement. The respondent can read back the statement to ensure that they have chosen are reflecting to what they thought.

Step 1:

The respondent answered whether he agrees with the statement on the particular factor in the rank of importance in the "Selection" column, as shown in Table 3.2.

Table 3.2: Example of questionnaire table 1

Question	Selection	Rating	Your Answer
Do you think **Involvement and Engagement** of employee, external suppliers and customer is more important than **Managemenent Initiative** or effort in success of LSS implementation?			
		Equally Important	
		Weakly more important	
		Strongly more important	
		Very strongly important	
		Absolutely more important	

Step 2:

The system will come out with the sub-question, guide the subject, and choose the rating corresponding with the answer in the "Selection", as reflected in Table 3.3.

Table 3.3: *Example of questionnaire table 2*

Question	Selection	Rating	Your Answer
Do you think **Involvement and Engagement** of employee, external suppliers and customer is <u>more important</u> than **Management Initiative** or effort in success of LSS implementation?	Yes		
How do you rate the Involvement and engagement of employee, suppliers and customer is more important? (Only one rating)		Equally Important	
		Weakly more important	
		Strongly more important	
		Very strongly important	
		Absolutely more important	

Step 3:

The system will put the respondent‟s choice into a statement to prevent any wrong interpretation or misunderstanding, as reflected in Table 3.4.

Table 3.4: *Example of questionnaire table 3*

Question	Selection	Rating	Your Answer
Do you think **Involvement and Engagement** of employee, external suppliers and customer is <u>more important</u> than **Management Initiative** or effort in success of LSS implementation?	Yes		
How do you rate the Involvement and engagement of employee, suppliers and customer is more important? (Only one rating)		Equally Important	
		Weakly more important	
	x	Strongly more important	Involvement and Engagement is Strongly more important than Management Initiative
		Very strongly important	
		Absolutely more important	

Step 4:

The steps are repeated until all the questions are completed. The system will auto convert the pairwise comparison into a matrix table, as being used by Sahin et al. (2013), as shown in Table 3.5.

Table 3.5: Example of questionnaire matrix

Factor A	<--Factor A more important than B					Factor B more important than A -->				Factor B
	Absolutely	Very strongly	Strongly	Weakly	Equally Important	Weekly	Strongly	Very strongly	Absolutely	
	5	4	3	2	1	2	3	4	5	
Involvement and engagement			Y							Management Initiative
Involvement and engagement							Y			Technology and knowledge
Management Initiative								Y		Technology and knowledge

This method is an additional step to reduce any misjudgment due to the complex structure. Besides, it is another feature in the MS Excel format to calculate the CR ratio. The respondent can check the CR ratio right after the questionnaire is completed. The embedded CR ratio avoids data collection delays due to the questionnaire being sent back to the respective respondent if the final assessment fails the CR ratio. It is helping to have a higher rate of usable questionnaires with this design as long as the respondent returns the questionnaire. The sample of categorie"s CR ratio in the Healthiness results is reflected in Table 3.6.

Table 3.6: CR Ration table

Category	CR ration	Healthiness
Main	4.91%	Good
Involvement & Engagement	4.91%	Good
Management	8.10%	Good
Technology Knowledge	7.30%	Good

3.6 DATA COLLECTION

The collected data will be sent via email in MS Excel format to be pre-formatted to suit the Fuzzy AHP matrix calculation.

The targeted respondents are those LSS candidates trained and certified in Lean or LSS. The candidate covers different positions and functions; some belts deal with external parties, such as OEM vendors and suppliers. Some handle the daily problem-solving in process, equipment, or smart manufacturing with IR4.0 pillars development.

However, there could be a challenge that the responses could be biased because the LSS candidate is most likely to judge the importance of respective CSF based on their hands-on experience. Therefore, the questionnaires must include the respondent‟s functions when interpreting the result. The functions are categorized into three groups, and they are:-

I. Engineering group
II. Quality group
III. Operation group

The targeted respondents are categorized into three groups based on their daily job functions. These groups are the major function group as defined in the internal training program. The engineering group deals with process and equipment in the problem-solving. This group is also applying more six sigma tools and some lean tools. While operation group, their working nature is more focused on the material transaction; thus, lean tools is the prominent application. Lastly, Quality Assurance (QA) group deals with matrices, statistical data analysis, defect, and root cause analysis; thus, applying more six sigma tools. Besides, engineering and operation groups often use the IR4.0 as the supplementary in their project; while quality groups mainly rely on big data analysis. These groups are the key participants and practitioners in the company.

This study also includes the internal and external LSS experts besides the respondents of three major functional groups. Therefore, it can compare the responses among the experts and practitioners from the different functional groups.

3.7 SAMPLING

AHP survey is used to evaluate the comparability of the perceived selection criteria; thus, the penetrating insights from relevant experts or professionals were highly valuable to an empirical inquiry. Since AHP is not a statistical technique but a subjective method, as propounded by Wong et. al. (2006) and Sahin et al. (2013). As reflected in Table 3.7, some researchers have used different values of actual sample sizes in the different types of study areas.

One of the advantages of Fuzzy AHP is it is not necessary to involve large samples in a survey. Reversely, a large sample size could result in a very high degree of inconsistencies because the participants may provide arbitrary answers (Cheng et al., 2002).

Belhadi et. al. (2018) suggested that having ten or below sample sizes is sufficient for generating reliable and useful information. Therefore, the research"s sample is ten responses or below from each functional group from the LSS candidates or belts by the functional groups.

Table 3.7: Examples of Fuzzy logic sampling plan

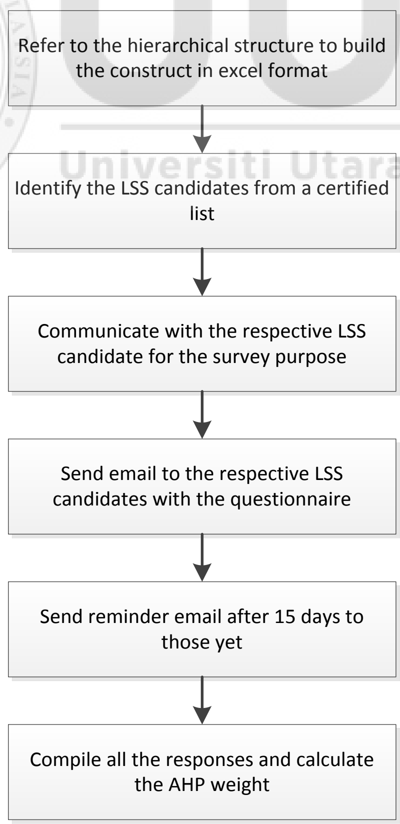
	Researcher	Actual Sample Size	Area of study
1	Kuo et al. (2002)	16	Location Selection
2	Hosny et al. (2013)	20	Construction contractor
3	Lee et al. (2013)	242	Sociability in education
4	Sahin et al. (2013)	19 Residents, 10 Experts and 4 Politician	Sea level adaptation

3.8 DATA COLLECTION PROCEDURES

As the targeted respondents for this research are certified belt holders, identifying the right ones is crucial, as they are dispersed throughout the company in various areas and departments. The list and contact information of the belt holders are obtained from the LSS certification coordinator for communication purposes to increase the response rate. A questionnaire will be sent to the respondents, and the respondent will send back the completed survey through email. All answers will combine and further analyzed to get the information.

The response collection plan is as reflected in Figure 3.7.

Figure 3.7: Sample collection plan



3.9 TECHNIQUES OF DATA ANALYSIS TO BE USED

A few steps need to be followed to establish the fuzzy AHP and finally calculate the ranking based on the recommendation by Yadav et al. (2017) and Patil et al. (2014).

1. Identify and set up the decision group.

In this study, the respondent‟s group is the certified LSS, either in Lean or Six Sigma, or Lean Six Sigma, from different departments in the company. Some of the certified LSS is the head of a department. They were the pioneer who attended the company's LSS training and certification.

2. Identify the CSF criteria to create a hierarchical structure.

As recommended by Yadav et al. (2017), the list of CSF was listed by main and subgroup categories of respondents in the hierarchy.

3. Uses the pairwise comparison matrix by defining the scale of relative importance to consider human imprecision in qualitative assessment.

Criteria are the critical terms used to collect the information for ranking analysis. Patil et al.‟s (2014) recommended scaling of importance, and the survey question criteria are used in this research. The linguistic variables are translated into TFN as propounded in Amrita et. al., (2018). As illustrated in Table 3.8, the triangular fuzzy number (TFN) and the reciprocal TFN are used to translate the linguistic rating by using six linguistic scales to rate the importance of each judgment based on the research by Chen et. al. (2014).

Table 3.8: *Triangular Fuzzy Number table*

Scale of important	Triangular fuzzy scale			Reciprocal Triangular fuzzy scale		
	l	m	u	l	m	u
Just Equal	1	1	1	1	1	1
Equally Important	1/2	1	3/2	2/3	1	2
Weakly more important	1	3/2	2	1/2	2/3	1
Strongly more important	3/2	2	5/2	2/5	1/2	2/3
Very strongly important	2	5/2	3	1/3	2/5	1/2
Absolutely more important	5/2	3	7/2	2/7	1/3	2/5

The subsequent steps are the mathematical processes in the prioritization calculation.

1. Creates a Fuzzy pairwise Comparison matrix (FCM)

The TFN is used to build the comparison matrix, known as the Fuzzy pairwise comparison matrix (FCM). Respondent‟s choices from the survey are converted to FCM by referring to the scale of importance in Table 3.5.

$$\tilde{X} = \begin{Bmatrix} 1 & x_1 & x_2 \\ \frac{1}{x_1} & 1 & x_3 \\ \frac{1}{x_2} & \frac{1}{x_3} & 1 \end{Bmatrix}$$

2. Convert FCM to CCM

The α-cut operation is applied to convert the FCM to the Crisp pairwise comparison matrix (CCM). As recommended by Adamo (1980), the probability for each judgment, denoted by α, is added. It is used to calculate the confidence interval over the decision maker‟s preference or judgment, as shown in equation (1), and the formula (2) is used to convert the FCM to CCM. That is an extension of the Fuzzy AHP when the data is associated with the linguistic nature. It is calculated with the probability of any other occurrence on a judgment.

$$[l^{\propto}, u^{\propto}] = [(m-l) \propto +l, -(u-m) \propto +u)] \quad \text{-- (1)}$$

Where,

m is the rated fuzzy number by the experimenter

l is the lower TFN value

u is the upper TFN value

α is equal to 0.5 probability

$$x_{ij} = \mu \tilde{x}^{\alpha}{}_{ijl} + (1-\mu)\tilde{x}^{\alpha}{}_{iju} \quad \text{Where the } 0 \leq \mu \leq 1 \quad \text{--- (2)}$$

The formula (1) and (2) are referred to; the α and μ can be any value from 0 to 1. It depends on the decision-making environment. The α value can be increased if the environment is stable;. At the same time, the μ denotes the degree of a decision maker's optimism; the lower value of μ means the decision-maker is very optimistic (Chen et al., 2014).

3. Check the consistency

This step calculates the consistency ratio (CR), starting from the consistency index (CI). Referring to Yadav et al. (2013), the author has applied a geometric mean to calculate λmax; therefore, each row of the criteria in a matrix is multiplied with the square root by the number of factors for each row.

$$\tilde{x}_i = \sqrt[j]{\prod_{j=1}^{j} x_j} \quad \text{--- (3)}$$

Sum all the rows,

$$\tilde{x}_{max} = \sum_{0}^{i=n} \tilde{x}_n \quad \text{---(4)}$$

Calculate the priority vector or the local weight

$$w_j = \frac{\tilde{x}_i}{\tilde{x}_{max}} \quad \text{---(5)}$$

Calculate the consistency index (CI),

$$\lambda_{max} = \sum_{k=1}^{n} \tilde{x}_{ik} w_{kj} \quad \text{---(6)}$$

$$CI = \frac{\lambda_{max} - n}{n-1} \quad \text{--- (7)}$$

Calculate the consistency ratio (CR),

$$CR = \frac{CI}{RI} \quad \text{--- (8)}$$

The Random consistency index (RI) is a simulated average CI where the judgments were randomly filled into matrices and expected to be highly inconsistent if the ratio of CI / RI is high. Referring to Table 3.9, the RI value is simulated with 100,000 and 500,000 matrices, respectively, as propounded by Alonso et al. (2006).

CR is used to compare the CI of the matrix versus the Random Consistency Index (RI). The AHP is acceptable if CR with less or equal to 0.1 or 10% (Yadav et al., 2017; Alonso et al., 2006); the judgment must be revised by identifying the cause of inconsistency.

Table 3.9: Alonso-Lamata RI values

N	RI (100000 matrices)	RI (500000 matrices)
1	0	0
2	0	0
3	0.5245	0.5247
4	0.8815	0.8816
5	1.1086	1.1086
6	1.2479	1.2479
7	1.3417	1.3417
8	1.4056	1.4057
9	1.4499	1.4499
10	1.4854	1.4854
11	1.5141	1.5140
12	1.5365	1.5365
13	1.5551	1.5551
14	1.5713	1.5713
15	1.5838	1.5858

4. It is a similar method for sub-group calculation; therefore, repeat steps 3 to 4 for sub-group CCM.

5. Multiplying the subgroup CCM to calculate the priority vector from formula (5) will give the priority ranking

6. The consistency ratio is accessed, as stated in (6) to (8).

7. As the study involves multiple subjects for each functional group, some steps are needed to aggregate the individual matrices into a group matrix. Petra et al. (2018) stated two

approaches to a group or aggregated the individual fuzzy comparison matrices into a group matrix. The most commonly used method is selecting the minimal fuzzy value for lower TFN and maximal value for upper TFN. Meanwhile, the middle TFN is applying formula (11), based on the geometric mean by using the formula. Chen et al. (2015) has used a similar method to calculate the traditional AHP that applies the arithmetic mean to group the individual judgment.

Refer to formula (1), the individual TFN judgments are $\tilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right)$, where i,j = 1,….,n.

The formulas are used to group fuzzy, as the comparison matrix is shown below.

$$\left(\tilde{a}_{ij}^{group}\right)_{n\times n} = \left[\left(l_{ij}^{group}, m_{ij}^{group}, u_{ij}^{group}\right)\right]_{n\times n} \qquad \text{---(9)}$$

$$l_{ij}^{group} = \min_{k=1,2,\ldots,m}\left\{a_{ij}^{k}\right\} \qquad \text{---(10)}$$

Where m is the number of the individual matrix

$$m_{ij}^{group} = \left(\prod_{k=1}^{m} a_{ij}^{k}\right)^{1/n} \qquad \text{---(11)}$$

The formula also can expand in such a way

$$\tilde{a}_{ij}^{k} = \left(\tilde{a}_{ij}^{1} \odot \ldots\ldots \odot \tilde{a}_{ij}^{n}\right)^{1/n}$$

$$u_{ij}^{group} = \max_{k=1,2,\ldots,m}\left\{a_{ij}^{k}\right\} \qquad \text{---(12)}$$

According to Narens et al. (1993), the arithmetic mean is the most commonly used to combine a set of alternatives to form a consensus rating. However, it must assume the rating of the individual judges is used to create ration scales. Nevertheless, this is not valid if the purpose is to yield the same overall ranking where the particular units are selected independently for each individual scale. In this case, the author proposes using the geometric mean to combine all the ratings for ranking. Similar comment from Dijkstra (2013), the author cites that the geometric mean is used to synthesize two judgments or two pairwise comparison matrices of the same problem, a situation that happens when the different condition of an agreement between two subjects or experts has to be considered.

Therefore, the second method, the geometric mean, is applied to the group of the individual matrix. Referring to Buckley (1985), in his article on Fuzzy Hierarchical Analysis, which is also applied by Beskese et al. (2015), the average of positive reciprocal matrices is determined or calculated as shown in (11). This research used the method from (9) to (11) for data aggregation because the first method is the most commonly used, as mentioned in Petra et al. (2018).

Last but not least, the individual priority vector or the local weight for each subcategory is multiplied with the main category‟s local weight to gain the global weight (Mu et al., 2017; Kil et al., 2016), which are used for the overall ranking of each factor.

Other statistical methods are applied in the analysis, such as descriptive statistics and clustering, to explain better and compare. It helps summarize the analytic result and provides a more comprehensive explanation and conclusion.

CHAPTER 4: RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter presents the Fuzzy calculation result to get the local weight, the priority vector used for prioritization. The first analysis prioritized the three major categories and their subcategories to answer the hypotheses. Finally, the global weight or global priority vector is calculated for CSF prioritization.

The data analysis goes by functional groups: external experts, internal experts, engineering groups, quality groups, and operation groups. The last analysis is the overall ranking for the organization by excluding the external experts.

The clustering technique is used on the priority vector, efficiently analyzing the priority pattern among the functional groups to find the similarities or differences. The result gives an in-depth analysis of the group's ranking, and the differences between them are briefly explained.

The questionnaires were distributed to two external experts and four internal experts as validation before distributing the questionnaires to all respondents. The expert‟s validation approved the questionnaire as acceptable and is used to analyze the priority of CSFs.

Ten questionnaires were sent to three groups, with a return of six responses from a quality group, eight responses from the engineering group, and six responses from the operation group within 1 month. It comprises a total of 20 responses or a 66.7% response rate, as reflected in Table 4.1. Table 4.2 to table 4.4 are the respondent‟s demography by position, age, and gender.

Table 4.1: Response from the survey

Group	Distributed number	Received number	Percent of response
Quality	10	6	60.0%
Engineering	10	8	80.0%
Operation	10	6	60.0%
Total	30	20	67.7%

Table 4.2: Respondent's position distribution

Position	Count	Percent
Manager	7	35%
Engineer	8	40%
Supervisor	5	25%

Table 4.3: Respondent's age distribution

Age	Count	Percent
≤30	2	10%
30<x≤ 35	6	30%
35<x≤ 40	4	20%
40<	8	40%

Table 4.4: Respondent's gender distribution

Gender	Count	Percent
Male	12	60
Female	8	40

4.2 FUZZY AHP ANALYTIC METHOD

The data from the respondents have gone through 2 tiers of calculation, which are explained below.

Tier 1: Step 1 to step 6 from section 3.8 are applied to calculate the lambda to gain the CR for each matrix and assess the CR as an acceptance criterion.

The individual matrix is calculated in excel with coded functions. Only then the content of the matrix table is transferred to another excel worksheet for the combination matrix. This method can guarantee the CR criteria are being met and increase the usable rate. It also eliminates the cycle time to follow the returning path if it fails the criteria.

Tier 2: Step 7 is applied to combine all the matrices and rank up the priority for the main category and subcategory to assess the importance of CSF in LSS deployment in the organization. Finally, all functional groups are combined into one matrix.

4.2.1 TIER 1: INDIVIDUAL MATRIX

The first step is converting the questionnaire to a matrix table, as shown in Table 4.5. The table is the original format for a rating pairwise. The respondent's answer is converted to the table, and the response is reciprocal to each other, which means the answer must tend to either side for each pair. For instance, the respondent rate of involvement and engagement is very strongly important compared to the management initiative; thus, the "Y" is at factor A rating 4.

Table 4.5: Fuzzy logic questionnaire matrix

Factor A	<--Factor A more important than B					Factor B more important than A -->				Factor B
	Absolutely	Very strongly	Strongly	Weakly	Equally Important	Weekly	Strongly	Very strongly	Absolutely	
	5	4	3	2	1	2	3	4	5	
Involvement and engagement		Y								Management Initiative
Involvement and engagement								Y		Technology and knowledge
Management Initiative								Y		Technology and knowledge

The rating from the table is the arrays of data that are used to form a matrix structure. It creates the Fuzzy Pairwise Comparison matrix (FCM) by using the TFN to build the comparison matrix consisting of TFN and reciprocal TFN.

Table 4.6: TFN and Reciprocal TFN table

			Triangular fuzzy scale			Reciprocal Triangular fuzzy		
Prefered Factor	Relationship	Selection	m	l	u	m^{-1}	l^{-1}	u^{-1}
A	Absolutely	5	3.000	2.500	3.500	0.333	0.286	0.400
	Very strongly	4	2.500	2.000	3.000	0.400	0.333	0.500
	Strongly	3	2.000	1.500	2.500	0.500	0.400	0.667
	Weakly	2	1.500	1.000	2.000	0.667	0.500	1.000
	Equally Important	1	1.000	0.500	1.500	1.000	0.667	2.000
B	Weekly	2	0.667	0.500	1.000	1.500	1.000	2.000
	Strongly	3	0.500	0.400	0.667	2.000	1.500	2.500
	Very strongly	4	0.400	0.333	0.500	2.500	2.000	3.000
	Absolutely	5	0.333	0.286	0.400	3.000	2.500	3.500

The FCM matrix consists of the upper (u), middle (m), and lower (l), which are known as Triangular Fuzzy Numbers (TFN). This matching method is also applicable for reciprocal fuzzy numbers. The rating 4 from factor A has six values for TFN and reciprocal TFN for m, l, u, m^{-1}, $l^{-1,}$ and u^{-1}. These values are used to create the FCM matrix for upper TFN, TFN, and lower TFN; refer to Table 4.7 to 4.9. FCM matrix is used to contain the potential uncertainty to assess the respondent's ambiguity when making a choice.

Table 4.7: Matrix of upper fuzzy number

Upper TFN, *u*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	3.000	0.500
Management initiative	0.500	1.000	0.500
Technology and knowledge	3.000	3.000	1.000

Table 4.8: Matrix of middle fuzzy number

TFN, *m*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.500	0.400
Management initiative	0.400	1.000	0.400
Technology and knowledge	2.500	2.500	1.000

Table 4.9: Matrix of lower fuzzy number

Lower TFN, *l*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.000	0.333
Management initiative	0.333	1.000	0.333
Technology and knowledge	2.000	2.000	1.000

However, to convert the FCM to CCM, the matrices must go through another calculation step to create the lower and upper alpha matrix. The formula – (1) from chapter 3 is applied to creates two tables for $l^{\propto}$ (Table 4.10) and $u^{\propto}$ (Table 4.11).

Table 4.10: Lower alpha matrix

lower alpha, *l-α*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.250	0.367
Management initiative	0.367	1.000	0.367
Technology and knowledge	2.250	2.250	1.000

Table 4.11: Upper alpha matrix

Upper alpha, u-α	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.750	0.450
Management initiative	0.450	1.000	0.450
Technology and knowledge	2.750	2.750	1.000

The next step is applying the formula – (2) from chapter 3 to convert FCM to CCM, as shown in Table 4.12.

Table 4.12: Crisp pairwise comparison matrix

x_{ij}	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.500	0.408
Management initiative	0.408	1.000	0.408
Technology and knowledge	2.500	2.500	1.000

The CCM is used to calculate the priority vector, or some researchers call it local weight (w). The formula – (3) to (5) from chapter 3 is used to calculate the priority vector (w) or local weight.The priority vector or the local weight is used to prioritize all the factors, as shown in Table 4.13.

Table 4.13: Crisp pairwise comparison matrix with priority vector or local weight

xij	Involvement and engagement	Management initiative	Technology and knowledge	Priority Vector
Involvement and engagement	1.000	2.500	0.408	0.296
Management initiative	0.408	1.000	0.408	0.162
Technology and knowledge	2.500	2.500	1.000	0.542

The priority vector used to calculate the CR validates the response and determines whether the answers are logically accepted or rejected. Any rejected response must send back to the corresponding respondent for redoing. However, as the construct design embedded the validation portion, the respondent can immediately go for rectification if the CR fails. It helps to increase the usability when receiving the response.

The same steps are repeated for all the subcategories and create Table 4.14 for each respondent"s result. The matrix will be accepted if the CR is below 10%; all the matrices have to be tested with the CR ratio before proceeding to the next step and combining them.

Table 4.14: *CR ration for a health check*

Category	CR ration	Healthiness
Main	7.30%	Good
Involvement & Engagement	7.30%	Good
Management	7.30%	Good
Technology Knowledge	4.91%	Good

4.2.2 TIER 2: GROUP MATRIX

The FCM matrices are combined to get an overall ranking to evaluate every CSF from all the respondents.

Table 4.15: Combined matrix of lower fuzzy number

Lower TFN, *l*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	0.400	0.333
Management initiative	0.286	1.000	0.333
Technology and knowledge	0.286	0.333	1.000

Table 4.16: Combined matrix of middle fuzzy number

TFN, m	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	1.223	1.297
Management initiative	0.818	1.000	1.121
Technology and knowledge	0.771	0.892	1.000

Table 4.17: Combined matrix of upper fuzzy number

Upper TFN, *u*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	3.500	3.500
Management initiative	2.500	1.000	3.000
Technology and knowledge	3.000	3.000	1.000

The combined matrix is used to create two tables for $l^{\propto}$ and $u^{\propto}$.As shown in Table 4.18 and Table 4.19. This similar method is repeated to other functional groups: the quality department, engineering department, operation department, internal experts, and external experts.

Table 4.18: Lower alpha table for group matrix

lower alpha, *l-α*	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	0.594	0.679
Management initiative	0.697	1.000	0.730
Technology and knowledge	0.631	0.610	1.000

Table 4.19: Upper alpha table for group matrix

Upper alpha, u-α	Involvement and engagement	Management initiative	Technology and knowledge
Involvement and engagement	1.000	2.201	2.262
Management initiative	2.304	1.000	2.064
Technology and knowledge	1.988	1.943	1.000

The formula (2) is used to create group CCM as shown in Table 4.20, where the priority vector is used to prioritize the factors for the main category and subcategory. The subcategory's priority vector is multiplied by the main category's priority vector. It is to create a global priority vector for overall prioritization. The global priority vector is used to prioritize all factors in the three main categories, which are used to analyze further the effects of the main category and CSF pattern in the organization in LSS deployment.

Table 4.20: Local priority for main category

xij	Involvement and engagement	Management initiative	Technology and knowledge	Priority Vector	Local Priority
Involvement and engagement	1.000	1.398	1.471	0.340	2
Management initiative	1.500	1.000	1.397	0.342	1
Technology and knowledge	1.309	1.277	1.000	0.317	3

4.3 HYPOTHESIS ANALYSIS AND RESULT

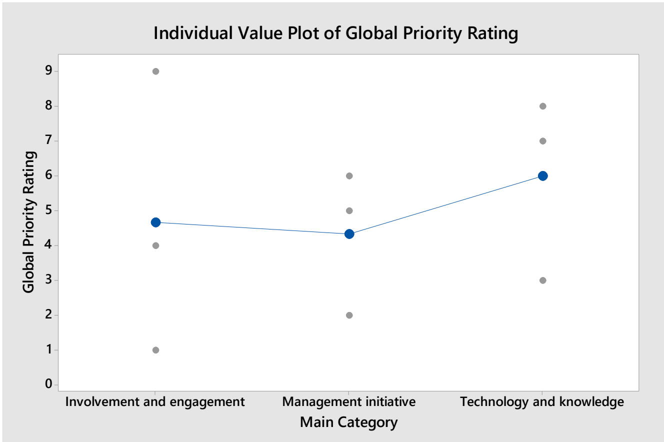
The overall ranking analysis has excluded the external consultants. Table 4.21 represent the overall ranking of CSF in the Company. Refer to the global priority rating for the ranking result. The main category ranking is highlighted in blue, while the individual CSF ranking is those cells at the bottom without blue highlighted.

Table 4.21: Overall ranking

Factor/Sub factors	Average	Priority Vector	Local Priority Rating	Global Priority Vector	Global Priority Rating
Involvement and engagement	1.271	0.340	2	-	2
Management initiative	1.280	0.342	1	-	1
Technology and knowledge	1.187	0.317	3	-	3
Employee involvement	1.246	0.337	2	0.114	4
Customer Focus	1.392	0.376	1	0.128	1
Supplier Focus	1.065	0.288	3	0.098	9
Management Commitment	1.209	0.323	2	0.111	5
Organizational Culture	1.201	0.321	3	0.110	6
Communication	1.332	0.356	1	0.122	2
Understand tools and technique	1.402	0.369	1	0.117	3
Training and education	1.219	0.321	2	0.102	7
Organizational infrastructure	1.179	0.310	3	0.098	8

As shown in Figure 4.2, the Minitab is used to plot an individual value plot for visualization, which helps conclude the main category's importance. Figure 4.2 uses the global priority vector in the chart plotting. The higher global priority vector gives the most high ranking (lower number) and reversely with the low global priority vector.

Figure 4.2: Individual plot for Global Priority Rating by Main Category



H_a: Involvement and engagement elements and their subcategories are the most important

The priority rating shows that the hypothesis is not the most important category but ranks as the second most important category. The employee involvement and supplier focus cause the overall ranking of Involvement and engagement main category falls behind the Management Initiative. However, customer focus is the most important CSF among all critical factors within this category and overall ranking with other CSFs.

H_b: Management initiative elements and their subcategories are the most important

The management initiative is being rated as the most critical factor in the LSS deployment's success. Communication is the second higher-ranked factor in the overall CSF ranking; Management commitment and organizational culture rank at fifth and sixth respectively under the management initiatives.

H_c: Technology base elements and knowledge of its subcategories are the most important

This category is rated as the least important category compared to others. Training and education, and organizational infrastructure are lower ratings under the technology and knowledge category. Nevertheless, understanding tools and techniques ranks the top 3 in the overall CSF ranking.

The top three come from different main categories. It hints that the CSF from each category carries its weight in overall ranking though its main category is the most important or least important. The overall ranking is independent of its main category. In general, the factors under management initiative are falling at high priority compared to others. The scores of management initiative and involvement, and engagement are very close. It hints the respondents perceived both main factors are essential and critical to the success of the deployment.

4.4 RANKING ANALYSIS BY FUNCTIONAL GROUP

The analysis was further performed with different functional groups to analyze the CSF ranking structure and compare the similarities and differences between the various categories and sub-categories of respondents. It provides a more in-depth analysis and understanding of any discrepancy or similarity from the respondent's choices by their function in the company. The ranking result from different functions shows in Table 4.22 to Table 4.26. The analysis also includes the internal and external experts, which assesses any similarity between expert and practitioner‟s perspectives.

Table 4.22: External Expert RatingExternal Expert Rating

Category/Sub-category	Priority Vector	Local Priority Vector	Global Priority Vector	Global Priority
Involvement and engagement	0.338	2	-	2
Management initiative	0.402	1	-	1
Technology and knowledge	0.261	3	-	3
Employee involvement	0.378	2	0.127	5
Customer Focus	0.423	1	0.143	1
Supplier Focus	0.199	3	0.067	9
Management Commitment	0.354	2	0.142	2
Organizational Culture	0.323	1	0.130	3
Communication	0.323	3	0.130	3
Understand tools and technique	0.284	2	0.074	8
Training and education	0.417	1	0.109	6
Organizational infrastructure	0.299	3	0.078	7

Table4.23: Internal Expert Rating

Category/Sub-category	Priority Vector	Local Priority	Global Priority Vector	Global Priority
Involvement and engagement	0.317	2	-	2
Management initiative	0.375	1	-	1
Technology and knowledge	0.307	3	-	3
Employee involvement	0.371	2	0.118	6
Customer Focus	0.437	1	0.139	1
Supplier Focus	0.192	3	0.061	9
Management Commitment	0.344	1	0.129	3
Organizational Culture	0.330	2	0.124	4
Communication	0.326	3	0.122	5
Understand tools and technique	0.440	1	0.135	2
Training and education	0.343	2	0.106	7
Organizational infrastructure	0.216	3	0.067	8

Table 4.24: Operation Group Rating

Category/Sub-category	Priority Vector	Local Priority Vector	Global Priority Vector	Global Priority
Involvement and engagement	0.265	3		3
Management initiative	0.393	1		1
Technology and knowledge	0.341	2		2
Employee involvement	0.346	2	0.092	7
Customer Focus	0.393	1	0.104	6
Supplier Focus	0.261	3	0.069	9
Management Commitment	0.293	3	0.115	4
Organizational Culture	0.400	1	0.157	1
Communication	0.307	2	0.121	3
Understand tools and technique	0.451	1	0.154	2
Training and education	0.237	3	0.081	8
Organizational infrastructure	0.312	2	0.107	5

Table 4.25: Engineering Group Rating

Category/Sub-category	Priority Vector	Local Priority Vector	Global Priority Vector	Global Priority
Involvement and engagement	0.372	1	-	1
Management initiative	0.314	3	-	3
Technology and knowledge	0.314	2	-	2
Employee involvement	0.332	2	0.123	2
Customer Focus	0.363	1	0.135	1
Supplier Focus	0.306	3	0.114	4
Management Commitment	0.348	2	0.109	6
Organizational Culture	0.261	3	0.082	9
Communication	0.391	1	0.123	3
Understand tools and technique	0.323	2	0.101	7
Training and education	0.319	3	0.100	8
Organizational infrastructure	0.358	1	0.113	5

Table 4.26: QA Group Rating

Category/Sub-category	Priority Vector	Local Priority Vector	Global Priority Vector	Global Priority
Involvement and engagement	0.332	3		3
Management initiative	0.334	2		2
Technology and knowledge	0.334	1		1
Employee involvement	0.327	2	0.109	4
Customer Focus	0.372	1	0.124	3
Supplier Focus	0.301	3	0.100	7
Management Commitment	0.320	2	0.107	5
Organizational Culture	0.295	3	0.098	8
Communication	0.385	1	0.129	2
Understand tools and technique	0.410	1	0.137	1
Training and education	0.290	3	0.097	9
Organizational infrastructure	0.300	2	0.100	6

The ranking in various functional groups will be used in further analysis in clustering to check the similarity.

4.4.1 MAIN CATEGORY BY FUNCTIONAL GROUP

The internal practitioner‟s opinion is similar to external consultants, where both have agreed that the Management Initiative is the most important factor, followed by Involvement and Engagement. At the same time, Technology and Knowledge are comparably less critical. Compared to other groups, the operation group is very much closer to the LSS expert‟s opinion. They agreed that the management initiative is the most crucial factor. Still, they reverse the other two factors as they deem Technology and Knowledge is more important than Involvement and Engagement with different parties. Engineering and quality groups held different thoughts; meanwhile, engineering puts Involvement and Engagement with different parties as most important, whereas respondents from the quality department put this category as a lower priority. Quality department respondents deem Technology and Knowledge the most important, followed by Management Initiatives. Engineering department respondents list technology and knowledge as the second important factor, while management initiatives are less critical. The ranking by primary category respondents are reflected in Table 4.27.

Table4.27: Ranking by Main Category

Main Category	Ext Expert	Int Expert	Engineering	Operation	QA	Overall
Involvement and engagement	2	2	1	3	3	2
Management initiative	1	1	3	1	2	1
Technology and knowledge	3	3	2	2	1	3

4.4.2 SUB-CATEGORY BY FUNCTIONAL GROUP

The clustering approach is applied to group up the high similarity group for further analysis. The priority vector is used to improve the discrimination level, which will help to determine the precise outcome analysis. The ranking is a discrete number, where the distance between the values is to be ignored. The number of rankings has a constant distance between the numbers. Thus it will be missing some information in the analysis. Priority vector is used to rank each factor's importance and measure the degree of importance between the factors. The ranking is determined by referring to this value hence the analysis will give more meaningful outcomes.

Clustering analysis method is used to sort a correlation matrix to yield clusters (Blashfield et al., 1988). Amalgamation steps are used in clustering to explain the log-ratio variances to study any set of contrasts and assesses by log-ratio variance explained on a complete set of log-ratios to define a clustering of parts based on their amalgamations (Greenacre, 2019). This technique identifies the clusters of different functions to know which functions can be included in the same cluster. The result will provide the information of similarity for further study.

The amalgamation steps are used to identify the appropriate number of clusters to analyze the similarities among the functional group's subcategory rankings. The amalgamation steps show that the number of three clusters is the most appropriate because there is a significant change in the similarity level. The distance level between steps 2 and 3 is huge.

Figure 4.3: Cluster the groups to study the similarity

Amalgamation Steps

Step	Number of clusters	Similarity level	Distance level	Clusters joined		New cluster	Number of obs. in new cluster
1	4	84.4980	0.31004	1	2	1	2
2	3	72.3183	0.55363	4	5	4	2
3	2	53.3882	0.93224	1	4	1	4
4	1	25.2932	1.49414	1	3	1	5

Final Partition

	Variables
Cluster 1	External Expert Internal Expert
Cluster 2	Engineering
Cluster 3	Operation QA

The groups are partitioned into 3 clusters, as shown in Figure 4.3, where the external and internal experts have a higher similarity. In contrast, respondents from both operation and quality groups have high similarity, and the engineering group respondents are standalone. On the other hand, engineering department respondents hold a different thought than operation and quality department respondent groups.

Table 4.28: Sub-category ranking by functional group

Sub-Category	Code	Ext Expert	Int Expert	Eng	Ops	QA	Overall
Employee involvement	EI	5	6	2	7	4	4
Customer Focus	CF	1	1	1	6	3	1
Supplier Focus	SF	9	9	4	9	7	9
Management Commitment	MC	2	3	6	4	5	5
Organizational Culture	OC	3	4	9	1	8	6
Communication	Co	3	5	3	3	2	2
Understand tools and technique	TT	8	2	7	2	1	3
Training and education	TE	6	7	8	8	9	7
Organizational infrastructure	OI	7	8	5	5	6	8

Table 4.28 shows the overall ranking, while the function‟s ranking varies. Applies the individual plots for better visualization and standard deviation test to study the degree of agreement between the functional groups. Figure 4.4 shows the confidence interval for each CSF and indicates the choices of each function are very much different.

Figure 4.4: Individual plot of priority vector for different factor/subcategory with all functional groups

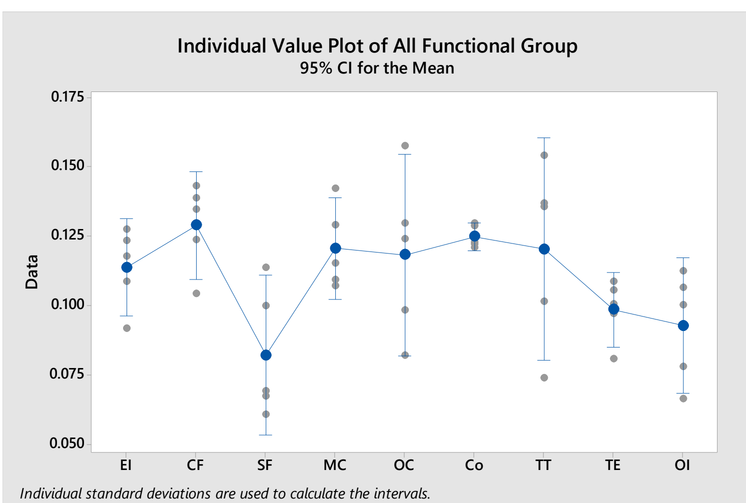


Figure 4.5: *Standard Deviation test for each factor*

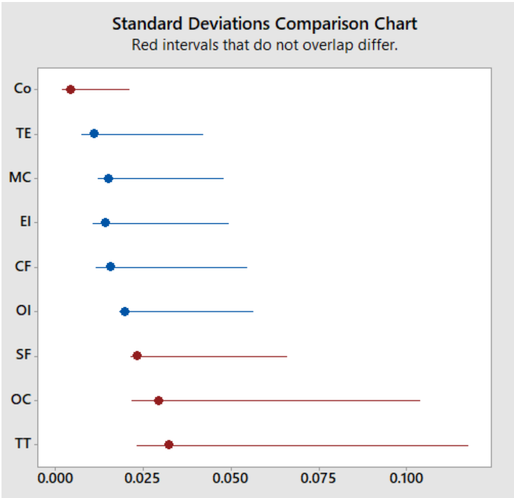


Figure 4.5 shows that communication has minor fluctuations among the other subcategories. This hints that different functional groups have a high degree of agreement on the same rating. Supplier Focus, Organizational Culture, understand tools and techniques are the three factors lacking in the unanimous agreement between these functional groups. The other factors or subcategories have gained moderate agreement among the functional group on the rating, such as Training and Education, Management Commitment, Employee Involvement, Customer Focus, and Organizational Infrastructure.

4.5 DISCUSSION

This portion is an in-depth discussion of the three hypothese‟s findings to explain the hypothese‟s results for three major categories of CSFs and elaborate the findings. Last but not least, further discuss the application of Fuzzy AHP in the development analyzing.

4.5.1 HYPOTHESIS ON INVOLVEMENT AND ENGAGEMENT

Overall, this main category is the second important area that would affect the organization's LSS deployment's success. More functional groups agree that the category is not the most important. Nevertheless, customer focus is the most crucial CSF than other CSF in other main categories; while employee involvement is moderate, supplier focus is the less critical.

Respondents from the engineering department gave different ratings than other functional groups. They perceived the importance of various partie‟s involvement as critical to the LSS deployment's success, whereas the Operation and Quality team deemed it the least important area. The operation team did not perceive the value of people involvement or participation of a third party as significant. The internal or external experts believed that involvement and engagement are essential, while customer focus is a predominant factor compared to other CSFs.

Customer focus is the most critical CSF, as another researcher, Salah et al., (201, reflects the purpose of LSS deployment to achieve customer satisfaction with quality, delivery, and cost by improving the process. Nwokah, (2009) cites customer focus includes the activities on the customer's comments, complaints, evaluation ways to assess the product value, and customer satisfaction level, affecting its market performance. Therefore, the practitioners perceived the customer focus as critical because it is the motivation to embrace the LSS in the company. The adoption of LSS in the IMS is also practiced in the company to fulfill the requirement of continual improvement. Some companies applied the continuous improvement concept in quality management as Agrawal (2020) proposed to satisfy the customer. Majstorovic et al., (2015) mentioned it provides better internal efficiency and external benefit as expected by customers. Mehralian et al., 2016) cites it is important, as a supplier's low-quality material will damage the product or its image

The study revealed that the supplier is at the lowest in ranking, close to Lande et al. (2016) that the supplier factor is at the top 8 amongst the CSFs. The result also matches the conclusion from Laureani et al. (2012). The author suggested the company focus on mastering the LSS methodology and deployment before proliferating its suppliers. The company has to spend years getting the LSS deployment to be mature. Thus, collaboration with suppliers is not the key focus. However, it is important to manage the relationship with a supplier to gain their commitment and sustain the excellent quality right from the incoming stage, Mehralian et. al., (2016) support this point.

According to the internal practitioners, some quality and engineering engineers have to work on the DMAIC project with essential suppliers, where they lead the project. The engineer may not think it is necessary to involve the supplier intensively because they can work on the project and direct the supplier to support them in problem-solving. The supplier follows the instruction because most of them are not familiar with LSS tools and techniques. As the situation is, the relationship is more directive than a partnership to work on the LSS project.

The employee involvement rank at 4, the result also supported by many researchers as Anthony et al., (2019). The authors urge to have consistent and uniform policies to motivate its employees to achieve the goal. While Amah et al., (2013) and Antony (2002) cite the employee's involvement varies in different areas, the participation in decision making, reward, recognition, training, and project and knowledge sharing for productivity improvement. The company also engages the employee with monetary and non-monetary rewards. The LSS certification is one of the engagement channels; as stated in the Jayaraman et al. (2012) study, it is common under the Malaysia context. The employee‟s participation from all departments in the LSS initiative is vital in inculcating its LSS culture. The LSS sustainability depends on the degree of LSS permeation into all departments in the organization, as propounded by Michael (2020). As a result, the success in the project competition raises awareness of the importance of employee involvement. Thus, the ranking has fallen to a higher position than supplier involvement.

4.5.2 HYPOTHESIS ON MANAGEMENT INITIATIVE

Based on Jayaraman (2012), whose research is based on an empirical study in the Malaysian context, the success of the LSS in the organization needs engagement and commitment from the management, communication, and supportive organizational culture. The research has supported the second hypothesis since management initiative, which is the main category in this research, is the most critical in LSS deployment.

However, the engineering department respondents have rated this category as least significant, followed by the quality group perceived, as it has a moderate effect on the LSS deployment. LSS experts and operation's targeted group perceived the category's factors, namely Management Commitment, Organizational Culture, and Communication, as critical categories in the company‟s LSS success.

Swarnakar, V., et. al. (2021) and Raval, S.J., et. al. (2021) rank the management commitment as the most critical CSF. It reflects that CSF is a vital factor in the whole deployment program. Assarlind et. al., (2014) and Ahire et. al. (1998) also support top management‟s commitment and customer focus seem to be critical factors, and these factors have linkage. The author cites top management's commitment to satisfy the customers and improve organizational performance by creating values, goals, and systems. Nevertheless, management commitment ranks 5th; the experts deem the factor is the top three of the critical factors compared to the practitioners from different functions.

Alhaqbani et al. (2016) found that commitment from the top management is a significant factor, but the commitment from other managerial levels is also equally crucial. The participants may not have a direct connection with the top management. The part of the middle management might also explain the micro-climate as stated. The respective department head may vary in commitment, either aligned with or disagreeing with the top management direction. Their response or commitment may finally affect each individual's perception in each functional group.

Communication has been very consistent in rating from various functional groups compared to other CSFs. This factor seems to be critical within the main category, and most of the functional groups rated it as either a second or third in terms of it importance. Thus, it is a second important factor in the overall rating. It is supported in many kinds of research, and communication is essential, as mentioned by Yadav et al. (2019) and Antony et al. (2017). It has been concluded by Chairini et al. (2016) that the strong commitment of top and senior managers in communication are critical to start the deployment. It is the top one in the management initiatives, and it suggests that the management should prioritize the CSF in the LSS deployment program.

However, the result contradicts the research conducted by Brkic et al. (2016); the author concluded that communication is not significantly observed in a multinational organization. Similar comment from Alblooshi et. al., (2020), the author gave a different result in his study. He revealed that the organizational culture and management commitment are critical. However, communication has been a less critical factor.

According to the internal experts, communication is extensively considered in delivering success stories from the participants who succeed in the program and the employee's suggestions on good practices in their workplace. This practice is supported by Laureani et al., (2015). Success story sharing happens in monthly LSS projects sharing. The most effective success story sharing is joining the external project sharing, such as Regional Team Excellence (RTEx), Annual Productivity & Innovation Conference and Exposition (APIC), and International Convention on QC Circles (ICQCC). The broadcasting and various communication on the success of the glorious winning is part of the communication to excite the employees to join the LSS program. The result has been very encouraging, which has successfully attracted many employees and had been a catalyst in change management to the culture than any other types of communication.

Organizational culture is one of the three most controversial factors in the ranking from different functional groups. According to Douglas et al. (2017), organizational culture and climate are two distinct factors even though interrelated. Organizational climate is about the perception of employees on the organizational culture. The author argues that organizational climate readiness is critical before the deployment, meaning the organizational culture is ready for a change, whereby readiness refers to the quality-driven culture in his research. Therefore, the ranking from different groups could indirectly measure their perception of preparedness and importance. Operation perceived the factor as the most important, whereas the quality and engineering group held a different thought. Expert groups take it as the third and fourth vital factor to succeed the organization's LSS. The expert groups ranked organizational culture as the top 3 factors, but in overall ranking, it ranked 6. This CSF is one of the most inconsistent rankings from different functional groups from the standard deviation analysis.

Douglas et. al. 2017 mention it is not easy to understand the culture, as it can pose a challenge when dealing with psychological experience: knowing why and how and counteracting resistance to initiate a change, as cited in Johnson et. al, (2016). Nevertheless, cultural change effort is always linked to management (Arcidiacono et al., 2016; Hilton et al., 2012; Alidrisi, 2014). Thus, management should identify the resistance to facilitate the cultural change. One of the challenges is that the managers assume the organization is always ready to change, which could be the reason why the rating is moderate and reflects the degree of importance of the organization's factor. However, the degree of perception is significantly dissimilar between the different functional groups, which could hint at the various degree of efforts from the respective head of department (HOD) to change the culture. Alternatively, it can code the observation as a micro-climate in the organization. A similar finding also happens in the study of Jesus et al. (2016), which prioritizes various groups by different positions instead of functions.

4.5.3 Hypothesis on Technology and Knowledge

Technology and knowledge have been found to be the least essential category in this research. However, the respondents from quality perceive the category as most critical compared to other groups. Nonetheless, this category has the lowest ranking among the three categories in the overall rating assessment.

Internal practitioners perceived the category as the second important category; it might be attributed to the LSS tools used on process monitoring and improvement. Nevertheless, compared to the engineering department respondents, the tools and techniques in the category were not their priority. Nevertheless, Makrymichalos et al. (2005) emphasized that industrial engineers must appreciate the statistical tools and techniques to improve overall business performance quality.

The quality functional group perceived this category as the most important. It might attribute to the LSS deployment has fulfilled quality standards, especially the continual improvement to the customer (Karthi et al., 2011). Chaudhry et. al., (1989) mention it is common to create a continual systematic improvement in a contemporary company (Karthi et al., 2011) and satisfy the customer (Chaudhry et al., 1989) & Makrymichalos et al., 2005). Kornfeld et al. (2013), usage of inappropriate tools in a project could lead to dissatisfaction from the practitioners and the customer. Deploying the LSS tools has to meet international quality standards such as ISO9001 and IATF16949 qualification (Yadav et al., 2020) since the standard certification is a prerequisite to being a supplier in many international companies, especially in the automotive sector. It is crucial and positively related to the implementation of the integrated management system (IMS) (Majstorovis et al., 2015). IMS is a combined Quality certification where the company has three certifications, namely ISO9000, ISO14000, and OSHA. Tjahjono et al. (2010) point out that the statistical tools adopted in quality management are process improvement frameworks. Applying different tools and techniques in a quality management system will achieve a better result, which is not limited only to the product's output or financial gains but enhances the diffusion of the quality to the organization's surrounding aspects (Ismyrlis, 2017). It reflects the linkage of quality management with the LSS tools and techniques, which explains the quality group's preference.

The LSS experts do not assume technology and knowledge main category are as essential as CSFs from the two categories. It contradicts Swarnakar et. al. (2020) findings that training and education are deemed necessary to adopt a modern technology such as IR4.0.

Nevertheless, the internal practitioners emphasize understanding the tools and techniques in problem-solving, with their rating between 1 to 2, except the engineering department respondents. On the other hand, external experts or consultants hold the same, but the engineering department group rated the factors between 7 and 8. Training is not a top priority to all the respondents, where the rate is from 6 to 9, and it takes 7 in the overall ranking, which is lower than the average rating. It contradicts some findings from the research, such as Singh, M. et..al.(2021). The author claims that it is necessary to provide extensive training in advance to improve awareness about the benefit of LSS adoption in an organization.

Organizational infrastructure, which is very much relevant to the IT and IR4.0 elements, as it is a new trend in global manufacturing, occupied the lowest within this category with eighth place in the overall rating. The Organizational Infrastructure and Training have larger variance and are statistically significant compared to other factors, which points to the functional group's agreement consisting of substantial conflict. Although Understanding Tools and Techniques is the top three CSF, these two CSFs cause the category to drop to the last position in the overall ranking.

The lower rating on the organizational infrastructure shows weak support on the academician suggestions to adopt IR4.0 elements in DMAIC projects such as Arcidiacono et al. (2018). The author proposed the LSS4.0 by adopting the IR4.0 elements or tools into the DMAIC. In contrast, Siddiqui et. al. (2016) cited that the management shall commit to adopting new technology is vital in the LSS deployment. One of the potential reasons is that the company has just been embarking on the IR4.0, and the integration of IR4.0 and LSS has just started a few years back. Thus, some of the belts might realize the importance, as only a few engineers were involved in new technology development in the organization.

According to the internal experts, the training is not considered essential because the LSS belts practice these applications through mentoring and coaching. The mentoring and coaching happens with an apprentice approach by assigning an experienced coach to every trained LSS belt in project mentoring and coaching. The practices in the company are similar to the study of Anthony et al. (2019), where adequate training and learning are provided to an employee with an identified project and putting them under expert supervision with guidance on using appropriate tools. Antony et al. (2012) give a similar finding and explanation. The author cites it is difficult to change overnight with only a limited budget available for training purposes; thus, training alone is not a key focus.

4.5.4 Fuzzy AHP Analysis and Consistency Ratio Check

Some researchers commented that the Fuzzy AHP is an appropriate tool in assessing the importance of the CSF; therefore, this discussion focuses on the application of Fuzzy AHP in the study. In general, the Fuzzy AHP is helping to avoid any illogical response, which affected the conclusion and trustworthiness of the study. CR for consistency test plays a very important role to ensure the respondent is not deciding by whim but rationale.

The Fuzzy AHP can resolve the uncertainties by converting the linguistic assessment of fuzzy numbers, and Triangular Fuzzy Numbers (TFN), as being used in the practical situation by Amrita (2018). However, the drawback of the Fuzzy AHP is that the respondent needs to answer the questions logically. Most of the subjects have failed to meet the CR, thus requiring a redo of the answering with a more intensive assessment on the importance. However, some gave up after a few trials. Be that as it may, the respondent should not blindly answer the questions compared to other ranking study approaches, such as the Pareto method, as it controls the answering logic. It also explains that the responses can not get a 100% return as some respondents refuse to continue answering.

5.1 INTRODUCTION

This chapter provides high-level summary of the finding in the conclusion. This chapter also explains the manager‟s implication on the LSS deployment, which contributes to the concepts of the LSS framework for the deployment's success. It is mainly for those embarking on IR 4.0 and intends to work on the LSS 4.0 integration in the organization.

The last part of the chapter is to review and discuss the study's limitations and recommend further research that may extend the focus of this research.

5.2 CONCLUSION

Based on the research, it can be concluded that the Management Initiative is the most critical category. The second important category is the Involvement and Engagement of different parties, followed by Technology and Knowledge. However, each category's subcategories or the CSF do not show predominate the overall ranking. The CSF from each category is distributed in overall ranking, which hints at the main category's ranking, which may have some effects without fully impacting the individual CSF rankings.

The study also revealed that the CSF ranking is various with different job functions; while the expert‟s perception is different from the practitioners. Different functional groups within the organization have different thoughts on the importance of the CSFs, and it may attribute to their working environment and interaction with their surrounding factors. It might also rely on the management‟s function expectations, which is always translated into department goals.

The result reveals that customer focus is very important, the management commitment and other CSFs are very much linked to the factor. Therefore, the deployment strategy shall start with it to gain the momentum to succeed and sustain the LSS journey.

Compared to Pareto‟s approach, the AHP gives more information on the ranking and can be further analyzed by using statistical tools. It provides more information if further analyzed with other statistical tools. The statistical analysis reveals that the Supplier Focus, Organizational Culture, understand tools and techniques fail to agree unanimously in rating. It also avoids biases due to blindness selection, and it is suitable for a small population for an in-depth study.

5.3 CONTRIBUTIONS AND IMPLICATIONS OF THE STUDY

The research outcome is to assist the top management of the organization to decide which is the priority, focusing on those factors that could lead to the desired result in the form of outcome variables as propounded by Alok et al. (2013), that generally link the business profit to customer satisfaction. It indirectly shows that the focus is pursuant to the expectation from management, thus creating value for the organization.

According to Aziz et al. (2020), Malaysia is relatively slow in new technology adoption compared to Singapore and Thailand because the manufacturing industry is quite conservative in adopting new technology. Therefore, the result of the study could be used as a guideline to develop the LSS4.0 framework in another company. This research could also refer to the LSS framework for managers, especially in the semiconductor sector, to consider their LSS deployment journey.

This research gives a practical study in a semiconductor manufacturer, especially in the memory industry, while enriching similar research in different areas, as suggested by Mahipal et al. (2019) and Walter et al. (2019). It is crucial because the way of implementation could be different according to sectors (Muganyi et al., 2019; Sreedharan et al., 2016) and by countries (Jesus et al., 2016). Nevertheless, this framework might not apply to SMEs because they may face different challenges such as lack of expertise in relevant fields, budget constraints on new technology adoption, lack of awareness of LSS, and time constraints, as propounded by Antony et al. (2019). The investment is tremendous to work on a significant cultural change in a company with several thousand employees, especially with IR4.0. From another aspect, proper planning is required to avoid the investment void without achieving the desired outcome.

Prioritizing the CSFs in LSS deployment is a critical action to meet the goal, according to and sustainable (Krishna et al., 2015); Sameh et al., 2017); Yadav et al.,2017). The proposed framework can help orient the activities if internal practitioners and the organization eliminate the barrier to success. It needs to target and control the factors with a structured approach from the team (Ambekar et al., 2017). The result provides the information and awareness to the other organization in the same industry on the expected failure or CSF that should be considered to succeed the deployment (Albliwi et al., 2014), as well as a piece of beneficial information to the practitioners who intend to study the effect of the CSFs. It may help in the smoother implementation of LSS with a better understanding of LSS adoption, modifications, implementation, and even alignment processes (Lande et al., 2016). The managers can refer to the study's result to customize the LSS practical guide as shared to help companies achieve better business performance (Kader Ali et al., 2016). The study fulfills the argument from Reosekar et al. (2014). He cited that many researchers work on various models and frameworks. Their researches do not discuss the implementation status in a real environment. Similar argument from Raval et al. (201), this research covers the gap between the researcher‟s finding and the framework which results from a real environment with the opinions from the experts and internal practitioners. One exciting observation and findings is the ranking reflecting the actual need or experience derived from different functional group‟s respective environments.

The framework that experts or consultants propose might not be applicable to the company because internal and external experts may hold different thoughts. This phenomenon is probably due to experts always referring to what they have learned and experienced, which may vary to the companies' internal environments. Although Shokri (2017) suggested that collaboration between academicians and practitioners is needed, it must work wisely because different thoughts may lead to failures in sustainability. Thus, employee involvement in strategic planning is more appropriate.

Gandhi et al. (2018) has identified and prioritized the lean and green manufacturing adaptation driver using the AHP approach. He cited that the drivers could vary by sector, and prioritization differs across the nations. Therefore, the variation is deemed to be very common among the researchers. Given this notion, this research provides a piece of add-on information to compare the different nations and industries, as it is essential to avoid the wrong focus on the critical factor resulting from a deployment failure to prevent waste effort in developing the continuous improvement culture.

Raval et al. (2018) and Gurwinder et al. (2020) pointed out the lack of past research in Fuzzy AHP. It is signifies that there is a great need to research this area. The study covers a more detailed analysis of the micro-climate within a company by applying the Fuzzy AHP compared to many studies (Daniel et al., 2014; Silva et al., 2018; Yadav et al., 2017; Talib et al., 2015; Pandey et al., 2018; Silva et al., 2018; Gandhi et al., 2018).

This research contributes to the CSF prioritization with the Fuzzy AHP approach in line with a proposition. It disclosed the different functions and thought of the importance of the CSFs due to their daily job functions. This research has also revealed that the consultant and internal experts held almost similar rankings but varied with other functions, which hints that the perception is also different among the practitioners from different departments and functions. According to Kesberg et al. (2018), value is defined as an abstract belief as it provides guidelines in people"s lives and effects on how to evaluate the event and people. This value is related to the attention and interpretation of situational information. This research revealed that the perception of importance relies on the attention and interpretation of respective individuals to their day-to-day functions.

Alidrisi (2014) states many types of research have always intended to work on generalization. However, this isn't easy to achieve because a company may have its way in implementation and practice. The developed model provides a roadmap that could help the practitioner better understand some specific practices, but it solely plays as a reference. The discussion on expert"s and practitioner"s differences in thoughts suggests that generalization is difficult to happen to the holistic structure, though they do in some areas. The generalization can happen in the list of CFS, though the ranking could vary.

This research has also proposed to group the CSFs into different aspects or categories when working on the strategic plan. The management can work on the plan with the three groups, and chronologically, the deployment of CSFs is about following the ranking during the actual implementation in the company, even though the ranking of the individual CSF does not precisely follow the pattern of main categories.

LSS4.0 could be the next evolution in LSS when integrated with big data, which is part of the IR 4.0 element, giving a new life to LSS (Anthony et al., 2017). In line with this, the findings of this research provides a new framework that integrates the IR4.0 elements into the LSS. The application of IR4.0 in the new organizational infrastructure is a new trend, but it does not happen quickly and happens naturally. The research result hints that IR4.0 is not the first area to pay attention to the full deployment from the study. The company in this research has focused on other factors to set up a basic structure before working on the new organizational infrastructure in integrating LSS and IR4.0 elements, which gives rise to the LSS4.0 project with the need for an LSS framework. At the same time, IR4.0 is an additional tool and concept to enhance its effectiveness and analytical tools. Therefore, the LSS framework is a fundamental and critical platform for converging all the techniques and concepts to form a successful outcome.

Below is the summary of implications for the manager who intends to embark on LSS4.0 in their organization:

1. The initiative must link to customer or business needs.
2. Communication is essential but limited to a shared vision, sharing success stories to make the employee excited and attracted to the program.
3. Training is essential, but understanding the tools and techniques is relatively significant.
4. LSS framework should be ready, especially the proper knowledge of LSS tools, before integrating the IR4.0 into the new organizational infrastructure.
5. The deployment can parallel three areas (the major category) but prioritize the respective CSF accordingly.

5.4 LIMITATIONS AND RECOMMENDATIONS OF FUTURE STUDY

Like any other process improvement method, LSS requires costly investment due to the involvement of every layer in the organization with dependable tasks and responsibilities (Bos et al., 2014). Most SMEs lack the financial and physical resources to succeed in the LSS adoption (Albliwi et al., 2014). Therefore, the result of this research may not be able to provide an implication for small and medium local company managers to plan their framework without allocating sufficient resources. The resources include the training and hiring of relevant experts such as six sigma Black Belt/Master Black Belt or Lean Expert/Lean Master. The LSS experts are deemed the most important person in the company to be involved in the deployment because Black Belt is the company's change agent and project leader (Antony et al., 2016). The success of the LSS project is associated with the competency of the BB/MBB (Hilton et al., 2016), but the training is very costly (Albliwi et al., 2014).

The CSF ranking of importance could also vary due to motives and objectives. It may happen in the ISO-certified and non-ISO-certified companies. The ISO-certified company deploys the LSS to fulfill the continuous improvement requirements (Chiarini, 2011) and cost concerns (Kumar et al., 2008; Pinto et al., 2008; Abolhassani et. al, 2016). Continuous improvement is a mandatory requirement, and it is not a choice. Therefore, the ranking might differ between ISO-certified and non-ISO accredited companies; therefore, the result may not be suitable for non-ISO accredited companies.

Besides, the research conducted in the memory semiconductor industry can give a detailed review of the deployment framework. Still, it may not be sufficient to generalize to other industries in Malaysia due to limited study on the LSS 4.0 integration. However, a similar research methodology can be used in generalizations with various sectors.

This research is not conducting an intensive in applied tools, especially the IR4.0 application in the LSS deployment, as suggested by such as Anthony et al. (2018). The author also suggested exploring the application of big data in Six Sigma (Anthony et al., 2019). but the author also urged to explore the integration between LSS and IR4.0 (Anthony et al., 2020). This research included the IR4.0 facilities as part of the CSFs in the success of the LSS deployment. However, the research did not study the application of IR4.0 infrastructures in LSS deployment's success. Future studies can explore the importance of the tools. The research is to group IR4.0, Lean, and Six Sigma tools and study the ranking and the interrelationship, which will reference the LSS4.0 practitioner on the project framework to drive a significant continuous improvement project.

The second limitation in the research is it does not narrate the IR4.0 pillars maturity in LSS deployment. The study can correlate the importance of the IR4.0 infrastructure to practitioner‟s perceptions. It potentially may affect the ranking of its importance. It is an excellent motivation to have an intensive study on integration. A revisiting or follow-up study may also be good to understand the adoption progression on the LSS4.0. It is a new framework in Malaysia when maturity is improving.

Future studies may use the same model to research similar subject matter in other industries, but the CSF number needs to be expanded to include other factors. Antony et al. (2020) cited that the discrepancy in LSS implementation might be affected by cultural values and behaviors. It links the discrepancies with Hofstede's cultural dimensions, results in a meaningful conclusion from the generalization with cultural values.

This research reveals that different functional groups have different CSF rankings that contradict external consultants and internal experts or practitioners. However, the study did not further analyze the reasons which caused the difference. This research is still lacking in intensive exploration that explains the different perceptions or thoughts that a functional group has on the CSF, whereby future research may address this gap. There is a need to understand how the CSF ranking links to their function, which could help the academician better understand the relationship between the factors and job function and facilitate the strategic planning on LSS deployment.

The variances in this research might suggest that the categorization is not correctly grouped within the relevant CSF under the main categories. The common practice in AHP is relying on the expert‟s opinion to group the factors. Therefore, there is some weakness in applying Fuzzy AHP in CSF ranking analysis in the grouping, where grouping the CSFs into a main category is purely based on an expert's opinion that causes the grouping variances in the past research. The ranking could be affected by different hierarchy structures because the priority vector will normalize with the main category‟s priority vector. Thus, future studies might identify relevant factors within the groups as it helps practitioners in strategy planning and facilitating the CSF"s execution plan. The grouping could generalize different industries and geographical positions, as it provides insights on the relationship among the CSFs.

Kader Ali et al. (2016) concluded that the maturity level of LSS deployment is a significant factor affecting operational performance. His research concluded that operational performance mediates the relationship between the maturity level of deployment and awareness of the importance of business performance. However, it does not consider the LSS"s maturity level in CSF prioritizing study, where the rating might have different results corresponding to the different maturity levels. The level of awareness and maturity could change the CSF's importance because of the cognition on each factor shifts in parallel with the alignment of deployment within environmental factors. Jones et al. (2011) developed an instrument to measure Six Sigma implementation where it covers different aspects of the role of the black belt, financial responsibility, and executive support. However, this instrument only focuses on Six Sigma, and there is room for improvements by expanding to cover lean and other aspects. Souza Campos also developed a similar instrument (2012) to assess the integrated elements of lean and Six Sigma and has a more comprehensive assessment instrument and coverage than Jones et al. (2011). It extends to leadership, culture, strategy, customer, human resources management, flow management process, continuous improvement partnership and society, and quality. The study did not assess the deployment maturity in the prioritization; thus, future research may use this instrument or other similar instruments to rate the organization's maturity and correlate it with the CSF ranking. The maturity level might explain the resulting ranking pattern. It can be done by grouping the maturity level and generalizing the ranking pattern for each maturity group.

Although there is an argument that the organizational culture must be ready for change, Achanga et al. (2006) and Douglas (2017) argue that organizational cultures is a prerequisite and must be ready. No pre-assessment was carried out to investigate whether the company is ready to adopt change or not. Reversely, the management hopes to change the culture with the deployment. Laureani et al. (2017) and Paro et al. (2017) found that the cultural changes start before the changes may occur and go along the way. Nevertheless, the management only observed the cultural change after the implementation (Ozkan et al., 2017; Ray et al., 2010). Thus, the perceiving value could be less critical because most participants might expect to change the culture after the success of the transformation. Besides, Knabb (2015) & Hilton et al. (2012) have concluded that two types of culture link to deployment's success: developmental and group culture. Developmental culture relates to flexibility in innovative focus, while group culture focuses on teamwork towards successful deployment. Thus, organizational culture could be an exciting topic for intensive research in the future; as a result, it can answer the relationships between the pre-implementation and post-implementation of the organizational culture; and the effectiveness of the developmental and group culture in the deployment's success. The paper did not study the cultural change in-depth, especially when integrated with IR4.0. Therefore, future studies can focus on the organizational culture from different aspects.

Another similar gap was found in another CSF; communication has many ways and methods, similar to training, employee engagement, and other factors. Training is not imminent on DMAIC but also on leadership, communication, and project management (Vallejo et al., 2020). Therefore, forthcoming research can extend with detailed elements about the rankings and provide more information on each CSF's appropriate implementation methods. Extending the AHP from two layers in the study can happen to three layers. Two layers in AHP might too surface. The extension could help in gathering more detailed information and in-depth study.

Another area, where it did not covers in the study, which can be inclusive of LSS 4.0 integrated with Green. The Green is related to applying the LSS to remove the wastes in preserving the natural environment, which is part of the business strategy on the organizational profitability by using the environmentally friendly material and operational process (Gaikwad et al., 2020). Sony et al. (2020) has urged to link the LSS initiatives with an environmental management plan. Another researcher, Gandhi et l.‟s (2018), lists the green operation environments in his CSF ranking study; thus, future research can use a similar approach to study the importance of CSF in the LSS4.0 Green instead of LSS Green.

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