

Exploring the Diffusion of Industry 4.0 Technologies in Apparel Supply Chains of Sri Lanka

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ABSTRACT

Industry 4.0 have become a hype among the manufacturing industries across the globe. Recent developments require significant capital investments, but these technologies are yet to be established in developing countries such as Sri Lanka, especially the labour-intensive industries such as the apparel industry. This study has investigated the extent to which Industry 4.0 has diffused into the Sri Lankan apparel industry and examined whether Industry 4.0 adoption affects the organizational and supply chain performance of apparel firms in Sri Lanka. The study follows a qualitative approach to identify the technologies adopted and their effect on organizational and supply chain performance. Data were collected from eight respondents from four major apparel firms. Content analysis was performed to identify the extent to which the technologies are adopted and their effect on organisation and supply chain performance. Content analysis reveals that Augmented and Virtual Reality, Big Data and Analytics, Cloud Computing, Cyber Security, the Internet of Things (IoT), and Robotics are adopted by apparel firms in the Sri Lankan apparel industry. However, the adoption of Cyber Security is at a lower level. Study findings also highlight the key benefits of Industry 4.0 technologies that drive the adoption of Industry 4.0 and the barriers the apparel firms face in adopting Industry 4.0 technologies face. Further, these technologies improve organisational performance in terms of efficiency, effectiveness, and competitiveness. These technologies also improve the overall supply chain performance. Findings show that Industry 4.0 improves Supply Chain Performance through quality, efficiency, responsiveness, effectiveness, and flexibility. The study contributes to Industry 4.0 literature by highlighting the diffusion and effect of Industry 4.0 in the Sri Lankan apparel industry by providing empirical support for the impact on organisational and

supply chain performance. The study offers managers insights into the potential of Industry 4.0 technologies.

Keywords: Apparel Supply Chains, Diffusion, Industry 4.0 technologies

1. INTRODUCTION

Globalisation and rapid technological development have significantly improved the modern business environment. Industry 4.0 is powered by advanced technologies connected and interacting with each other, which can adapt to changes to avoid failures (Rüßmann *et al.*, 2015). The concept was initially presented in Germany in 2011 (Roblek, Meško, and Krapež, 2016). Academic and business communities have well-accepted Industry 4.0s experts estimate it can positively impact life standards (Oztemel and Gursev, 2020). Several nations have adopted Industry 4.0 as a tool for national development and invested in Industry 4.0 projects (Koh, Orzes and Jia, 2019; Oztemel and Gursev, 2020).

Researchers are investigating the effect of Industry 4.0 technologies on industries, markets, business operations and supply chains (Lu, 2017; Dallasega, Rauch and Linder, 2018; Kamble, Gunasekaran and Gawankar, 2018; Nara *et al.*, 2021). Information is a source of competitive advantage. Industry 4.0 eases information sharing, which drives the success of the supply chain, and the physical flow of materials has improved using technologies such as the Internet of Things (IoT), Radio Frequency Identification Devices (RFID), and Cyber Physical System (CPS) through real-time tracking (Tiwari, 2021). Several researchers have highlighted that Industry 4.0 enhances supply chain performance by providing flexibility, collaboration, accessibility, and better decision-making (Roblek, Meško and Krapež, 2016; Dallasega, Rauch and Linder, 2018; de Vass, Shee and Miah, 2018; Hald and Kinra, 2019; Chauhan and Singh, 2020; Ghadge *et al.*, 2020; Dudukalov *et al.*, 2021; Ganbold, Matsui and Rotaru, 2021; Mastos *et al.*, 2021; Tiwari, 2021).

Developing economies play a significant role in most of the global supply chains. A considerable proportion of the manufacturing facilities are in these regions primarily to benefit from the lower labour costs. On the other hand, developing economies are lagging in adopting technological innovations due to substantial capital investments and advanced technological infrastructure requirements. Consequently, the existing

knowledge base is biased towards developed economies as only a limited number of research studies have targeted developing economies such as Sri Lanka. While acknowledging this gap, this study investigates the diffusion of Industry 4.0 technologies in apparel supply chains.

The technologies under the umbrella of Industry 4.0 were initially developed for technology-intensive manufacturing facilities. Therefore, adopting these technologies in labour-intensive industries such as apparel may pose specific challenges. Thus, this study explores how far Industry 4.0 has been diffused into the Sri Lankan apparel industry and the effect of such technologies on Organisational Performance and Supply Chain Performance.

2. LITERATURE REVIEW

Industry 4.0

Industry 4.0 is the fourth phase of the industrial revolution that originated in Germany in 2011 and is defined as a digital manufacturing method (Roblek, Meško and Krapež, 2016; Oztemel and Gursev, 2020). The fourth industrial revolution is powered by advanced technologies connected and interacting, which can adapt to changes to avoid failures (Rüßmann *et al.*, 2015; Xu, Peak, and Prybutok, 2015; Xu, Xu, and Li, 2018; Dudukalov *et al.*, 2021). As a result, Industry 4.0 has gained the attention of academic and business societies (Abdirad and Krishnan, 2020; Oztemel and Gursev, 2020). Several nations have invested in Industry 4.0 projects to improve processes and performance (Koh, Orzes and Jia, 2019). Industry 4.0 transforms the production system into fully integrated and automated systems that will enhance vertical and horizontal interaction (Rüßmann *et al.*, 2015; Kamble, Gunasekaran and Gawankar, 2018; Xu, Xu and Li, 2018; Shah *et al.*, 2019). Thus, Industry 4.0 reduces lead time, improves responsiveness and productivity, and influences social, economic, and environmental sustainability (Rajput and Singh, 2019; Abdirad and Krishnan, 2020; Nara *et al.*, 2021). Adopting Industry 4.0 can improve the performance and sustainability of many industries, including automotive, electronics, food and beverage, textiles, apparel, and footwear (Abdirad and Krishnan, 2020). In addition, researchers also proved that Industry 4.0 significantly improves the service sector and manufacturing industries (Rahman *et al.*, 2020).

Industry 4.0 comprises a variety of advanced technologies (Rüßmann *et al.*, 2015; Dalenogare *et al.*, 2018; Koh, Orzes and Jia, 2019; Bai *et al.*, 2020; Esmaeilian *et al.*, 2020; Ghadge *et al.*, 2020; Oztemel and Gursev, 2020; Dudukalov *et al.*, 2021; Fatorachian and Kazemi, 2021). Industry 4.0 technologies can be classified into nine pillars: Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data and Analytics (BDA), Cloud Computing (CC), Robots, Simulations, Additive Manufacturing (AM), Augmented Reality (AR), and Cyber Security (Rüßmann *et al.*, 2015; Erboz, 2017; Fatorachian and Kazemi, 2021).

Cyber-Physical System (CPS)

Cyber-Physical Systems include components essential for the implementation of Industry 4.0. These systems help integrate processes and functionalities to prevent systems, allowing instant control and checking feedback to achieve the expected output (Hermann *et al.*, 2016; Oztemel and Gursev, 2020). Cyber-Physical System (CPS) is a fundamental pillar in implementing Industry 4.0 (Fatorachian and Kazemi, 2021). CPS plays a crucial role in meeting the agility of production and the efficiency and effectiveness of organizations (Lu, 2017). CPS improves collaboration and cooperation and enhances decision-making throughout the supply chain leading to the flexibility of operations and supply chain responsiveness (Fatorachian and Kazemi, 2021). CPS highly supports information sharing through Information flow and process flow, essential components of Supply Chain Management. Thus, incorporating CPS into business processes can improve information and knowledge sharing, which enhances the integration among the supply chain members, leading to higher performance (Tiwari, 2021).

Cloud Computing

Cloud Computing is the technology that permits the use and storing of applications data and other programs in a virtual environment using the internet and enables real-time access to extensive data (Xu, Xu and Li, 2018; Ghadge *et al.*, 2020; Oztemel and Gursev, 2020). Cloud technology positively affects supply chain integration and supports the performance that improves the capability to facilitate and complement resources within and outside the organisation (Shee *et al.*, 2018). Researchers have evaluated Cloud Computing across the supply chain in terms of the capability of the

cloud technology to share inventory information, conduct demand forecasting, obtain order status, and track and from suppliers and customers (Yao, Palmer, and Dresner, 2007; Shee *et al.*, 2018; Fatorachian and Kazemi, 2021).

Internet of Things (IoT)

IoT is developed based on intelligent technology that can be adopted across several operations fields, including infrastructure, health, logistics, and security (Roblek, Meško and Krapež, 2016). The Internet of Things improves the efficiency of the supply chain through real-time data, which reduces the bullwhip effect and enhances traceability. Thus, IoT plays a vital role in initiating the fourth industrial revolution (Hermann *et al.*, 2016; Roblek, Meško, and Krapež, 2016; Kamble, Gunasekaran and Gawankar, 2018). IoT allows devices and sensors such as RFID, mobile devices, computers, and sensors to interact to achieve a common goal that will enable machines to capture, process, and communicate data, which helps coordinate and synchronize information flow (Kamble, Gunasekaran and Gawankar, 2018). Researchers have highlighted IoT as an additional capability for the organisation to improve the value across the supply chain and as a resource that enhances performance through integration across the supply chain (Shah *et al.*, 2019). IoT across the supply chain includes devices' capability to provide unit-level identification, monitor, track and trace supply chain entities, control supply chain processes remotely and provide real-time information. These capabilities can significantly affect supply chain integration, performance, and organisational performance (de Vass, Shee and Miah, 2018, 2021; Pasi, Mahajan and Rane, 2020).

Big Data and Analytics (BDA)

Big Data collects large amounts of data generated by everything around us through digital processes and social media (Oztemel and Gursev, 2020). Fatorachian & Kazemi (2021) define Big Data Analytics as the use of computing and analytical power offered by computers and analytical techniques against such a large and diverse data set. Organisations have realised the importance of analytical capabilities to gain a competitive advantage as it supports organisations to make better decisions through simulations and insights. Big Data and Analytics and the ability to undertake comprehensive analysis in real-time help organisations avoid failures and improve

agility and sustainability (Koh, Orzes and Jia, 2019). Big data can improve the information flow and real-time information sharing across different supply chain functions, facilitating the firm to collaborate with all supply chain participants and improving the supply chain's efficiency and responsiveness (Yu *et al.*, 2018). Researchers show that the data-driven supply chain significantly impacts the supply chain for information exchange, coordination, integration, and responsiveness.

Robots/ Autonomous Robots

Autonomous Robots are also being used in the manufacturing industry, which has replaced human factors in production. These robots are capable of being more independent, flexible, and cooperative. They can also interact with one another and with humans, improving the organization's productivity while reducing the cost of operation (Rüßmann *et al.*, 2015). Robots are becoming dominant in production because they can carry out complex tasks that human labor cannot undertake in more adverse conditions while maintaining productivity (Rüßmann *et al.*, 2015; Oztemel and Gursev, 2020). The use of robotics plays a significant role in driving Industry 4.0. Robots can be used in several areas, such as production, logistics, and transportation (Erboz, 2017). Rapid technological development results in flexible, autonomous, and Smart systems that can learn, named co-bot (Koh, Orzes and Jia, 2019). These advanced robots can facilitate learning and knowledge management, providing a competitive edge.

Additive Manufacturing (AR)

Additive manufacturing refers to technologies that can produce by adding incremental layers of material using computer models. Additive manufacturing reduces manufacturing complexity. Along with CAD systems and 3D printing, additive manufacturing is applied in various operations, including prototyping, part production, tooling, and spare parts (Durach, Kurpjuweit and Wagner, 2017). The growth in additive manufacturing is exponential in several industries, including automotive, aerospace, medical, and electronics (Delic and Eysers, 2020). Across the supply chain, additive manufacturing is vital in improving supply chain integration and performance (Delic, Eysers, and Mikulic, 2019; Delic and Eysers, 2020). Durach *et al.* (2017) highlighted that additive manufacturing could facilitate the supply chain by compressing transportation costs and lead time.

Augmented Reality/ Virtual Reality (AR/ VR)

Augmented/ Virtual reality is the technology that can augment or recreate the natural world in a virtual world with the ability to enhance with additional and virtual information (Wang *et al.*, 2020). Augmented reality-based systems are adopted by businesses to support various activities such as selecting items from warehouses, training employees, and even sending instructions over mobile devices such as in case of repair (Rüßmann *et al.*, 2015). Augmented reality plays a vital role in reducing errors, and even adverse outcomes as operators can learn to interact with machines in a virtual world, thus preventing any impact on the real world. Further, Wijewardhana *et al.* (2020) emphasize that VR and 3D prototyping can be a technology that facilitates the sample approval process in the apparel industry, reducing the cost of sample development, operation cost, and lead time for order processing. Thus, it has an impact on the supply chain performance.

Simulations

Simulations recreate the real-world data into a virtual model that helps the user evaluate and optimize before the physical changes to improve the quality and reduce the cost (Rüßmann *et al.*, 2015). Simulations minimize the waste of time and resources that can improve the efficiency and productivity of the operation (Gunal, 2019). Organizations can increase worker safety by simulation training for more critical and high-risk tasks. In addition to these processes, simulations are used extensively in the supply chain. Simulations are used to evaluate alternative supply networks and existing supply chains and experiment with alternative configurations (Katsaliaki and Mustafee, 2019). Simulations improve organizational and supply chain efficiency by eliminating resource and time waste from changing complex supply chains.

Cyber Security

Industry 4.0 has increased the integration and connectivity of processes, entities, devices, and information. This increased connectivity has also raised threats such as cyber-attacks (Erboz, 2017). Information is a crucial resource that can lead an organization to gain a competitive advantage over its rivals. With higher importance in integration, the organization holds information about the customers, suppliers, and business partners. As a result, any information breaches can affect the organization's

overall supply chain and competitiveness. As a result, cyber security has also increased with technology development to provide a higher value to customers.

Organisation, Supply Chain, and Industry 4.0

Supply Chain Management has become a growing concern in the business world. Specifically, the concepts associated with supply chain performance, sustainability and agility have become challenging themes in supply chain literature (Najmi and Makui, 2012; Whitten, Kenneth, and Zelbst, 2012; Bourlakis *et al.*, 2014; Datta, 2017; Altay *et al.*, 2018; de Vass, Shee and Miah, 2018; Mani, Gunasekaran and Delgado, 2018). Supply Chain Performance is an indicator to assess the supply chain's competitiveness against the supply chain of the other competitors. The performance of the supply chain affects the performance and competitiveness of the individual firms in the value chain.

According to Bourlakis *et al.* (2014), Supply Chain Performance indicators are related to flexibility, efficiency, responsiveness, and quality. Further, Fatorachian & Kazemi (2021) identify responsiveness, flexibility, dependability, product/ service quality, efficiency, and effectiveness as dimensions for evaluating Supply Chain Performance. Whitten *et al.* (2012) cited that the performance of the supply chain is measured based on the ability to deliver the right quantities of products demanded by the customers at the right quality and time and the ability to minimize the cost to the final customer.

Companies adopt modern technologies to improve information sharing and transparency through effective communication and coordination to improve Supply Chain Performance. Industry 4.0 could significantly improve the supply chain through a higher level of integration and transparency throughout the supply chain (Fatorachian and Kazemi, 2021). Researchers have highlighted that Industry 4.0 technologies and digitalization affect supply chain performance (Dudukalov *et al.*, 2021). Industry 4.0 impacts various supply chain stages and information sharing (Preindl, Nikolopoulos and Litsiou, 2020).

Existing literature and findings support that adopting Industry 4.0 to supply chain management improves supply chain performance through integration and information sharing. Concerning the apparel industry, B. Wang & Ha-Brookshire (2018) emphasized enhancing digital competency in the fashion supply chain to improve organizational training and education.

Due to improvements in the supply chain performance, individual organizations in the supply chain experience better performance. Thus, researchers have supported that organizational performance can be improved by implementing Industry 4.0 technologies. Several pieces of literature emphasize that technologies enhance organizational performance (W. Yu, 2015; Y. Yu et al., 2021). Some researchers have also highlighted that supply chain performance significantly improves organizational performance (Bourlakis *et al.*, 2014). Further, Ganbold et al. (2021) highlighted that those technologies significantly impact all operational performance indicators through supply chain integration. Researchers also related the supply chain performance to organizational performance and validated that organizational performance can be improved through improving the supply chain performance (Whitten, Kenneth, and Zelbst, 2012). Available literature highlights that Industry 4.0 technologies significantly improve information sharing, integration efficiency, and effectiveness of organisations that can improve organisational and supply chain performance.

The above discussion shows that Industry 4.0 technologies significantly improve the organisation and supply chain. Several pieces of literature have highlighted that adopting Industry 4.0 impacts operational and supply chain performance positively. However, most of the identified literature discusses the effect on the performance caused by these disruptive technologies. Furthermore, scholarly studies have been conducted in resource-rich economies with comparatively high investments and technological advancement.

Very few studies have focused on the use and effect of Industry 4.0 technologies in developing countries. However, the extent to which the technologies are diffused into different production sectors is rarely discussed.

The adoption of Industry 4.0 in Sri Lankan industries remains unexamined in Sri Lankan context. Thus, the study's primary purpose is to explore how far these technologies have been diffused into the Sri Lankan apparel industry and the effect of such technologies on organizational and supply chain performance.

Theoretical background – capability-based view

The resource-based view focuses on the firm's internal environment and highlights the resources as a driver for competitive advantage (Wang, 2014). Organization capability theory extends the resource-based view theory, emphasizing the importance of developing the resources and capabilities to improve performance. Capabilities are how the resources are used or deployed (Johnson *et al.*, 2016). As H. Wang (2014) cites, the organization must deploy resources and develop capabilities and learning implicitly and explicitly to gain a competitive advantage. The capability of Industry 4.0 technologies in the organisation can be evaluated for process improvement. With Industry 4.0 technologies and capabilities, an organization can improve its performance within and across the supply chain leading to higher integration and performance (de Vass, Shee, and Miah, 2018, 2021).

Conceptual Framework and initial proposition

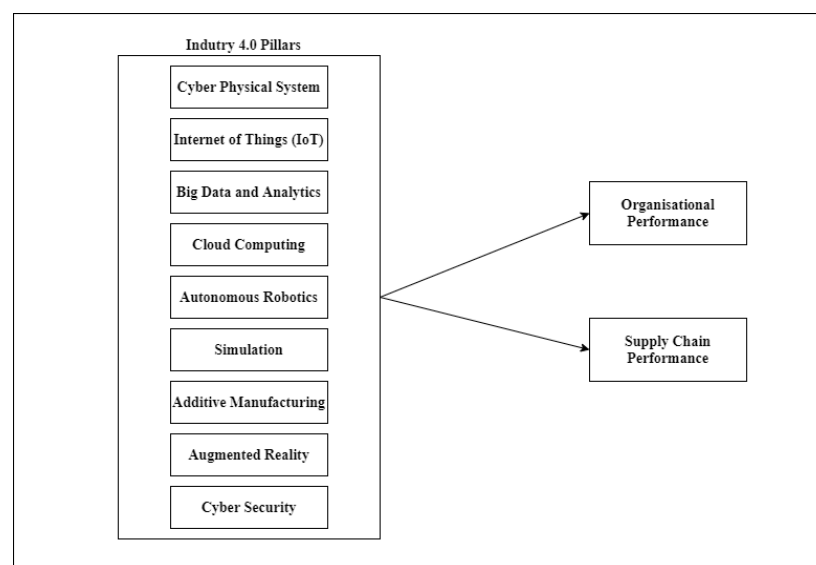


Figure 1 Theoretical Framework

The initial literature review emphasizes that adopting and implementing Industry 4.0 technologies improve Supply Chain Performance and Organisational Performance. So, the researcher follows the theoretical Framework developed based on the existing literature to assess the diffusion of Industry 4.0 technologies in the Sri Lankan apparel industry.

3. METHODOLOGY

This study follows an inductive approach (Saunders, Philip, and Thornhill, 2016) to explore how far Industry 4.0 technologies have diffused and contributed to organizational and supply chain performances in the Sri Lankan apparel industry. The qualitative research approaches were explicitly selected to understand the diffusion of Industry 4.0 technologies and their effect on organizational and supply chain performance.

The population comprises around 300-350 Board of Investment (BOI) registered apparel firms in Sri Lanka (EDB, 2020). As the adoption of Industry 4.0 is the latest technological trend in the Sri Lankan apparel industry, organizations that have not invested in Industry 4.0 technologies were not considered for the sample. Consequently, a sample has been selected for the study using purposive sampling. Within each organization, two participants with over five years of experience in the apparel industry were selected. Table 1 below summarises the profile of the respondents.

The interview guide was developed with two sections. The first section investigates the respondents' profiles, and the second section involves open-ended questions to gather in-depth information about the subject. The interview questions were structured into four key areas: Respondents' Profile, IT application in Supply Chain Management, Industry 4.0 technologies in the Apparel Industry, Future Trends, and Barriers.

The data for the study was collected through structured interviews. A set of structured interviews through the Zoom platform have been conducted to collect data. The interviews were recorded and transcribed. Initially, themes were developed based on the research questions, and such broader themes are divided into subcategories. These subcategories were used in the coding process to answer the research questions. Content analysis was performed to systematically analyze the themes and core ideas found in the text (Eranda, 2021; Mayring, 2000) with NVivo qualitative analysis software to answer the research questions. The technologies adopted, the benefits of such technologies, barriers to adoption of technologies, and their impact on organizational performance and supply chain performance are identified based on the analysis.

Participant ID	Organisation ID	Job Title	Experience (Years)	
			Supply Chain	Apparel Industry
1	B	Supply Chain Manager	13	13
2	A	Senior Executive – Supply Chain	4.5	5
3	C	Senior Executive – Sourcing and Supply Chain	5	5
4	D	Assistant Manager Supply Chain	13	13
5	B	Supply Chain Manager	8	8
6	D	Senior Executive – Supply Chain	2	1.5
7	A	General Manager	7	22
8	C	General Manager	15	18

Table 1 Respondents Profile

4. ANALYSIS

Based on the initial background analysis of the data collected, a mind map (Figure 2) was designed to develop the themes for the analysis of the study. Primary themes are developed to answer the research questions based on the content analysis corresponding with the existing literature. The codes generated from the coding process were grouped and formulated into themes to answer the research questions. Each theme developed is discussed in detail below.

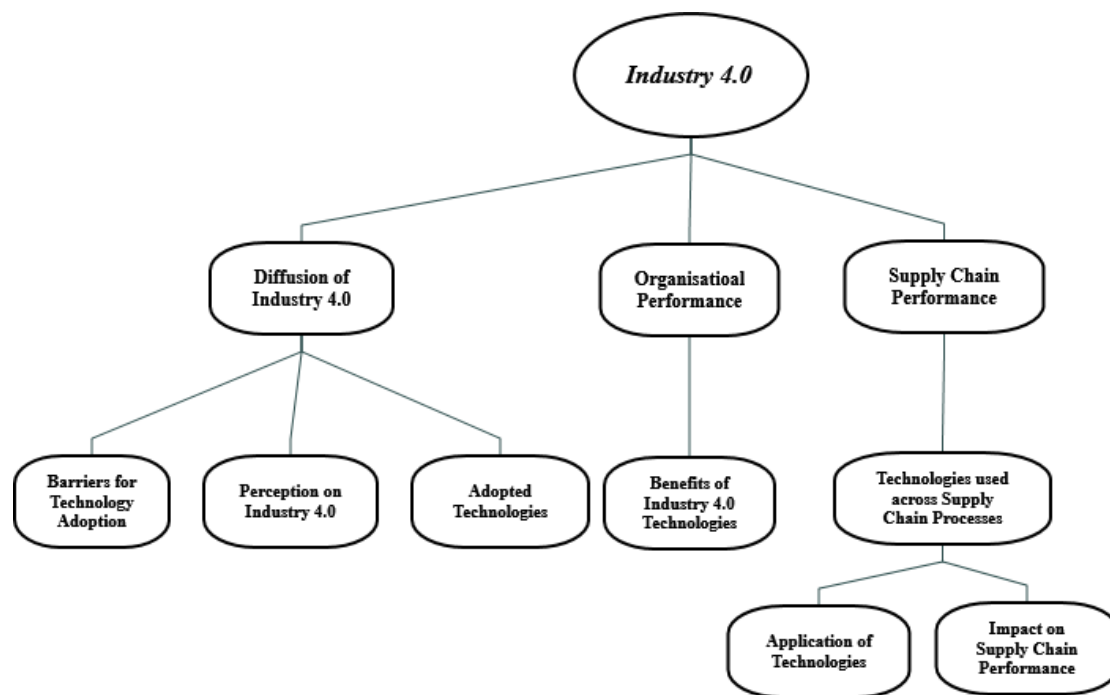


Figure 2 Mind Map for Theme Development

Diffusion of Industry 4.0 technologies

The organizations have adopted multiple Industry 4.0 technologies in the Sri Lankan apparel sector. The respondents revealed that Augmented and Virtual Reality, Big Data and Analytics, Cloud Computing, Cyber Security, the Internet of Things (IoT), and robotics are among the technologies adopted in their organizations. The organizational adoption of these technologies is presented in Table 2.

	Organisation A	Organisation B	Organisation C	Organisation D
AR and VR	Yes	Yes	Yes	Yes
Big data	Yes	Yes	Yes	Yes
Cloud Computing	Yes	Yes	Yes	Yes
Cyber Security	No	Yes	Yes	No
IoT	Yes	Yes	Yes	Yes
Robotics	Yes	Yes	Yes	Yes

Table 2 Technologies adopted.

Respondents revealed that their organisations are adopting a total of six technologies. It has also been revealed that the two selected organisations have not invested in cybersecurity technologies. This omission is a surprise for such organisations considering the ubiquitous nature of these technologies. It is also evident that the popularity of the said technologies had a boomerang effect as the management of those organizations failed to recognize the specific importance of cyber security in Industry 4.0 ecosystems. Instead, they have overlooked the cyber security technologies as generic technologies and diverted their efforts toward the remaining five technologies.

Codes	Interview participant	Quotations
Barr iers to Tech nolo gy Ado ptio n	1	“People do not like to save in clouds. They like to save on their desktops. Now, it's like an open environment in terms of data. Sri Lankan doesn't like that, and they keep things in their pocket.”
	4	“The investment or we can say the initial cost to adopt such technology is very much a high challenge in Sri Lanka.”
	6	“We are in crisis. Hence capital wise we have problems in capital investments.”
	2	“There are a lot of regulatory barriers in Sri Lanka like, for example, if you want to implement RFID still RFID frequencies are not properly approved in Sri Lanka.”

Table 3 Barriers to technology adoption

Further, the respondents also highlighted that the reasons for the poor adoption are that decision-makers make decisions based on short-term performance, which sometimes reduces technology adoption. In addition, while discussing the barriers to technology adoption, respondents highlighted factors from financial, legal, and technical aspects. Table 3 shows the respondents' comments regarding the barriers to technology adoption.

In addition, the responses summarised below in Table 4 highlight Sri Lankan entities' perception of adopting Industry 4.0 technologies. The discussion on perception

supported that decisions based on short-term performance affect the adoption of Industry 4.0.

Codes	Interview Participants	Quotations
Perc ption on Indu stry 4.0	2	“My opinion is yes, we have to, to be to be competitive to be competitive in this market, especially the raw materials and operating costs are going up day by day and there are supply chain difficulties.”
	3	“I would say that, Yeah, my opinion is we must extend our investment in Industry 4.0. Because it helps improve efficiency and profits.”
	5	“It is not feasible to adopt this technology 100 % to the operation because still there will be human involvement in the activities such as decision making. But adopting these technologies will favorably impact on organization. Because these technologies reduce the dependence.”

Table 4 Perception on Industry 4.0

Industry 4.0 and Organisational Performance

Respondents perceive that adopting Industry 4.0 technologies has benefitted organizations in sustaining their competitiveness. When queried about the benefits gained from Industry 4.0 technologies, the respondents revealed that their organizations' performance had significantly improved. Table 5 presents selected comments made by the respondents on the benefits of Industry 4.0 on organizational performance.

The respondents have revealed explicitly that the organizational efficiency, the effectiveness of the decisions, and the flexibility of the operations of the respective firms were positively impacted in parallel to the adoption of Industry 4.0 technologies. The primary reason for these improvements may be the enhancement of information flow within the organization. Further, the technologies have developed unprecedented capabilities to collect data targeting various dynamics of the organizational operations

and process them into meaningful information. As a result, Industry 4.0 technologies have significantly reduced operational costs, compensating for the considerable capital investments.

On the other hand, adopting Industry 4.0 technologies positively and negatively impacts human resources. Respondents highlighted that adopting such technologies can reduce employees' workload, stress levels, and fatigue. However, such initiatives will make some existing skills obsolete; thus, the employees will be challenged to develop newer skills to survive in the organisation. On top of this, organisations have made plans to downsize the workforce, threatening the job security of some traditional jobs requiring manual labor.

Codes	Interview Participant	Important Quotations
Benefits of Industry 4.0 Technologies	1	“People need to accept the new systems and new available technologies and be ready to be patient till the technologies get mature..... from the first instance if you throw it out the system because of errors it will then never serve to the purpose.”
	2	“We can provide customized manufacturing, and then we are trying to bring the mobility manufacturing in place.”
	4	“... improving the efficiency and we can go for more quality products because as I said we can predict the product; we can create more value to the customer.”
	5	“You know the fashion industry is rapidly changing and decision making is important or, else we will become outdated. But now it also can be done within less time. So, we can say innovations play an important role in improving performance.”
	7	“Industry 4.0 technologies play an important part such as Cut down waste and identifying non-value adding items and then most importantly, because of the demand and such time-consuming activity can affect production activities. We managed to cut down almost 95% of the cost with technologies.”

Table 5 Benefits of Industry 4.0 Technologies

Industry 4.0 and Supply Chain Performance

Industry 4.0 technologies are vital resources that can improve not only the individual organization's performance but also the performance of supply chains that link suppliers, manufacturers, and customers. When the respondents were asked about the technologies that may affect the supply chain performance, they highlighted three of the six implemented in the organizations. i.e., Big Data, Cloud Computing, and the Internet of Things. Table 6 summarises the presence of technologies in an organization's supply chain processes. Table 7 summarises some critical comments of the respondents on applying such technologies across the supply chain.

	Used in Supply Chain Processes
1: AR and VR	No
2: Big data	Yes
3: Cloud Computing	Yes
4: CyberSecurity	No
5: IoT	Yes
6: Robotics	No

Table 6 Technologies used across supply chain processes.

Codes	Technology	Interview Participant	Quotations
Application across Supply Chain	Big Data and Analytics	1	"The big data is there to even analyze the supply chain function and take decisions data transaction and analysis are the biggest part of the supply chain."
		4	"We also use this big data to find some analytics and decision making is across the supply chain that is also highly utilized."
		5	"We use predictive tools such as big data using some power bi and also, we take decisions across the supply

		chain using dashboards and those things and even that is very much useful in forecasting raw material prices..... these analytics play a significant role to secure our profit margin and to provide a better value to customers.”
	5	“We can say reducing the cost and reducing the lead time mainly in terms of processing cycle time.”
	1	“.....through the mailing system and postal system these it takes a huge time, now in terms of the timing, if we need three months to execute an order, now it's become 14 days. So, it is more than 10 times faster.”
	4	“We are using cloud computing in all of our communication by using a network through communication and that was much useful.”
Cloud Computing	6	“Cloud computing or ERP system is implemented across the supply chain we have a portal that suppliers can communicate through this ERP system.”
	8	“Also, the current cloud computing is used widely with our suppliers and customers, and we use it to communicate and share information across our facilities.”

Internet of Things	2	“We are implemented all those IoT, standardized robotic and guided vehicles to implement that traceability part, etc want to track our shipment when it's real-time location.”
	5	“We are also using RFID techniques in this operation because logistics are maintained basically on those so it's also an important part in the supply chain.”
Other uses	2	“We eliminated those steps using technology and we have minimized the cost due to that process.”
	5	“These analytics play a significant role to secure our profit margin and to provide a better value to customer.”
	4	“These technology support improving performance when we compared with traditional systems they are improving the efficiency.”
	2	“We have implemented IT solutions like automated defect detections on raw material inspection. Now, at least 40% of the defects are being identified without any human intervention.”
	8	“Currently there is has a huge demand for the transparency all that

	like the traceability. So, for that traceability also, this Industry 4.0 has done a total contribution.”
1	“The information sharing, the information availability is there for anyone. the information sharing is there for everyone.”

Table 7 Application of Industry 4.0 technologies across the supply chain

All respondents agreed to the fact that the adoption of Industry 4.0 technologies can positively impact supply chain performance. The impact on the supply chain is discussed broadly regarding cost reduction, quality improvement, process improvement, information sharing, integration, lead time reduction and improving transparency and visibility. According to the respondents, Big Data and Analytics play a significant role in cost reduction, quality improvement, process improvement, information sharing, integration, and lead time reduction. Cloud computing and IoT improve information sharing and transparency across the supply chain. Cloud computing plays a significant role in customer and supplier integration, whereas IoT supports process improvement of apparel organisations.

5. DISCUSSION

Diffusion of Industry 4.0 Technologies

The evidence suggests that the Sri Lankan apparel industry is moving towards Industry 4.0. Currently, well-established apparel firms have adopted suitable Industry 4.0 technologies to improve their performance and meet the competition from the global apparel industry. Major technologies adopted by apparel firms are Augmented and Virtual Reality (AR and VR), Big Data and Analytics (BDA), Cloud Computing, Cyber Security, the Internet of Things (IoT), and Autonomous Robots. AR and VR technologies are used in product design and maintenance. Robotics are used to improve manufacturing processes. Technologies such as Big Data and Analytics, Cloud Computing, and IoT improve information sharing and support decision-making. Implementing Cyber Security is at a very early stage where only a few apparel manufacturers have invested in such technologies. Organisations face several barriers

in terms of financial, legal, and technical requirements in adopting Industry 4.0 technologies.

In addition, an analysis of the responses revealed the key benefits of adopting Industry 4.0 technologies. These technologies can reduce the workload and stress of the workforce, leading to skill development and innovation. Despite the favourable impact on human resources, adopting these disruptive technologies also has unfavourable effects on the organisation's human resources in the apparel industry. The labour requirement in manufacturing can be significantly reduced due to automation and the digitalisation of operations. Further, technological advancement has created the workforce's need for new skill development and reduced workload and stress.

According to the respondents, Industry 4.0 technologies are crucial in improving organisational performance in terms of efficiency, effectiveness, and competitiveness. Industry 4.0 plays a significant role in mass customisation. Real-time information sharing and high technology integration have resulted in highly responsive operations that support high flexibility to meet the rapidly changing fashion industry.

Further, Industry 4.0 has a significant contribution toward supply chain performance improvement. In the Sri Lankan apparel industry, Big Data and Analytics, Cloud Computing and IoT are used across the supply chain processes. These technologies improve supply chain performance through cost reduction, lead time reduction, information sharing, integration, quality improvement, process improvement, and transparency.

Industry 4.0 technologies improved business processes, including supply chain performance. The Sri Lankan apparel industry is facing growing competition from the global market. Thus, organisations aim to improve the efficiency of their operation while improving the quality of the products to meet customer expectations. The findings from the study highlighted the critical Industry 4.0 technologies that can be adapted to the Sri Lankan apparel industry and how such technologies can improve organisational performance and supply chain performance. The findings inspire industry practitioners to consider adopting Industry 4.0 technologies in the apparel industry to strengthen the relationship and coordination among supply chain processes.

6. CONCLUSION

Industry 4.0, being a growing concern in academic and business society, is at an early stage in the Sri Lankan apparel industry. Only a few well-established apparel firms have adopted key Industry 4.0 technologies. The commonly adopted technologies are Augmented and Virtual Reality (AR and VR), Big Data and Analytics (BDA), Cloud Computing, Cyber Security, the Internet of Things (IoT), and Autonomous Robots.

Industry 4.0 adoption improves the benefits to the organisation perpetually. Findings validate that organisations improve their operational performance through higher efficiency and effectiveness by implementing Industry 4.0 technologies. Further, when supply chain participants adopt these technologies, the overall effect of these technologies that arise from integration and coordination leads to higher value creation for the entire supply chain participants.

Organisations can improve their supply chain performance through information sharing, coordination, and integration. Findings also validate that organisations that adopt Industry 4.0 technologies have attained enhanced supply chain performance in terms of cost reduction, lead time reduction, information sharing, integration, quality improvement, process improvement, and transparency.

Findings emphasised the presence of resistance and barriers in integrating the process across the supply chain that could fail to achieve the full potential of the technologies. Thus, organisations must pay more attention to overcoming these challenges in implementing Industry 4.0 technologies to embrace the full potential of such technologies.

Further, Sri Lankan organisations face barriers regarding infrastructure facilities in adopting Industry 4.0 technologies. Hence the authorities must initiate projects to improve the infrastructure facilities to facilitate the adoption of Industry 4.0 technologies.

Theoretical and Managerial Implication

As a growing business discipline, the literature that addresses the adoption and effect of Industry 4.0 technologies in diverse industries is limited. A relatively high number of studies related to Industry 4.0 and Supply chains are being carried out in Developed economies than in developing economies. This study contributes to the supply chain literature by providing a comprehensive picture of the adoption of Industry 4.0 in the Apparel Supply Chain in Sri Lanka.

Secondly, the study guides the practitioners and policymakers to understand that Industry 4.0 technologies provide additional capabilities to organizations leading to improvement in overall performance in the supply chain. Although Industry 4.0 adoption is at an early growth stage in Sri Lanka, several organizations have progressed with a few key Industry 4.0 technologies. On the other hand, organizations that do not adopt these technologies will face challenges to compete in the long run and lose their competitive advantage.

Furthermore, the study also provides managerial insights to managers to extend their focus on holistic supply chain management that benefit all supply chain partners more significantly. Overall, the findings may be necessary to manufacturers in the apparel industry and logistics service providers, policymakers for the national development and even managers and investors in every industry to understand the value of Industry 4.0 technology to improve day-to-day operations and ensure sustainability.

Limitations and Future Research Directions

The study was undertaken with only a small sample from the apparel industry. Future research may like to study with a broader sample of different organizations. Such potential findings may allow more detailed results to explain the impact of Industry 4.0 on supply chain performance. Secondly, the study only addresses the diffusion of Industry 4.0 technologies in the Sri Lankan apparel industry. Thus, the findings cannot be generalized. Further, the study findings can be supported through quantitative analysis, which statistically validates the impact of Industry 4.0 technologies on Organisational Performance and Supply Chain Performance.

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