Readiness Assessment for Industry 4.0 in Sri Lankan Apparel Industry

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Abstract

Sri Lankan apparel industry is the most significant contributor to the country's economy by constituting a large portion of GDP. In the competitive apparel world, manufacturers search solutions for future problems such as worker inadequacy to minimize human intervention to increase productivity. Therefore, there is a need to align value chain operations with the latest technologies. The world is now experiencing the fourth industrial revolution that integrates emerging digital technologies; cyber-physical systems, Internet of Things, big data, simulation, cloud computing and augmented reality. Industry 4.0 enhances process functions by providing real-time visibility for smooth production flow. Before aligning with Industry 4.0, there is an urgent need for assisting companies to improve their capabilities. Current literature mentions various existing readiness assessment models, but there is no standard and well-accepted model. This research presents applications of industry 4.0 in apparel industry and analysis of existing Industry 4.0 readiness assessment models based on systematic review of literature. Evaluation criteria were proposed to evaluate the strengths and weaknesses of each model. This study will guide academics to develop a standardized readiness assessment model for Industry 4.0 that fills the current research gap, while practitioners may find assistance in implementing appropriate scenarios in apparel industry.

Keywords: Industry 4.0, Apparel 4.0, Readiness assessment model, Sri Lankan apparel industry

1. Introduction

Sri Lanka's apparel industry is the most significant and driving contributor for the country's economy by employing a labour force of over 990,000 and contributing over $5 billion to GDP (Central Bank of Sri Lanka, 2018), (Export Development Board, 2018). This industry has achieved rapid growth rates over the past four decades despite the increasing competition and a rapidly evolving global marketplace for apparel. Today, the apparel industry as the Sri Lanka's primary foreign exchange earner accounts for 40% of the total exports and 52% of industrial product exports (Export Development Board, 2018). Apparel categories such as lingerie, sportswear, swimwear and work wear are manufactured and exported with the flexibility of catering for specific seasons of many countries around the world. Apparel is a human-centric industry and that is a challenge for a small country like Sri Lanka when compared to other regional players. Labour shortages and the record number of labour turnover can be identified as the major challenges in the current apparel industry in Sri Lanka. Therefore, the apparel manufacturing organization needs to implement innovative solutions to overcome these challenges using new technological capabilities. As a result of that, these companies have been left with the option of automating some of their processes for being sustainable (Jayatilake and Withanaarachchi, 2016). It seems that the apparel manufacturers are in the first step of converting their plants into smart factories. Therefore, the apparel industry is likely to get the benefit of Industry 4.0 for most of the processes in the apparel value chain to find solutions to the aforesaid challenges while enhancing the overall performance and achieving their desired goals.

The world has experienced three distinct industrial revolutions since 1800s. The first industrial revolution (industry 1.0) was the usage of water and steam power for the invention of steam machines and all sorts of other machines. The second industrial revolution (Industry 2.0) is the period where electricity and new manufacturing inventions like the assembly line led to mass production and certain extent to automation. The third industrial revolution (Industry 3.0) was the rise of computers and computer networks; Robotics in manufacturing, the birth of the Internet, which is the big game-changer in the ways information, is handled and shared (Gökalp et al. 2018). The fourth industrial revolution (industry 4.0) is the current trend of automation and data exchange in manufacturing technologies including cyber-physical systems (CPS), the Internet of things (IoT), big data, autonomous robots, simulation, system integration, cybersecurity, cloud computing, additive manufacturing and augmented reality (AR) and creating the smart factory or in simple form the technological evolution from embedded systems to cyber-physical systems (Rojko, 2017). Industry 4.0 connects physical world with digital world and allows for a better combination and access across departments, partners, vendors, products and people. Industry 4.0 empowers the business with better control of the operation and allows leveraging real-time data to enhance productivity, improve processes and drive growth. According to industry experts' analysis, it shows that when implementing Industry 4.0 in real-world enterprise environments, the problems such as lack of strategic guidance, perception about highly complex Industry 4.0 concepts, uncertainty about outcomes of Industry 4.0 applications in the matter of benefits and costs, failure to assess Industry 4.0 capability and readiness of the company (Schumacher et al., 2016) come in view. Concerning these issues, readiness assessment for Industry 4.0 becomes highly important, since a lot of companies seem to struggle to initialize Industry 4.0 transformation.

An organizational readiness assessment is a checklist that is usually custom made based on the current situation at the organization and the parameters and requirements of the change or project that organization which to pursue (Rajani, 2018). Thus, an Industry 4.0 readiness assessment model help organizations to determine their state of readiness in the adoption of Industry 4.0 technologies, identify the gaps and areas of improvement for Industry 4.0 adoption as well as opportunities for productivity improvement and development of feasible strategies and plans to perform outcome-based intervention projects. IMPULS—Industrie 4.0 Readiness (2015) (Lichtblau et al., 2015), Industry 4.0/Digital Operations Self-Assessment (2016) (PricewaterhouseCoopers, 2016), The Connected Enterprise Maturity Model (2014) (Rockwell Automation, 2014) are some examples of existing standardized readiness and maturity assessment models. But the properties of each model are different and also there is no standard and well-accepted Industry 4.0 readiness assessment model (Akdil et al., 2018), (Gokalp et al., 2017), (Schumacher et al., 2016).

The objective of this paper is to conduct a comprehensive and systematic review of literature on challenges that Sri Lankan apparel industry is currently facing and applications of Industry 4.0 components in apparel industry. Subsequently, this scrutiny establishes a set of evaluation criteria as compatible with the literature to evaluate the strengths and weaknesses of existing Industry 4.0 readiness assessment models and help to guide future research and investigation in the discipline. The remainder of the paper is structured as follows; the methodology applied for this study, the results of systematic literature review, development of the evaluation criteria, and evaluation of existing readiness models and findings of the study. Finally, the closure of the paper by presenting conclusions and an attempt to provide some perspectives on future research.

2. Methodology

The systematic review of the literature was based on the content analysis to gather the state of the knowledge on Sri Lankan apparel industry, Industry 4.0 and existing readiness assessment models in the context of Industry 4.0. The literature review was conducted according to the procedure proposed by Kitchenham, "Procedures for Performing Systematic Reviews" (Kitchenham, 2004) and the literature review protocol based on Popay et al., "Guidance on the Conduct of Narrative Synthesis in Systematic Reviews" (Popay et al., 2006) Those two studies were considered in order to minimize the systematic error and bias in the screening of papers. The methodology adopted for this review is given in Figure1. The search language was selected as English to eliminate non –English articles at the first stage. Keywords for the search were identified as terms "Challenges in Sri Lankan Apparel Industry", "Industry 4.0 Manufacturing", "Industrial Internet", "Smart Factory", "Components of Industry 4.0", and "Applications of Industry 4.0 in Apparel Industry "," Industry 4.0 Readiness Model "," Industry 4.0 Maturity Model and Cyber-Physical System Readiness. The search of electronic databases was conducted on Emerald (www.emeraldinsight.com), Google Scholar (https://scholar.google.com), IEEE Xplore Digital Library (https://ieeexplore.ieee.org), Science Direct (www.sceincedirect.com), Scopus (www.scopus.com), Springer (www.springer.com) and Web of Science (http://apps.webofknowledge.com) etc. All together eighty-three articles were found. First elimination was conducted to remove duplications. The citation search conducted to exclude series, meetings, reviews and magazine articles. SSCI, SCI, and AIS index journals were selected in the results. Reviewed title, keywords and the abstract of the publications and suitability of articles were identified while finishing the second elimination. The collection of the data for literature has been reviewed from January 2004 to August 2019 ensuring that the novel researches were filtered. The range of investigation is a 15-year period. Fifty-nine articles remained for the last elimination. All of them were reviewed under the inclusion/exclusion criteria in detail. A full-text review was conducted and the studies on Industry 4.0 readiness/ maturity assessment models, Sri Lankan apparel industry and Industry 4.0 in the context of manufacturing were selected. Publications on Industry 4.0 readiness models applied in IT sector and Industry 4.0 applications except manufacturing industry were excluded at the final stage. Forty-six articles remained for qualitative synthesis and they were classified and analysed in Microsoft Excel spreadsheet as a reference database.

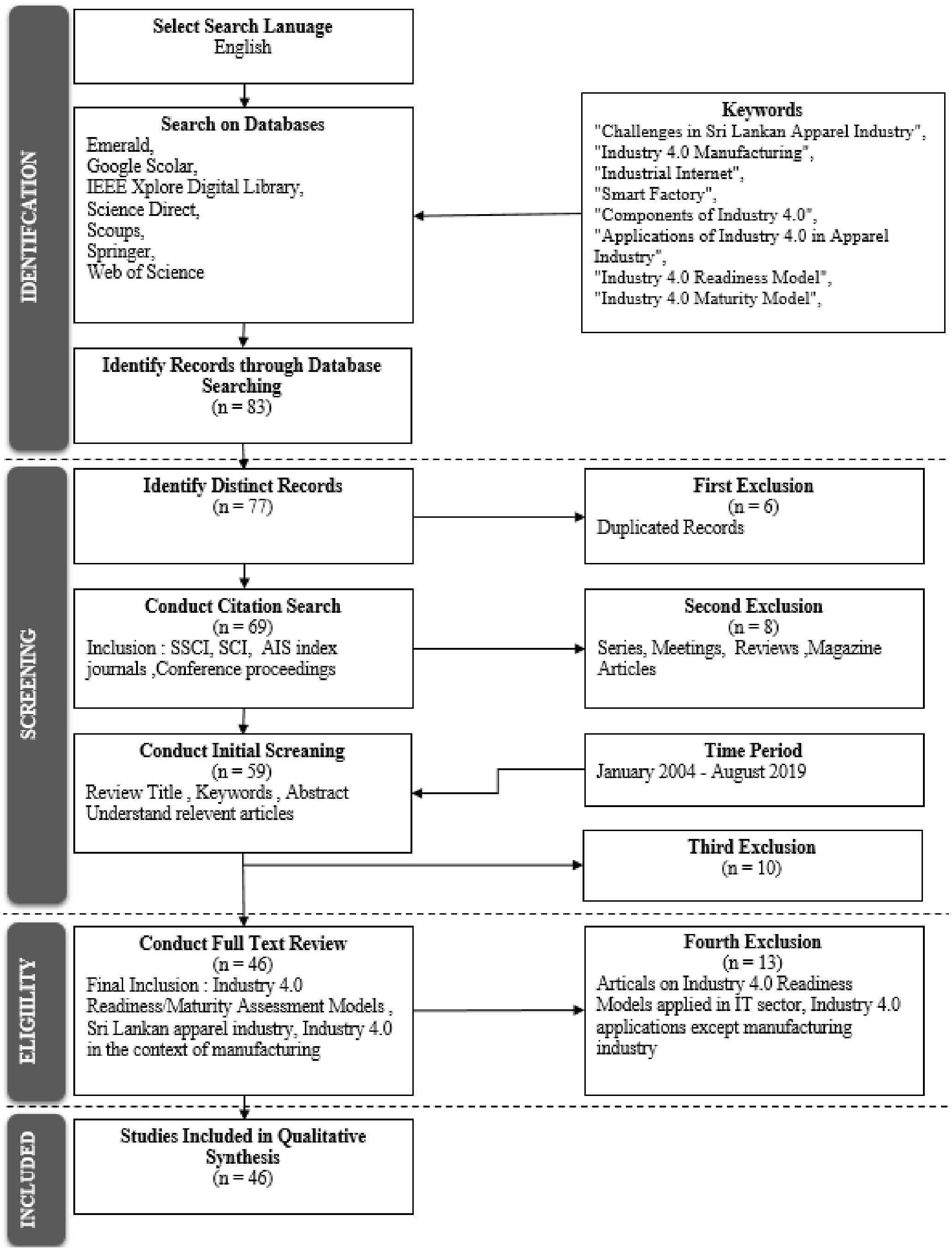

Figure 1. Systematic Review Methodology

3. Main Results of the Reviewed Studies

3.1. Sri Lankan Apparel Industry

The Annual Survey of the Industries of Sri Lanka reveals that the manufacturing is dominated by having 98.5% of the industrial establishments and 20% of them contains the apparel production (Department of Census and Statistics, 2013). According to the Joint Apparel Association Forum, Sri Lanka has always been recognized many times for its magnificent accomplishments at majestic forums for its excellence in quality manufacturing, green manufacturing and quick delivery of service (Sri Lanka apparel industry beyond 2015). Besides, several of Sri Lanka's leading apparel manufacturing companies have received international accolades over the years for their dedication and commitment towards earth-friendly initiatives alongside their core business responsibilities (Jayatilake and Withanaarachchi, 2016). The primary goal in the apparel industry is to improve the productivity in both employees and operations. For achieving this a significant amount of training and development, as automation has to go hand in hand with better knowledge and implementation of leaner manufacturing processes by employees. Only a limited number of publications were found under this domain. The major challenges in Sri Lankan apparel industry and reasons for them which were identified through the systematic review of literature are mentioned below (Table 1).

Table 1. Challenges in Sri Lankan Apparel Industry

Issue	Reasons
Insufficient product diversification (Dheerasinghe, 2015)	• Labour unavailability, limited capacity on available machines and existing technological capabilities in the production floor
Heavy dependence on a few large-scale industries (Dheerasinghe, 2015)	• 26%- small scale factories with less than 100 employees, 51% - medium-scale factories and 23% - large scale factories with 500 or more employees • 62% of total employment is accounted for large manufacturers
Labour shortage (Jayatilake and Withanaarachchi, 2016)	• Record number of labour turnover • Unable to hire rural labour since more than 65% of the garment factories are located in Colombo and Gampaha districts
Lack of solid raw material base (Kelegama, 2004)	• More than 70% of the raw material and 70-90% of the accessories are imported • Lack of backward integration
Over wastage (Dheerasinghe, 2015), (Jayatilake and Withanaarachchi, 2016)	• Rejects and overproduction • Unnecessary transportation within factory and between factory and warehouses • Machine idling and unplanned downtime • Wastage in stocking and in handing
Wage differentials (Kelegama, 2004)	• Cost of labour is about 15–16% of the total cost of production • Cambodia, Vietnam, Caribbean nations and sub-Saharan countries are emerging as lower-cost producers and have preferential access to US and EU markets
Lack of skilled labour (Dheerasinghe 2015), (Jayatilake and Withanaarachchi, 2016), (Kelegama, 2004)	• Lack of sufficient employees to recruit in operational grades • 8% vacancies in managerial grades are available due to a lack of suitable persons • Operational category represent 94% of the total workforce, 90% are female employees and most of them leave the industry after marriage • Average labour turnover per factory is 60% per annually • The net number of persons leave the industry- 25% annually • More than 64% of the labour force in the operational grade is in the age group of 18-24 years
Productivity of labour (Jayatilake and Withanaarachchi, 2016), (Kelegama, 2004)	• Low productivity of labour compared to competitors • Lack of properly trained labour, inflexibilities in labour legislation, high labour turnover, difficulties in obtaining outsourcing labour and seasonal labour • Investments in new labour training do not gain any profit
Lead time (Dheerasinghe, 2015)	• Raw material suppliers are based on overseas locations • Fast response is demanded by US and EU buyers

3.2. Industry 4.0

The era of Industrial Revolution was a period during which predominantly agricultural and rural societies in Europe and America became industrial and urban. The First Industrial Revolution began with the discovery of the steam engine in England in 1712. British inventor, Edmund Cartwright developed the first mechanical weaving loom in 1785. According to Gökalp et al. (2018), the progress in the textile sector during this revolution underlies the adoption of textile consumption as a basic need. Furthermore, this study elucidates that the Second Industrial Revolution which was started in 1870 when electricity began to be used in the industrial field. Henry Ford, first realized the serial production in 1910. The impact of this revolution in the clothing and apparel sector relies on the beginning of the serial production of sewing machines. Isaac Singer patented the first sewing machine in 1851, and with that the clothing production and the consumption increased. The Third Industrial Revolution; the Digital Revolution, began with the use of the first programmable management system in 1969. With this revolution, ICT started to be used in the industry and the transition took place from analogue to digital technology used with integrated systems obtained from developments in microprocessors, software, fibre optic cables, and telecommunication domains. According to Gökalp et al. (2018) the components in Industry 3.0 are Automation, Robotics, IT Systems and Networks. These components changed the apparel industry in a positive direction while improving profitability and now the apparel industry is trying to adjust to the next industrial revolution. The Fourth Industrial Revolution; Industry 4.0 can be defined as an umbrella term for a new industrial paradigm that embraces a set of future industrial developments regarding Cyber-Physical Systems (CPS), Internet of Things (IoT), Internet of Services (IoS), Robotics, Big Data, Cloud Manufacturing and Augmented Reality as defined by (Atobishi et al., 2018). One of the key objectives of Industry 4.0 is to combine two principles that are opposites, production line manufacturing and custom manufacturing in a smart environment referred to an as smart factory (Griecoa et al., 2017). Jayatilake and Withanaarachchi (2016) assert the fact that the concept "smart factory" makes the abstract idea of Industry 4.0 and it is the place where the Internet of Things (IoT) comes into play. Communication between things takes place through the internet in a smart way which calls; the "Process Knowledge Automation". The Process Knowledge Automation resolves and converts the problem that work-pieces do not have the technical capabilities to communicate on their transforming physical systems into cyber-physical systems (CPS) (Griecoa et al., 2017).

3.3. The Conceptual Smart Apparel Factory- Apparel 4.0

Gökalp et al. (2018) has proposed a conceptual smart apparel factory called "Apparel 4.0" in accordance with Industry 4.0 and Smart Factory visions. The innovative approaches that can be formed by the fourth industrial revolution in the clothing and apparel industry have been proposed as a conceptual smart apparel factory, called Apparel 4.0. The components included in Apparel 4.0 are Wireless Sensor Networks, Augmented Reality (AR), Cloud Computing, Machine Learning, 3D Printing, Cyber Security, Virtual Reality (VR), Cyber-physical systems, System integration and Big Data Analytics.

3.4. Applications of Industry 4.0 in Apparel Industry

The studies that have been done on the components of Industry 4.0 and applications of Industry 4.0 in manufacturing domain and apparel industry have aligned together to provide a comprehensive review on innovative applications of Industry 4.0 in apparel industry under nine components.

Additive Manufacturing: 3D printing belongs to the additive manufacturing processes in which an object is created by sequential layering. 3D visualization has changed the way of product designing and production, resulting in more and more virtual design and fitting processes (Spahiu et al., 2016). Mohajeri (2014) expects that this technology will enable to 3D scan each customer's body and register as unique body shapes. Then customers will have their own virtual identity for clothing. Customer will have the ability to specify the cloth that he/she would like to have, including colour, style, material, etc. All the customers' digital identity will be stored on a cloud manufacturing system which can be updated when necessary. Toeters et al. (2013) highlight two ideas on how to use 3D printing as a support for designers and clothing technologists. In this way, not only real garments can be displayed on scaled 3D printed models with the same body dimensions as a defined person. As Bruno and Pimentel (2016) 4D printing adds time as a variable to the three spatial dimensions.

Artificial Intelligence (AI): AI is a field of computer science that can simulate characteristics of human intelligence and human sensory capabilities (Oztemel and Gursev, 2018). Nayak and Padhye (2018) state that the different disciplines of AI that are mainly used in the apparel production process are Expert system, Neural network (NN), Fuzzy logic (FL), Evolution strategy, Artificial immune system, Generalized regression neural network and Genetic algorithm. AI can be applied in various processes of apparel production such as fibre grading, prediction of yarn properties, fabric fault analysis, dye recipe prediction and finally for supply chain management (SCM) and retailing (Xu et al., 2018). According to Hsu et al. (2009) and Nayak and Padhye (2018), AI can be used to identify the differences and similarities between two or more different styles and it can be used to analyse the relevancy of the input space, which can establish a relationship between consumer's fashion choices and the technical parameters of fabric products.

Autonomous Robots: Autonomous robots are a type of robot that can perform tasks/operations without or with minimum external environment influence and a higher degree of autonomy. Gökalp et al. (2018) mention that, in apparel manufacturing environment autonomous robots can be used to carry fabrics from the warehouse to the cutting room and to spread the fabric on the cutting table, finally to complete the cutting operation through laser systems with a minimum level of human interaction. Today, quality control is done by humans, but this causes incorrect results. The study highlighted that, the quality standards such as the accuracy of the product's body measurements and the quality of the fabric can improve by establishing autonomous robots. And also manufacturing operations can speed up with increasing its success and collect production-related data regularly.

Big Data: Xu et al. (2018) define Big Data, is an enormous amount of data. Babiceanu and Seker (2016) state that it can be defined by the 4V's - Volume, Velocity, Variety, and Veracity. The analysis of big data makes valuable conclusions by converting the data into information, otherwise could not be exposed using fewer data and traditional methods (Jain et al., 2017). All the data associated with apparel production flow can be used for line balancing, trend analysis, customer behaviour analysis, planning, forecasting etc. Predictive maintenance comprises a variety of data analytics and statistical techniques to uncover hidden patterns and capture relationships among devices. It mainly aims to predict possible device or equipment failures and to define a maintenance strategy accordingly, to decrease failure rate and increase device utilization and Overall Equipment Effectiveness (OEE) (Lee et al., 2014).

Cyber-Physical Systems (CPS): As per Monostori et al. (2016) Cyber-physical systems or cyber manufacturing, refers to an Industry 4.0-enabled manufacturing environment that offers real-time data collection, analysis, and transparency across every aspect of a manufacturing operation. Cyber-physical systems equipped with sensors, actuators, and processors are intelligent electronic systems with internet connectivity. They can make self-optimizing decisions by anticipating errors and quality problems occur at the apparel production floor (Gökalp et al., 2018). The paper suggested that Kinect technology can be used to teach CPS how to perform sewing processes.

Horizontal and vertical system integration: Horizontal integration avoids the failures and leakages throughout the information flow and enables the access of information at the right time in the right place along the entire supply chain for all business partners (Leyh et al., 2016). According to Kagermann et al. (2013) horizontal integration enables to respond to seasonal trends with the flexibility of production to sudden expansions/retraction in order positions. Finally, it enables a higher degree of innovation. Jayatilake and Withanaarachchi (2016) highlight that vertical integration improves the sub-optimal level of integration. And also digitize process such as quality management, compliance and operations planning **(**Suri et al., 2107).

Internet of Things (IoT): Sadiku et al. (2017) assert that IoT is a change in the predictable pathways that the information used to travel from in the physical world. The IoT allows 'objects', such as RFID, sensors, actuators, mobile phones, which, through unique addressing schemas, interact with each other and cooperate with their neighbouring 'smart' components (Giusto et al., 2010). Jayatilake and Withanaarachchi (2016) state that IoT will allow apparel producers to make their products more interactive, informative and personalized for their customers. And also integration of suppliers to get the optimal quantities of raw materials at required time (Gökalp et al., 2018). Moreover, it opens a new path to develop wearable devices embedded in apparel. IoT will also enable real-time data analytics to tackle issues like product authentication, brand protection and improving supply chain transparency and efficiency.

Simulation: Simulation is used during product design and verification where industrial organizations can employ this methodology to the next stage of their value chain as described by Mourtzis et al. (2015). Through that apparel manufacturing organizations get the opportunity to study the behaviour of manufacturing processes and systems before they are deployed (Molfino et al., 2008). Negahban and Smith (2014) discuss that simulation methods can yield enormous benefits; identification of manufacturing bottlenecks to increase throughput, identification of cost saving opportunities such as optimization of direct and indirect labour and validation of the expected performance of new value streams (Negahban and Smith, 2014). The main advantage of multi-agent simulation is in the parallel development of the processes with concurrent activities ongoing (Molfino et al., 2008).

Virtual Reality (VR) and Augmented Reality (AR): The new product development process can enable VR and AR to facilitate relevant partners to work in the same platform within apparel because AR models can be used to estimate the functionality of the design and to optimize it. Consumer interaction, personalization and product visualization make more reliable with AR and VR (Silva et al., 2018). This study mentions VR possesses the ability to lead customers through four stages of marketing; creating awareness, building everlasting loyalty, conversion of purchase decision into buying an increasing consideration. VR would help the retailers holistically move through these phases (Kennedy, 2019). With AR machine operators can be trained within a digital environment (Gökalp et al., 2018).

3.5. Readiness Assessment Models

In general, the term "readiness" refers to "the state of being fully prepared for something" and "assessment" defines "the action of judging someone or something". Accordingly, the readiness assessment is an official measurement of the preparedness of an enterprise/industry as an individual component or as a community to undergo a major change or take on a significant new project. According to Rockwell Automation (2014) the importance of assessing the readiness of an industrial company is that it helps to change its processes and information architecture to leverage timelier and more accurate information that is available in the enterprise at present. Industry4WRD (2016) mention, the readiness assessment uses a pre-determined set of indicators to understand their present capabilities and gaps, which will enable firms to prepare feasible strategies and plans to move towards Industry 4.0. Industry 4.0 readiness assessments at the organizational level are based on self-assessment. Information is collected mostly via surveys and interviews. Surveys target both general information on awareness, perceptions, attitudes, and detailed information on manufacturing decision making, smart manufacturing technologies, data security and branch-specific data.

In the manufacturing domain, recent readiness and maturity models have been proposed for energy and utility management and eco-design manufacturing/lean manufacturing. The emerging industrial revolution; Industry 4.0 which sought to re-define the role of manufacturing has also now become a popular segment where readiness and maturity assessment models have been proposed (Basl and Doucek, 2019). There are several reasons for the motivation of scholars and organizations in this area. One is implementing Industry 4.0 is a major strategic decision and before taking such an important decision organization has to assess the readiness for implementing Industry 4.0 (Schumacher et al., 2016). These readiness assessment models are a simple and intuitive way for companies to start to assess their readiness and future ambition to harness the potential of the cyber-physical age. Multiple significant readiness indexes have identified by Basl and Doucek (2019); Global Competitiveness Index (GCI) (Schwab, 2018), OECD scoreboard (OECD, 2017) and Industry 4.0 Readiness Index (Berger, 2015). The difference between the term "readiness" and "maturity" is that readiness assessment takes place before engaging in the maturing process whereas maturity assessment aims for capturing the as-it-is state whilst the maturing process (Schumacher et al., 2016).

3.6. Existing Industry 4.0 Readiness Assessment Models

As a result of the systematic literature review, ten studies were identified on both Industry 4.0 readiness assessment and Industry 4.0 maturity assessment because analysing only Industry 4.0 readiness assessment models alone was not sufficient. These models are given in the following table (Table 2) with their attributes and details.

Table 2. Existing Industry 4.0 Readiness & Maturity Assessment Models

Model / Research Name	Institution/ Source	Readiness/Maturity Levels	Dimensions	Assessment Approach
RM1: The Connected Enterprise Maturity Model (2014)	(Rockwell Automation, 2014)	Five maturity stages; Assessment, Secure and upgraded network controls, Defined & organized working data capital (WDC), Analytics and Collaboration	Four dimensions related to technological readiness.	Maturity model as part of a five-stage approach to realize Industry 4.0; IT focused assessment in four dimensions; lack of organization and operations dimension; no further information related to aspect dimensions and the creation process (white paper).
RM2: IMPULS - Industrie 4.0 Readiness (2015)	(Lichtblau et al., 2015)	Six maturity levels; Outsiders, Beginner, Intermediate, Experienced, Expert and Top performers	Six dimensions; Strategy & Organization, Smart Factory, Smart Operations, Smart Products, Data-driven Services and Employee	Include an action plan to enhance the readiness in the context of technology, environment, and organization by identifying barriers; maturity level of the organization is affected by the maturity level of competitors; organization's maturity level is

				defined only if any competitor conduct the survey.
RM3: Industry 4.0 / Digital Operations Self - Assessment (2016)	(PricewaterhouseCoopers, 2016)	Three maturity levels; Vertical Integrator, Horizontal Collaborator and Digital Champion	Six dimensions; Business Models, Product & Service, Portfolio Market & Customer Access, Value Chains & Processes, IT Architecture, Compliance, Legal, Risk, Security & Tax and Organization & Culture	Online-self assessment focus only on digital maturity ; application as a consulting tool as fee for assessment is required in three of the six dimensions; no details about items and development process offered; can assess both current and the expected level.
RM4: Industry 4.0 readiness and maturity of manufacturing enterprises	(Schumacher et al., 2016)	Likert-scale maturity levels; from rating 1= "not important" to rating 4 = "very important"	Nine dimensions; Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance and Technology	Extension of existing models and tools through its strong focus on organizational aspects; focus on transforming the abstract concepts of smart manufacturing into items that can be measured in real production environments; does not provide an action plan to overcome weak sides of the enterprises being assessed.
RM5: Empowered and Implementation Strategy for Industry 4.0 (2016)	(Lanza et al., 2016)	No information provided	No information provided	Assessment of Industry 4.0 maturity as a quick check and part of a process model for realization; gap-analyses and toolbox for overcoming maturity barriers are deliberated; no further information about items and development process offered.
RM6: Maturity model for Industrial Internet	(Menon et al., 2016)	No information provided	No information provided	Research is a preliminary study of assessing the industrial internet maturity.
RM7: SIMMI 4.0	(Leyh et al., 2016)	Five maturity stages; Basic Digitization, Cross-Departmental Digitization, Horizontal & Vertical Digitization, Full Digitization and Optimized Full Digitization	Three dimensions; Vertical Integration, Horizontal Integration and Cross-sectional Technology Criteria	Design process is not described in detail; the model's development is not fully completed; not proven practicability and usefulness in an enterprise environment; only focuses on software/technological aspects; The organizational and environmental aspects are not considered.
RM8: Industry 4.0 - MM	(Gökalp et al., 2017)	Five maturity levels; Incomplete, Performed, Managed, Established, Predictable and Optimizing	Five dimensions; Asset Management, Data Governance, Application Management, Organizational	Dimensions of the model based on SPICE process dimension and process attributes of SPICE are replaced by a total of nine aspect attributes; not

			Alignment, Process Transformation	validated for the usefulness and applicability of the model.
RM9: Maturity and Readiness Model for Industry 4.0 Strategy	(Akdil et al., 2018)	Four maturity levels; Absence, Existence, Survival and Maturity	Three dimensions (thirteen fields); Smart products & services, Smart business processes and Strategy & Organization	Consider the principles of real time data management, interoperability, decentralized, and service oriented.
RM10: Metamodel for Evaluating Enterprise Readiness	(Basl and Doucek, 2019)	Seven metamodel levels; Society, Area of society, Branch of area of society, Enterprise, Area of enterprise, Dimension of enterprise area and Sub dimension of enterprise area	Different readiness indexes and maturity models within the given level of the model	Single shared metamodel including individual levels and attributes; categorized levels according to main trends, readiness indexes and maturity models within the given level of the model.

4. Development of Evaluation Criteria

Since there isn't any standard method to evaluate the existing readiness assessment models, an evaluation criteria were implemented based on (CMMI, 2010) and (SPICE, 2010) by identifying the key points need to be included in a standardized assessment model and used to find the gaps that exist, strengths and weaknesses of each model. Since the degree of accomplishment of these criteria is different for each model, a Likert scale was introduced to evaluate the existing models systematically.

Table 3. Evaluation Criteria for Industry 4.0 Readiness Assessment Models

Criteria	Definition
C1: Accomplishment of objectives	Fulfilment of the objectives of assessing readiness in the context of Industry 4.0
C2: Flow of assessment method	Clarity and flow of explanation on creation of the model and readiness assessment process
C3: Focus on a specific domain	The focus on a particular area or industry-wide scope, e.g. technological readiness or enterprise IT and its information systems
C4: Scope of evaluation of components	The application of all/subset of components in the context of Industry 4.0 for readiness assessment
C5: Explanation of dimensions	The level of details provided about each dimension of the model.
C6: Explanation of assessment attributes	The level of details provided about the measurement attributes
C7: Evaluation scale of the assessment	The level definition and clarity of the attributes, practices and each level of the readiness. The evaluation of the overall readiness level or approach to enterprise maturity in the dimension.

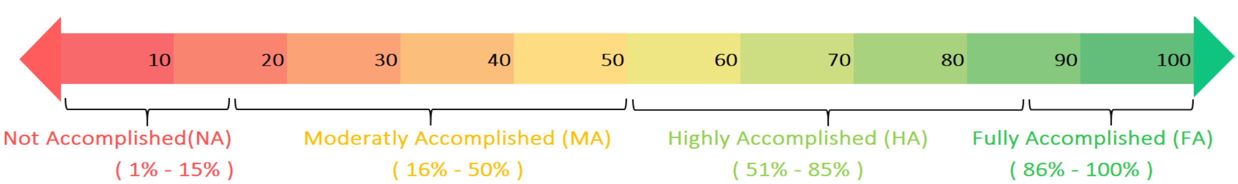

Figure 2. Likert Scale for Rating

5. Findings & Discussion

5.1. Systematic Evaluation

The following matrix (Table 4) shows the systematic evaluation of the existing Industry 4.0 readiness assessment models and industry 4.0 maturity assessment models.

Table 4. Evaluation of Existing Industry 4.0 Readiness & Maturity Assessment Models

		Readiness Assessment Models									
		RM1	RM2	RM3	RM4	RM5	RM6	RM7	RM8	RM9	RM10
Criteria	C1	NA	MA	MA	MA	NA	MA	MA	MA	MA	MA
	C2	NA	FA	NA	MA	NA	NA	HA	HA	HA	NA
	C3	NA	NA	HA	NA	NA	HA	HA	NA	NA	MA
	C4	MA	MA	MA	MA	NA	NA	MA	HA	FA	MA
	C5	NA	MA	MA	MA	NA	NA	MA	MA	FA	MA
	C6	NA	HA	MA	MA	NA	NA	MA	MA	FA	MA
	C7	NA	HA	MA	MA	NA	NA	MA	HA	FA	MA

5.2. Gaps Identified

The results from the systematic evaluation of existing Industry 4.0 readiness and maturity models show off many weaknesses and drawbacks where it motivates for development of a new Industry 4.0 readiness assessment model. Those weaknesses and drawbacks are that these models are very comprehensive but do not contain a detailed view. Moreover, the focus on enterprise-wide dimensions is on top management's level such as Technology, Corporate Culture, Strategy, Human Resources and Leadership. IT readiness dimension is the most popular dimension among these models and it has been defined in different manners among those models. Thus, there is a need for understanding the key dimensions to assess the readiness for implementing Industry 4.0 from a holistic perspective. Most of the models that have been used for analysis included the attributes of cross-sectional and sub-dimensions, none of them has been elaborated deeper where an organization could conduct an accurate assessment. The existing models provide an analytical tool for evaluating an enterprise's current state of Industry 4.0 readiness and maturity, but some models did not contain a guide to upcoming steps within a certain roadmap to move up to higher maturity levels. There are no solutions for manufacturing enterprise architecture holistically or the specifics of small and medium enterprises. None of the models is developed based on a well-established framework for the assessment and improvement. At the same time, they do not have a well-defined structure with practices, inputs and outputs. Most of the models have not provided further information related to aspect dimensions and the creation process of them. Ex. The Connected Enterprise Maturity Model - (Rockwell Automation, 2014). Also they have not proved practicability and usefulness in an enterprise environment. Ex. SIMMI 4.0 (Leyh et al., 2016) and Industry 4.0 - MM (Gökalp et al., 2017). Publications of preliminary researchers as developments of readiness/maturity models do not provide information on maturity levels and dimensions of suggested models. Ex. Maturity model for Industrial Internet (Menon et al., 2016). Finally, none of the research has been fully elaborated sector-wide solutions such as apparel or automotive. So there is an urge for an Industry 4.0 readiness assessment model for apparel industry in Sri Lankan context.

6. Conclusion

This research meaningfully contributes to the current literature on Industry 4.0 and the apparel industry in Sri Lankan context, as it presents and examines the Industry 4.0 and its applications customized into apparel industry. Similarly this paper analysed the existing Industry 4.0 readiness assessment models based on a systematic review of literature. A set of evaluation criteria were recognized as compatible with the literature, to evaluate the strengths and weaknesses of each model in terms of its level of accomplishment of objectives, review on assessment methodology, applicability on a specific domain, evaluation of components, explanation of dimensions and attributes and also evaluation scale of the assessment. Although there are many studies on readiness assessment for Information Technologies, there are only a few readiness assessment models for the manufacturing industry. None of the researches is available for Industry 4.0 readiness assessment in apparel industry. According to the analysis, dimensions, readiness levels and items are different from each model and there is no standard and well-accepted model readiness assessment model for Industry 4.0. As a result of the systematic evaluation, it is concluded that none of those models in the literature satisfied (Fully Accomplished (FA)) all criteria. Finally, it is concluded that there is a research gap in that domain and need for a standardized Industry 4.0 assessment model customized for apparel industry readiness measurement purposes remains valid. The motivation behind this study is to provide a comprehensive review and useful insights into the significant findings, current research gaps and future research directions. Taking into account these applications on components of Industry 4.0, academics may be enabled to further investigate on the topic, while practitioners may find assistance in implementing appropriate scenarios in apparel industry. The outcome of this study will help to guide future research on the development of standardized readiness assessment model for Industry 4.0 that fills the existing research gap.

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