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RESEARCH ARTICLE

Pathway for Industry 4.0 implementation in a Lean Manufacturing environment: evidence from Sri Lankan apparel sector

M. R. F. Nasra and A. M. A. S. M. Bandara*
[1]*Department of Operations Management, Faculty of Management, University of Peradeniya, Peradeniya, Sri Lanka.*

Abstract: The fourth industrial revolution (I4.0) was based on several technological pillars developed over the years. Organizations are expected to embrace these technologies to realize the benefits associated with I4.0. However, manufacturing organizations that have optimized their operations through Lean management philosophies need a clear pathway to embrace the I4.0 technologies without disrupting the existing good practices. Therefore, this study aims to conceptualize a much-needed path for implementing I4.0 technologies in a Lean environment. To achieve that, researchers followed a qualitative approach and an exploratory framework. Researchers started with Apparel organizations with highest export revenue and employed a snowball sampling approach within each organization to identify the most suitable professionals for the study. The data collection was carried out through semi-structured interviews conducted through Zoom online platform. The collected data was analyzed through thematic analysis, allowing the identification of different themes. Our findings suggest that such a pathway involves four steps: (1) setting a Lean base, (2) strategic management, (3) human resource development, and (4) getting external support. Since the implementation of I4.0 technologies in a Lean environment is a relatively recent phenomenon, our study provides guidelines for managers and practitioners to help them prioritize efforts and narrow their attention more objectively to the proper mix of procedures and technologies.

Keywords: Lean manufacturing, Industry 4.0, technology implementation pathway, apparel industry

INTRODUCTION

The manufacturing sector is one of the fastest-growing industry sectors in the world where organizations efficiently manufacture high-quality products to fulfill customer requirements. Increased global competition has made organizations look for ways to remain at the top of the competitive market (Langstrand & Ugochukwu, 2012). Lean Manufacturing (LM) is a management philosophy adopted primarily by the manufacturing sector to improve customer value by identifying and eliminating diverse kinds of wastages associated with the manufacturing process through scientific management and continuous improvement (Du *et al*., 2023). However, the expected benefits of LM such as low inventories, customer satisfaction, optimized efficiency, high quality, reduced cost, improved delivery regarding time, quality, and quantity specifications, and increased flexibility (Langstrand & Ugochukwu, 2012) attracted service-oriented organizations such as retail, healthcare, travel, and financial services to adopt lean philosophy.

In line with the global trend, many apparel companies in Sri Lanka embraced the Lean philosophy with the expectation of improving competitiveness by streamlining their operations (Wickramasinghe & Wickramasinghe, 2011). Sri Lankan apparel sector emerged to be a supplier for many global brands as the apparel companies from developed countries such as the UK and the USA tend to outsource their production plants to countries with low manufacturing costs such as China, Sri Lanka, and India to reduce production costs (Dachs *et al.,* 2019). Presently, Sri Lanka's apparel industry has become the most substantial and driving contributor to the country's economy. Over the years, it has grown very rapidly, from

* Corresponding author (amilab@mgt.pdn.ac.lk; https://orcid.org/0000-0002-4028-5341)

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local industry players to the number one export industry with a total export turnover of US$ 5000 Mn (Industry Capability Report Sri Lankan Apparel Sector, 2022) and contributing to 38% of the entire Sri Lankan exports (Export Performance Indicators-2021 Sri Lanka Export Development Board, 2021).

Being a part of the global supply chain, Sri Lankan apparel industry is expected to adapt to the changes in the global value chain. Often, these changes include the adoption of cutting-edge technologies that provide innovative solutions to overcome the challenges faced by the apparel industry (Lakmali *et al*., 2020). The Fourth Industrial Revolution, which is commonly referred to as Industry 4.0, was one of such technological advancements initiated by the German Federal Government. Hofmann & Rüsch (2017) define I4.0 as a shift in the manufacturing logic towards a more decentralized, self-regulating approach to value creation, aided by concepts and technologies such as the Internet of Things, Cyber-physical Systems, Internet of Service, Cloud Computing or Additive Manufacturing, and Smart Factories, to help companies meet the future production requirements.

It is observed that organizations have started integrating LM philosophies and I4.0 technologies as both methods to achieve superior performance and competitive advantages over their rivals in the market (Tortorella & Fettermann, 2018; Tortorella *et al.,* 2021). Consequently, growing debate among practitioners and academicians emerged on how to integrate I4.0 technologies and LM systems (Buer *et al*., 2018; Rossini *et al.*, 2019). This debate has caused a genre of publications that focused on studying the impact of integrating Lean and selected I4.0 technologies on performance improvement within a given context (Wagner *et al*., 2017; Gillani *et al*., 2020).

Productivity enhancement of employees and operations is the primary goal in the apparel industry. To realize this, a significant amount of training, development, and automation has to go hand in hand with better knowledge and application of Leaner manufacturing processes by employees (Gamage *et al*., 2020). Currently, the apparel industry of Sri Lanka is in a milestone of adopting the best manufacturing techniques, sustainability, and Lean concepts (Withanaarachchi *et al*., 2016). Contextually, challenges to adopting I4.0 technologies in emerging countries differ from those in developed countries (Dalenogare *et al.*, 2018). However, the literature base on the I4.0 adoption is largely biased towards developed economies while only a few studies focused on I4.0 implementation in developing economies. This number is further reduced when it comes to the adoption of I4.0 within an organization that has already mastered the Lean philosophy while operating in a developing economy.

The favorable influence of I4.0 technologies on LM was suggested by the strong direct effects between the two variables (Kamble *et al*., 2020). It is inferred that the implementation of I4.0 in manufacturing organizations will change the LM system into a lean virtual manufacturing network, connecting all the manufacturers and suppliers in a single network and allowing the sharing of tangible and intangible assets between the connected parties (Sanders *et al*., 2016). Therefore, combining LM and I4.0 enables the firm to aim for higher interchangeability and shorter information flows to meet future demands (Kolberg *et al*., 2017). Having said this the existing literature lacks a clear roadmap to direct the manufacturing organizations that have optimized their operations through LM philosophies to embrace the I4.0 technologies without disrupting the existing good practices. This study focuses on investigating this research gap in detail by answering the following research questions.

RQ1: How to implement I4.0 technologies in an apparel organization that has mastered LM philosophy?

RQ2: How to encapsulate the adoption process to depict a streamlined roadmap to be used by future adopters of I4.0 in LM environments?

RQ3: What are the specific drivers and challenges of implementing I4.0 in LM environments?

The remainder of the paper is structured as follows: after the introduction, Section 2 provides a review of the works of literature on which the paper is built. Section 3 explains the research methodology, while section 4 provides the main findings. In section 5, the paper discusses the pathway for implementing I4.0 technologies in a Lean environment. In the final section, the paper concludes with the contributions and the limitations of the study, also providing directions for future research.

LITERATURE REVIEW

This section reviews the existing body of literature relevant to the study. The researchers have searched the relevant literature in major journal databases such as SCOPUS, Web of Science, and Google Scholar using combinations of the keywords Lean Manufacturing, Industry 4.0 and Sri Lankan Apparel Industry. However, the scope of this section is set to be a narrative review that explores the existing literature and synthesizes the knowledge.

Lean Manufacturing philosophy

LM is a multi-faceted production approach that originated from the conceptualization of the Toyota Production System (TPS) by Taichii Ohno's efforts at Toyota Motor

Company, and gained popularity in recent decades (Sanders *et al.,* 2016). Lean practices gained traction in Western economies after the publishing of the book titled "The Machine That Changed the World" by Womack *et al.,* (1990) at Massachusetts Institute of Technology (MIT), USA. Womack *et al.* (1990) define LM as using less of everything. This means half the manufacturing space, human effort in the factory, investment in the tools, and engineering working hours to produce a new product in half the time. Additionally, LM results in fewer faults since it involves retaining less than half of the inventory on-site and creates a higher and continuously improving quality of products. As LM has a streamlined process flow, it allows the manufacturers to produce the products per the customer requirements with minimum or zero waste (Shah &Ward, 2003).

Objectives and significance of Lean Manufacturing

Liker (2004) states that the main objective of LM is reducing or eliminating waste/non-value-adding activities to produce products to meet or exceed customer expectations. LM creates higher value for the customers through holistic process optimization throughout the supply chain of an organization (Hu *et al.,* 2015). Hu *et al.* (2015) also state other direct and indirect advantages of implementing LM in organizational activities. Some such advantages are, improving the ability of the organization to compete efficiently and effectively, and close relationships with the supply chain members as LM requires the supply chain members to be collaborative and interdependent for the success of LM. In addition, Langstrand & Ugochukwu (2012) also identified different benefits of implementing Lean practices in the organization. Some such benefits are low inventories, customer satisfaction, optimized efficiency, high quality, reduced cost and improved delivery regarding time, quality, and quantity specifications, and high flexibility.

In LM, anything that does not benefit the end user can be deemed waste. Taiichi Ohno identified eight types of waste. They are Surplus production, excess transportation, waiting, excess processing, fallout, unnecessary movement, redundant stock, and insufficient use of employee potential (Leksic *et al.,* 2020). Further, a Shingo prize-winning study of the United States Environmental Protection Agency in 2003 added excessive energy consumption as the ninth type of Lean waste and claimed that LM can contribute to environmental sustainability by reducing energy waste.

Lean tools and techniques

LM encapsulates a multitude of tools and techniques to identify and eliminate wastages associated with organizational processes. Some such tools and techniques can be listed as Just-In-Time, Kanban, 5S, Value Stream Mapping, Total Productive Maintenance, Production Leveling, Kaizen, Poka-Yoke, Statistical Quality Control, Standardized Work, and Quality Circle, etc. (Langstrand & Ugochukwu, 2012; Palange & Dhatrak, 2021). Each of these tool or technologies has a designated role to be played in an organization that has embraces the LM philosophy.

Just-in-Time is a LM technique that aims to deliver the right product at the right time, cost, quality, and quantity (Mayr *et al*., 2018). Kanban on the other hand provides value to customers through a visual system that enhances flow, cuts lead times, and spots bottlenecks or prospective bottlenecks (Renteria-Marquez *et al*., 2020). 5S of LM ensures that everything has its place, must be kept there, be kept in good condition, and must be readily available anytime it is needed (Veres *et al*., 2018). is a visual way of illustrating a product's production process, including the materials and data from each workstation for diagnosing, implementing, and maintaining a lean approach. (Nihlah & Immawan, 2018). Heijunka also known as Production Leveling, is a crucial tool that aids in eradicating inconsistent customer pull and turning manufacturing into a predictable process (Renteria-Marquez *et al.,* 2020). Kaizen is one of the lean techniques that help to make sure that operations run more smoothly and efficiently by eliminating unnecessary activities that don't add value from the customer's point of view to aid in innovative performance (Habidin *et al*., 2018).

Lean in the Sri Lankan apparel industry

When considering Lean implementation within the apparel firms of Sri Lanka, many organizations have made many efforts to implement LM practices in their organizations ((Silva et al., 2012). These non-indigenous practices, like Lean practices, which are learned from diverse external contexts, can be internalized into the local SME sector of Sri Lanka (de Alwis Seneviratne *et al.*, 2021). LM improves productivity, and data collection reduces cycle time, minimizes material wastage, and provides higher clarity in material and information flow in the apparel industry (Ukey *et al.,* 2022). This study also states that implementing LM in the apparel industry results in enhancing employee morale and increases the organization's total profit and residual value as a result of reduced asset costs. In addition, Gunarathne *et al.* (2017) state that LM practices, such as waste elimination practices, positively impact the operational performance of apparel firms in Sri Lanka.

LM is a human-based system where people are involved in continuous improvements. Many researchers suggest that lean implementation is positively related to

operational performance in both developed (Demeter & Matyusz, 2011; Netland *et al.,* 2015) and developing economies' contexts (Panizzolo *et al*., 2012; Jasti & Kodali, 2016). Also, Jasti & Kodali (2016) suggest that manufacturing organizations should conduct frequent training programs for their workforce to understand how to practice LM concepts in detail in their organization and encourage them to continue to achieve the vision and mission of LM principles.

Industry 4.0

The commonly accepted notion is that industrialization began with the introduction of manufacturing equipment powered by the steam engine during the end of the 1800s. As the name suggests, there were three industrial revolutions before the I4.0. The discovery of the steam engine demarcates the beginning of the First Industrial Revolution (Gökalp *et al.,* 2018). The Second Industrial Revolution (I2.0) began when electricity started to be used in the industrial field (Gökalp *et al.,* 2018) and it involved using automated mechanics in manufacturing that consumes electric power. This was followed by the Third Industrial Revolution (I3.0) which increased the automation of manufacturing processes by implementing Information and Communication technologies. I3.0 replaced a large proportion of the labor force (Gökalp *et al.,* 2017), and technology transferred from analog to digital form.

The I4.0 also known as Industry 4.0, was initiated by the German Federal Government. Hofmann & Rüsch (2017) define I4.0 as a shift in the manufacturing logic towards a more decentralized, self-regulating approach to value creation, aided by concepts and technologies such as the Internet of Things, Cyber-Physical Systems, Internet of Services, Cloud Computing or Additive Manufacturing, and Smart Factories, to help companies meet the future production requirements.

The I4.0 widely explains the concept of a digital factory that involves automated manufacturing processes with reduced human intervention. It defined highly digitized production processes in which information flows between machines in a controlled environment with minimal human participation (Qin *et al.,* 2016). It allows people to communicate in real time. Industry 4.0 is not hype, but rather a potential success. Because of this, all firms must get ready to embrace this prospective industrial revolution to compete in the volatile and intensely competitive market (Ghobakhloo, 2018).

Significance of Industry 4.0

I4.0 and related technologies are expected to generate many advantages such as improved innovation capability, easy monitoring a diagnosis of system multifunction, high productivity, increased customer satisfaction, improved flexibility with decreased costs, unbiased, real-time, knowledge-based decision-making, increased quality, more customized products, smart factories, buildings, and cities increase the quality of life and easy access to personal information (Gökalp *et al.,* 2018; Oztemel & Gursev, 2020).

Stock *et al*. (2018) state that I4.0, as a new industrial paradigm, enables firms to deliver higher financial, ecological, and social performance. In addition, through the deployment of digital technologies, I4.0 facilitates new product and service developments (Dalenogare *et al*., 2018) and enables the mass customization of products and services (Zawadzki & Zywicki, 2016), which allows the firm to achieve higher levels of performance. Companies can profit greatly from I4.0's capabilities, which include the ability to customize products, analyze data in real-time, boost visibility, implement autonomous monitoring and control, create dynamic products, and increase efficiency (Dalenogare *et al*., 2018).

Adoption of I4.0 technologies within the Sri Lankan apparel industry

Apparel companies from developed countries such as the UK and the USA tend to outsource their production plants to low-cost countries such as China, Sri Lanka, and India to reduce production costs (Dachs *et al*., 2019). However, there is an increased focus on relocating the manufacturing plants since there is more emphasis on I4.0. As a result, the apparel industry is positioned to implement innovative solutions to overcome these challenges by implementing technologies (Lakmali *et al*., 2020). The Sri Lankan apparel sector will take the next step from its current milestone when the I4.0 concepts are implemented (Withanaarachchi *et al*., 2016).

To maximize productivity by making the most use of the available resources, the future goal of apparel manufacturing would be to decrease human intervention at all levels of manufacturing (Withanaarachchi *et al*., 2016). Therefore, parts of manufacturing processes are increasingly automated, resulting in improved efficiency and decreased labor costs regarding time manual tasks (Lakmali *et al*., 2020) and reshaping apparel production into a more sustainable and customer-driven business (Bertola & Teunissen, 2018). Firms have been able to generate new methods for designing, marketing, and managing complicated manufacturing systems due to wider technological diffusion.

When considering Sri Lanka's apparel industry readiness level for I4.0 implementation, the overall readiness of the Sri Lankan apparel industry is in level 2: Intermediate Level. Thus, the Sri Lankan apparel industry

is in a situation where computer-based technologies are in use, but human-machine interaction is still available (Lakmali *et al*., 2020). It is clear that Sri Lankan textile manufacturing companies have the capability and strength to adopt ideas like smart factories in order to align their business plans with I4.0 (Withanaarachchi *et al*., 2016).

Integrating Lean Manufacturing and Industry 4.0

Different industries have widely used LM since the 1990s because of its high effectiveness and simplicity. But to satisfy upcoming market demands, LM reached its limits. Even though LM can handle a broader range of items, it is not appropriate for producing individual single items due to its defined production sequence and fixed cycle times. In addition, LM has limited applicability for items with shorter product life cycles (Kolberg & Zühlke, 2015; Kolberg *et al*., 2017). Therefore, manufacturing organizations are in a position to seek out new approaches to face these challenges.

Recently, technology-driven I4.0 technologies have been increasingly implemented in many industries. Process standardization, waste reduction, and a constant emphasis on customer value are essential components of the adoption of Industry 4.0 (Mayr *et al.*, 2018). However, this new paradigm does not replace LM. Organizations are increasingly integrating I4.0 technologies with LM systems because both LM and I4.0 have improved performance and helped organizations achieve competitive advantages over their rivals in the market (Tortorella & Fettermann, 2018; Tortorella *et al*., 2021). In light of technological advancements related to I4.0, the relationship between I4.0 and LM has been increasingly highlighted as a prominent research area in operations management (Buer *et al*., 2018; Rossini *et al.,* 2019).

Successful execution of LM practices aids organizations in being ready to introduce the I4.0 implementation process (Kamble *et al*., 2020). Rossini *et al*. (2019) suggest that the manufacturing firms that aim to adopt I4.0 should simultaneously implement LM practices for process improvements. Buer *et al*. (2018) state that a setting with streamlined flows, standardized processes, and without waste is required for an effective digital transformation.

LM is acting as a prerequisite for successful digital transformation (Bittencourt *et al*., 2019; Rossini *et al*., 2019). Although I4.0 technologies have a direct and favorable impact on sustainable organizational performance, they might not contribute to sustainable organizational performance if they are developed as a standalone application without LM. Therefore, LM implementation enables organizations to be ready to begin the I4.0 implementation process (Kamble *et al*., 2020).

Significance of integrating Lean Manufacturing and I4.0 technologies

Sanders *et al.* (2017) and Wagner *et al*. (2017) state that integrating I4.0 and LM practices may allow the firms to overcome the traditional barriers in a Lean transformation achieving significant results. Implementing I4.0 technologies in a Lean environment will not only accelerate the improvement of the LM system but will also lessen the perceived risk brought on by the high implementation costs of I4.0 technologies (Kolberg & Zühlke, 2015). Integrating I4.0 with LM leads to more extensive improvements in organizational performance (Tortorella & Fettermann, 2018).

Kamble *et al*. (2020) state that when I4.0 is implemented without LM, it may not contribute to organizational performance. Further, this study states that, when simple LM techniques are difficult to execute, the integration of LM and I4.0 technologies offers significant cost-saving advantages. Further many studies suggest that combining I4.0 and LM increases the reliability (Wagner *et al*., 2017), productivity (Sanders *et al*., 2016), or flexibility (Kolberg *et al*., 2017). Most of the LM tools and techniques, such as Just-In-Time, Kanban, Value Stream Mapping, Total Productive Maintenance, Visual Management, Leveling, etc., will benefit from the introduction of I4.0 (Rosin *et al.*, 2020) while they act as a prerequisite for a move towards I4.0 (Sanders *et al.*, 2017).

While aiming for small, readily integrated components with lower levels of complexity, both LM and Industry 4.0 favor decentralized, simple structures over massive, complicated systems (Zuehlke, 2010). These two systems are focused primarily on the potential for data collection for resource efficiency matters (Prinz *et al*., 2018). In addition, increasing added value and shared goals are also identical for both systems. According to Mayr *et al.* (2018), value creation is fundamental for the introduction of I4.0 technologies in a lean environment since both LM and I4.0 technologies create value for the organization.

Drivers for implementing I4.0 technologies in a Lean Environment

There are many drivers for implementing I4.0 technologies in a lean environment. One important driver is LM. LM itself is acting as a driver for implementing I4.0 technologies. LM implementation enables organizations to be ready to begin the I4.0 implementation process (Kamble *et al*., 2020). LM facilitates the implementation of I4.0 technologies by providing waste-free, simplified

processes to implement I4.0 technologies. (Buer *et al*., 2018).

The apparel industry needs to enhance their operational performance to deliver high-quality goods with shorter lead times (Dissanayake & Ilangakoon, 2023). The apparel value chain process commences with the design phase and concludes with the delivery of the final product. It is necessary to have a highly innovative design phase and excellent standards in the manufacturing process for a successful product in the apparel industry (De Silva & Rupasinghe, 2016). Industry 4.0 gives businesses more operational control and enables them to use real-time data to boost output, streamline workflows, and drive growth. The apparel industry is likely to get the advantage of I4.0 for most of their processes in the apparel value chain to boost overall performances and to achieve competitive advantages over their rivals (Lakmali *et al*., 2020).

Some other key drivers for implementing I4.0 technologies identified by Rossini *et al.* (2021) include I4.0 technologies enhancing data availability, detecting waste, improving production capacity, improving efficiency and productivity performance, and improving flexibility, quality, and time. By conducting a literature review Ghadge *et al.* (2020) identified some key drivers for implementing I4.0 technologies. They are agility and customization, I4.0 provides accurate, real-time, consistent data for decision-making and efficiency improvement. Further, I4.0 technologies optimize cost savings and generate higher revenues (Ahmad *et al.,* 2020).

Apparel firms are facing frequent changes in customer demand for personalized and customized fashion. This has resulted in the implementation of I4.0 technologies to enhance customer satisfaction (Wijewardhana *et al.,* 2021). Further, labor shortage and increase in labor turnover are major issues faced by the Sri Lankan apparel industry. Many apparel firms are focusing on automation and other innovative methods to meet these challenges (Withanaarachchi *et al*., 2016).

Challenges for implementing I4.0 technologies in a Lean Environment

The higher investment cost is an important challenge faced by organizations when implementing I4.0 technologies. In addition to higher costs, resistance to change, change management, and lack of expertise are some other challenges to implementing I4.0 technologies (Ahmad *et al.,* 2020; Ghadge *et al.,* 2020).

Gökalp *et al*., (2018) identified some other challenges of implementing I4.0 technologies in the apparel industry. They are the initial investment costs for integrating I4.0 technologies such as CPS, robotics, BD infrastructures, IoT, etc., privacy and security issues of the collected data, technical challenges such as lack of skilled workers, lack of global standards developed for I4.0 technologies, and social issues such as unemployment because the demand for low-skilled workers will be replaced by high-skilled workers who can manage emerging technologies.

The major issue with integrating LM and I4.0 technologies is the lack of an understandable architecture that allows these integrations (Ma *et al*., 2017). Although there is growing attention among practitioners and academicians on the studies about integrating I4.0 and LP systems (Buer *et al*., 2018; Rossini *et al*., 2019), they are mostly focused on either individual technologies or performance enhancements brought about by the employment of a single digital technology (Wagner *et al*., 2017; Gillani *et al.,* 2020). Many organizations still struggle with I4.0 technologies and concepts (Sanders *et al*., 2016; Tortorella & Fettermann, 2018) because of the lack of proper guidelines or patterns for the success of companies' digital transformation (Rossini *et al.,* 2021).

RESEARCH METHODOLOGY

This section summarizes the systematic approach used in the study to ensure the reliability and validity of the findings. A clear and transparent description of the research design, sample selection procedure, and data collection and analysis procedures are provided to facilitate a comprehensive understanding of how the results were derived.

Research design

A qualitative approach has been adopted to systematically explain the process of integrating Industry 4.0 (I4.0) technologies into an existing Lean environment. The selection of this research strategy is driven by the study's objectives and questions, as outlined by Saunders *et al*., (2019). By utilizing an exploratory framework, this study aims to gather comprehensive insights addressing the following research questions: How to implement I4.0 technologies in an apparel organization that has mastered LM philosophy? How to encapsulate the adoption process to depict a streamlined roadmap to be used by future adopters of I4.0 in LM environments? What are the specific drivers and challenges of implementing I4.0 in LM environments? This approach allows for a detailed exploration of the synergy between Lean methodologies and advanced digital technologies, providing a clear, step-by-step guide to successful implementation.

Sample selection

The sample selection for this study commenced with a thorough screening of all 158 apparel manufacturers registered under the Sri Lankan Board of Investment

(BOI). The goal was to identify companies that had initially implemented Lean methodologies and subsequently adopted I4.0 technologies. Once identified, these organizations were sorted based on their export revenue. The next stage of the sampling process involved establishing inclusion criteria for respondents to be eligible for the sample. After careful deliberation, the researchers decided that eligible participants must possess substantial knowledge and experience in both Lean and I4.0 implementations, with a minimum of three years of relevant experience.

Starting with the organization with the topmost export revenue, researchers initiated the process of identifying at least two senior-level professionals from each selected organization. To maintain consistency and transparency, a snowball sampling approach was employed within each organization to identify the most suitable professionals for the study. During this process, the researchers deliberated with the management of the selected organizations and ensured that the most appropriate professionals from each organization that satisfy the pre-established inclusion criteria are recruited for the data collection process. This method ensured that the most knowledgeable and experienced individuals were included in the study.

However, data saturation, the point at which no new information or themes emerge, was reached after completing 10 interviews across four organizations. Consequently, the researchers ceased the data collection process at this stage. The anonymized profiles of the final study sample are indicated in Table 1.

Data collection and analysis

The data collection was carried out through semi structured interviews conducted through Zoom online platform. Respondents were presented with a clear statement that emphasized the confidentiality of their answers and the inexistence of a right answer. Further, all respondents were acknowledged as appropriate informants because of their background in LM and I4.0. All interviews were recorded using the facility-provided at the Zoom software.

Subsequently, the interview recordings were transcribed using online transcribing software and the researchers replayed the recordings and cross-checked the transcriptions to ensure the accuracy of the transcriptions and that they match with the audio. The researchers then used the NVivo12 qualitative analytical software to assist the thematic analysis. Thematic analysis is a technique for finding, analyzing, and reporting patterns (themes) within data (Clarke *et al*., 2013; Braun & Clarke, 2006). After the initial coding, the codes were reviewed and grouped into broader themes based on their similarities, as detailed in the annexures. To ensure the coherence of the themes with the coded extracts and the complete data set, the themes were consistently refined by referring back to the transcripts and aligning them with the research questions.

Table 1: Anonymized profiles of the final study sample

Organization	Respondent	Position	Experience
Organization A	Respondent 01	Manager- Lean Enterprise	13 years
	Respondent 02	General Manager- Group Lean Enterprise	20 years
	Respondent 03	Deputy General Manager- Operations	12 years
Organization B	Respondent 04	Deputy General Manager- Engineering and Process Improvements	12 years
	Respondent 05	Manager- Process Improvement	13 years
	Respondent 06	General Manager	17 years
Organization C	Respondent 07	General Manager	21 years
	Respondent 08	Divisional Manager	21 years
Organization D	Respondent 09	Senior Executive- Lean	4 years
	Respondent 10	General Manager- Process and Digital Adoption	12 years

RESULTS AND DISCUSSION

Results

This section presents the main themes and sub-themes based on the research objectives of the study.

The process of implementing I4.0 technologies in an Apparel organization that has mastered LM philosophy

The implementation of I4.0 technologies in a Lean environment necessitates a thorough strategic pathway that illustrates each new step on the way from both strategic and technological perspectives. Based on the participants' responses four main themes were identified as the stages of a pathway for implementing I4.0 technologies in an already existing Lean environment.

1. Setting the Lean base

The Lean principles help organizations to streamline their manufacturing process. Therefore, the majority of the respondents have specified the importance of strengthening the existing Lean base before introducing the I4.0 technologies. For example, the Respondent 02 stated that

> *"... in the initial stage, if you have Lean in the organization established, moving into industry 4.0 is a little bit of a plus because the Lean puts the foundation."*

Thus, setting and strengthening the Lean base has been identified as the first theme.

2. Strategic management

A lack of managerial mindset related to I4.0 will result in a company culture that will not promote new technology implementation. Therefore, many respondents stated the importance of managing the organizational strategies for successful I4.0 technology implementation. For example, the Respondent 01 stated that,

> *"It's the top management itself that set up these goals to move into digitalization at the moment."*

So, managing the strategies of the organization has been identified as the second theme.

3. Human resource development

I4.0 technology implementation might be burdensome for organizations due to a lack of skilled human resources. Therefore, human resource development is identified as the third theme in the process of I4.0 technology implementation.

> *"If it is a specific new technology, definitely we have to train everyone related to those operations in this technology..."* (Respondent 07)

4. Getting external support

Relationships with external stakeholders influence the I4.0 implementation given the technology knowledge imbalance within the organizations. Respondents also specified that getting external support is important when implementing I4.0 technologies in a Lean environment.

> *"We get training, advice, and consultations from external parties."* (Respondent 03)

Therefore, getting support from external parties has been identified as the fourth theme.

14.0 Technologies adopted in a Lean environment

The participants' responses about the I4.0 technologies implemented in a Lean environment are captured by 6 main themes namely 1. Cloud Computing, 2. Internet of Things, 3. Automation and Industrial Robotics, 4. Big Data Analytics, 5. Computer-aided Systems and 6. Additive Manufacturing and Augmented Reality.

Cloud Computing technologies such as cloud-based ERP, and power Business Intelligence are used by all the interviewed organizations during the data collection process. Automated Guided Vehicle, Sensors in the machines, and RFID are the main Internet of Things technologies used by the Sri Lankan apparel industries. Other I4.0 technologies such as robotic process automation, machine and process automation, fast track system, 3D printing, etc. are some other I4.0 technologies used.

Respondents specified these technologies' implementation in a Lean environment as follows.

> *"Our ERP is SAP. It's cloud-based not only the ERP, but our all emails, share drives, and IT infrastructure is also cloud-based."* (Respondent 10)

> *"We use AGVs to carry finished goods within the manufacturing facility."* (Respondent 02)

> *"Metal detecting sensors are used."* (Respondent 02)

> *"We are using automated systems to get our garments down."* (Respondent 07)

> *"And currently, most organizations use the fast-track planning system to support the data and the information flow around the planning."* (Respondent 02)

Drivers for implementing I4.0 technologies in a Lean environment.

Many drivers contribute to implementing I4.0 technologies in an already existing Lean environment. The participants' responses are captured by four main themes as follows.

1. Lean principle

Successful execution of LM practices aids organizations in being ready to introduce the I4.0 implementation process. Therefore, the majority of the respondents specified that Lean sets the base and foundation for technology implementation. For example, Respondent 02 stated that,

> *"... in the initial stage, if you have Lean in the organization established, moving into industry 4.0 is a little bit of a plus because Lean sets the foundation."*

Therefore, the Lean principle has been identified as the first theme for drivers for implementing I4.0 technologies in a Lean environment.

2. Organizational factors

Committed leadership, increasing production and operational costs quality, and efficiency improvements are some drivers for implementing I4.0 technologies in a Lean environment. Respondents also specified that organizational factors such as leadership, the requirement to reduce cost, enhancing data availability, and improving quality and efficiency are acting as drivers for implementing I4.0 technologies in a Lean environment.

> *"Companies are using technology to bring the cost down."* (Respondent 04)

> *"I4.0 technology helps you to give real-time data so that management can make a quick decision within a shorter period."* (Respondent 03)

Therefore, organizational factors have been identified as the second theme.

3. External forces

External forces such as competition and customer expectations require organizations to move towards technology implementations which has been identified as the third theme for drivers for implementing I4.0 technologies.

> *"Customers are also expecting us to adopt different technologies."* (Respondent 10)

4. Human resource factors

Further, human resource factors such as increasing labor costs are some other drivers for implementing I4.0 technologies in a Lean environment. The majority of the respondents also specified that increasing labor costs is an important driver for I4.0 technology implementations. For example, Respondent 04 stated that,

> *"Companies tend to invest in technology rather than investing in people because of humans or the labor party, the cost is increasing."*

Therefore, human resource factors have been identified as the fourth theme.

Challenges in implementing I4.0 technologies in a Lean environment

In an emerging economy like Sri Lanka, implementing high-end technologies is challenging. The participants' responses about the challenges in implementing I4.0 technologies are captured by three main themes namely 1. Cost, 2. People-related challenges, and 3. Technological challenges.

High cost is a significant challenge in implementing I4.0 technologies. The majority of the respondents specified a higher cost of investment and cost of training the employees as the main challenge in implementing I4.0 technologies. For example, Respondent 08 stated that,

> *"Technologies are very expensive."*

Therefore, higher cost has been identified as the first theme.

Further, people are neither familiar nor confident about technologies. Therefore, they are reluctant to adopt them which is another challenge faced by the organizations. Many respondents specified that people resisting the technologies and lack of technological expertise within the organization are also challenges when implementing I4.0 technologies. Respondents 05 and 04 stated as follows.

> *"The people in the organization worried that these technologies would be taking over their jobs."* (Respondent 05)

> *"Still, people are not aware to adapt to use of these kinds of processes or technology."* (Respondent 04)

Therefore, people-related challenges have been identified as the second theme.

Effects of I4.0 technologies on human resources in a Lean environment

Technology implementation will have pros and cons for human resources within the organizations. Respondents also specified there are positive as well as negative effects of I4.0 technologies on human resources. For example, respondents 08 and 04 stated as follows.

> *"People will be upgraded because, with this technology and these new learnings, people are getting new technologies and new things. They have new markets."* (Respondent 08)

> *"The negative part of it is, it will reduce the people… If you take it as a negative, it could be a threat to the people."* (Respondent 04)

Therefore, favorable impacts and unfavorable impacts emerge as themes related to the effects of I4.0 technologies on human resources.

Discussion

This section discusses the findings of the data analysis of the study.

The I4.0 technologies that can be introduced first for a Lean organization

The data analysis highlighted those technologies such as Cloud Computing, the Internet of Things, Automation, Industrial Robotics, Big Data Analytics, and Computer-aided Systems are heavily used by many apparel firms while technologies such as Additive Manufacturing and Augmented Reality are used only by certain apparel firms in Sri Lanka. The existing literature also confirms the use of I4.0 technologies in the Sri Lankan apparel industry (Withanaarachchi *et al*., 2016; Wijewardhana *et al.,* 2021). However, our finding provides a classification of I4.0 technologies based on the adoption rates.

Drivers for Implementing I4.0 technologies in a Lean environment

Regarding drivers for implementing I4.0 technologies in a Lean environment, data analysis highlighted that LM itself is acting as a driver for implementing I4.0 technologies by eliminating waste and refining the manufacturing process while identifying the requirements for implementing I4.0 technologies. These findings are in line with the existing literature such as Kamble *et al*., (2020), Buer *et al*. (2018), and Kolberg & Zühlke, (2015).

Further, leadership support, cost reduction, enhanced data availability, quality and efficiency improvement, facing competition, meeting customer expectations, increasing labor costs, and technology-reducing human dependency have been identified as other key drivers for implementing I4.0 technologies in a Lean environment. These findings also are in line with the findings of Rossini *et al.* (2021), Ghadge *et al.* (2020), Ahmad *et al.* (2020), Ghobakhloo (2018), Ghobakhloo & Fathi (2020); Wijewardhana *et al.* (2021) and Withanaarachchi *et al*. (2016).

Challenges for implementing I4.0 technologies in a Lean environment

Higher costs associated with the technology implementation is an important challenge highlighted by the data analysis. Other challenges for implementing I4.0 technologies in a Lean environment highlighted by the data analysis are technology resistance, technical issues, choosing among alternative technologies, infrastructure availability, and privacy and security issues. These findings agree with the earlier studies (Ahmad *et al*., 2020; Ghadge *et al.,* 2020; Gökalp *et al*., 2018).

Effects of I4.0 technologies on human resources in a Lean environment

Data analysis highlighted both the positive and negative effects of I4.0 technologies on human resources. The positive effects of I4.0 technologies on human resources are human resource development and making jobs easier. Marengo (2019) and Rossini *et al.* (2021) support these findings. Negative effects include a reduction in income and termination of people. These negative effects are supported by earlier studies (Leonhard, 2016; Sima *et al.,* 2020; Gökalp *et al*., 2018).

THE PATHWAY FOR IMPLEMENTING I4.0 TECHNOLOGIES IN AN APPAREL ORGANIZATION THAT HAS MASTERED LM PHILOSOPHY

Findings from the data analysis develop and introduce a pathway for implementing I4.0 technologies in a Lean environment. Figure 4.1 derived from the data analysis shows a pathway for implementing I4.0 technologies in a Lean environment. Setting the Lean base is important because it provides the foundation for implementing I4.0 technologies. Lean eliminates waste and standardizes the process. The second step of the pathway is the strategic management of the I4.0 implementation which starts with defining the organizational strategies. Similar findings were stated in some of the existing literature (Kamble *et al*., 2020; Bittencourt, *et al*., 2019; Rossini *et al.,* 2019; Buer *et al*., 2018; Schumacher *et al*., 2016; Ghobakhloo, 2018). The strategic management phase also includes cost-benefit analysis, defining the technologies to be implemented, etc.

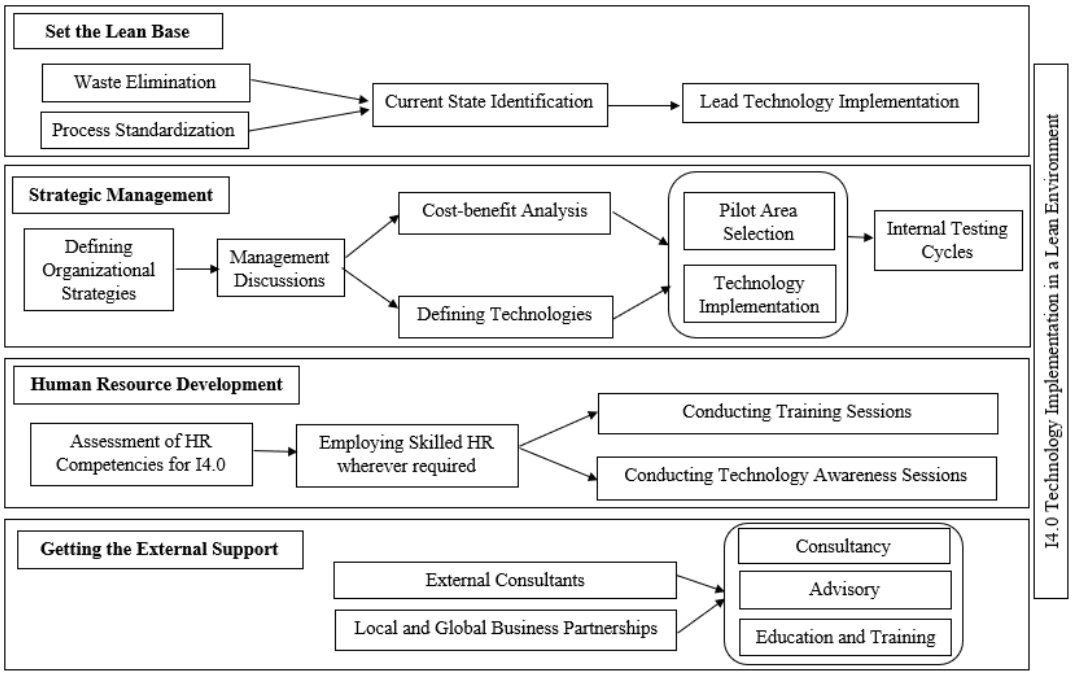

Figure 4.1: Pathway for I4.0 technology implementation in a lean environment

The third phase of the pathway for implementing I4.0 technologies in a Lean environment is human resources development. This includes assessing the HR competencies for I4.0, hiring new HR wherever required, and conducting employee training and awareness sessions for I4.0 technologies. Finally, as a part of implementing I4.0 technologies in a Lean environment, organizations should get the support of external consultants and local and global business partners in terms of consultancy, advisory, education, and training. The findings of Ghobakhloo (2018); Ghobakhloo & Fathi (2020) support these, which assess a strategic roadmap toward I4.0 and the enabling role of Lean-digitized manufacturing in the I4.0 era.

CONCLUSION

As both LM and I4.0 have been promised to improve organizational performance, many firms have started integrating both methods to achieve superior performance and competitive advantages over their rivals in the market. Although there is a large sum of research contributions on the I4.0 topic, companies are still facing issues with understanding and implementing I4.0 technologies. In addition, to the extent researchers know, only a few studies in the literature empirically investigate how I4.0 can be implemented in a Lean environment in a developing economy. The study is one of the first empirical studies in Sri Lanka to contribute to this debate.

This study contributes to the I4.0 technology and LM-related literature by identifying a pathway for implementing I4.0 technologies in a lean environment of the Sri Lankan Apparel Industry. The findings of the study highlight the I4.0 technologies that can first be implemented in a lean organization, drivers for implementing I4.0 technologies in a lean environment, the challenges in implementing I4.0 technologies in a Lean environment, and the effects of I4.0 technologies on human resources in a Lean environment.

The pathway for implementing I4.0 technologies in a lean environment of the Sri Lankan apparel industry provided in this study is a holistic view of the typical actions that apparel manufacturers can take to make the transition to I4.0. It is believed that the benefits of implementing I4.0 technologies in a lean environment may outweigh the costs involved, especially for top-tier manufacturers who have the expertise and manpower required to develop and implement underlying technological trends as well as the necessary stakeholder support to make significant investments in new technologies. Nonetheless, it cannot be denied that the fourth industrial revolution is accompanied by several difficulties such as privacy and security issues, technical issues, infrastructure availability, etc.

Therefore, this study recommends giving more priority to cyber security since there is less priority given to cyber security within organizations. Further, this

study recommends that organizations that implement I4.0 technologies can first create a lean base for the successful implementation of I4.0 technologies. As per the findings of the study, there's the termination of people and a reduction in the income level of employees due to technology implementations. Organizations can focus on increasing production capacity with technology implementations rather than terminating employees. Additionally, the infrastructure facilities in Sri Lanka to facilitate I4.0 technologies are comparatively lower than global standards. Hence, the authorities must initiate projects to improve the infrastructure facilities to facilitate the implementation of I4.0 technologies.

Theoretical and managerial implications

This research makes several contributions to the state-of-the-art I4.0 technology implementation and LM-related literature. The study proposes a new pathway to implementing I4.0 technologies in a Lean environment. Most of the studies that investigate I4.0 technologies and LM approach the topic without making any recommendations regarding a clear implementation sequence of practices and technologies. To our knowledge, few of these research studies have pointed to such a pathway, even though most of them have revealed a favorable association between LM and I4.0 in the direction of a successful I4.0 technology implementation. Further, only a very few such empirical research have been published so far about the apparel industry in Sri Lanka.

The study also provides a better understanding of how LM can support the implementation of I4.0 technologies, allowing companies undergoing I4.0 technology implementation to better manage their change process while they move towards the LM. There will be a greater need for integrating novel technologies as businesses continue to prioritize LM and effective business practices. This is one way in which I4.0 will transform manufacturing. It tends to increase productivity to various levels, while also generating fresh company ideas and innovative services. So, in this paradoxical situation where technology and human-based simplicity must coexist, finding the right balance for change may be the key to successfully competing.

This study has extended the knowledge regarding the pathway for implementing I4.0 technologies in a Lean environment. By starting from an empirical analysis, the study's findings provide indications for managers concerning how companies could implement I4.0 technologies in a Lean environment. In this sense, managers and practitioners from companies undergoing I4.0 technologies implementation in a Lean environment may find here guidelines that can help them to prioritize efforts and narrow their attention more objectively to the proper mix of procedures and technology. Thus, this study represents the new opportunities for implementing I4.0 technologies in a Lean environment.

Managers will be able to use this study and the associated results to initiate their implementations. Furthermore, the study provides a framework for the successful implementation of I4.0 technologies, especially for apparel manufacturing companies that have a Lean background by highlighting the challenges of implementing I4.0 technologies and the effects of I4.0 technologies on human resources. Companies can use this study approach to evaluate their I4.0 implementation as well as when they have already invested in such technologies and are unsure about their next steps. Also, this research gives crucial information for practitioners to comprehend the significance of integrating the I4.0 technologies with the Lean paradigm.

Overall, the findings may be necessary to manufacturers in the apparel industry, policymakers for national development, and even managers and investors in every industry when they initiate the I4.0 implementation process.

Limitations and future research directions

There are some limitations of this study that offer future research directions. The first limitation of the study is the sample size. Since this study has considered a sample of ten respondents from four apparel firms in Sri Lanka, the sample can be further expanded to conduct a more generalized study on the pathway for implementing I4.0 technologies in a Lean environment.

Secondly, the study only addresses the pathway for implementing I4.0 technologies in a Lean environment in the apparel industry. Future research could be performed for different industries and such findings can explain how these technologies can affect different industries.

Thirdly, this study has used a limited set of variables through a questionnaire-based survey. Future research could additionally examine the relationship's response between I4.0 technologies and LM to any moderating and mediating factors.

This study uses a qualitative study to conduct the research. Future research could be performed using a quantitative study to verify the results of this study.

Finally, the study focuses on the variables such as initial I4.0 technologies to be implemented, drivers and challenges, and the effect of I4.0 technologies on the

human resources of a Lean environment. There can be other variables that are not investigated in this study that will be necessary for implementing I4.0 technologies in a Lean environment that future research can focus on.

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Annexures: Themes and sub-themes developed under thematic analysis

Annexure 1: Pathway for implementing I4.0 technologies in a Lean environment

Main themes	Sub-themes
1. Set the Lean base	a. Waste elimination b. Process standardization c. Current state identification d. Lead technology implementation
2. Strategic Management	a. Defining organizational strategies b. Management discussions c. Conducting cost-benefit analysis and defining the technologies to be implemented d. Pilot area selection and technology implementation e. Conducting internal testing cycles
3. Human Resource Development	a. Assessment of HR competencies for I4.0 b. Employing skilled HR wherever required c. Conducting training sessions d. Conduct technology awareness sessions
4. Getting External Support	a. External consultants b. Local and global business relationships

Annexure 2: I4.0 technologies implemented in a Lean environment

Main themes	Sub-themes
1. Cloud Computing	a. Cloud-based ERP b. Power Business Intelligence
2. Internet of Things	a. Automated Guided Vehicle b. Sensors in machines c. RFID
3. Automation and Industrial Robotics	a. Machine and process automation b. Robotic process automation
4. Big Data Analytics	a. Shop floor system b. Fast track system
5. Computer-aided systems	a. Computer -aided designing systems b. Computer-aided quality control system
6. Additive Manufacturing and Augmented Reality	a. 3D Printing b. Digital technologies

Annexure 3: Drivers for implementing I4.0 technologies in a Lean environment

Main themes	Sub-themes
1. Lean principle	a. Improving waste detection b. Requirement identification
2. Organizational factors	a. Leadership b. Cost reduction c. Enhance data availability d. Quality and efficiency improvement
3. External forces	a. Competition b. Customer expectations
4. Human resource factors	a. Increasing labor cost b. Reduce human dependency

Annexure 4: Challenges in implementing I4.0 technologies in a Lean environment

Main themes	Sub-themes
1. Cost	a. High investment cost b. Cost of training
2. People-related challenges	a. Technology resistance b. Technical issues
3. Technological challenges	a. Choosing among alternative technologies b. Infrastructure availability c. Privacy and security

Annexure 5: Effects of I4.0 technologies on human resources in a Lean environment

Main themes	Sub-themes
1. Positive effects	a. Human resource development b. Makes the jobs easier
2. Negative effects	a. Reduction in income b. Termination of people