Framework Development Supply Chain Readiness Measurement 4.0

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Abstract

Supply chain 4.0 has become a growing issue for companies to survive and achieve better efficiency. Most of the existing Industrial 4.0 measurements focus on manufacturing technology applications. The current measurement tools of Industry 4.0 are lacking when considering the maturity level of the supply chain. The critical role of the supply chain is to ensure the flow of materials, products, and information to connect many actors in business processes within the company. The article aimed to compare the existing Industry 4.0 measuring tools, such as INDI 4.0, IMPULS, SIRI, and PwC, in the supply chain scope. This study used the qualitative method to compare the Industrial 4.0 measurement tools related to the supply chain 4.0 criteria. The supply chain is measured by six dimensions of Industry 4.0, such as instrumented, interconnected, intelligent, automated, integrated, and innovative. The result shows that the supply chain measurement in SIRI, and PwC has a higher score index than INDI and IMPULS. The score describes the level of the supply chain involved in the Industrial 4.0 assessment. All existing Industrial 4.0 tools did not consider innovative criteria in supply chain measurement.

Keywords:
Framework development, supply chain readiness, and Industrial 4.0.

1. Introduction

Supply chain processes are required to follow the development of technological and system advances as the effect of Industry 4.0 pressure. The supply chain application in companies must keep up with technological developments that are carried out for the production process. The technology leads the supply chain to maintain the flow of materials and products to make it easier for product tracing. The expected supply chain process in Industry 4.0 is an integration process concerned with the use of technology (Butner 2010). The supply chain development must be encouraged not to hinder the Industrialization 4.0 process and increase productivity in all chains. The supply chain (SC) readiness related to Industry 4.0 application requires optimization in strategic intelligence functions such as technology based on artificial intelligence, advanced robotics, the Internet of Things (IoT), and big data. The technologies help supply chain operational processes to support exponential efficiency improvements (Koten 2017).

A study of the supply chain (SC) in Industrialization 4.0 discussed about the concept and maturity framework. The SC 4.0 concept is a transformational and holistic approach to supply chain management that employs Industry 4.0 disruptive technologies. The contribution of technology 4.0 utilization in the supply chain is to integrate systems, activities, and linkage to generate significant strategic benefits for all stakeholders (Frederico et al. 2020). The framework of supply chain maturity is measured by the level of technology application based on the cyber-physical system in logistics, warehouse, and fulfillment orders activities (Tjahjono et al. 2017). The SC framework associated with implementing Industry 4.0 that is divided into four constructs: managerial and capability pillars, technology levers, process achievement requirements, and strategic outcomes. These constructs are described at each different level with performance measures in the form of integrated, transparent, and measured (Frederico et al. 2020). The SC integration can look like a cloud supply chain service, determining that all stakeholders direct and decide based on the same data so that the decision-making process is able to conduct with real-time information (García-Reyes et al. 2022). Supply chain measurement continues to evolve from traditional to supply chain towards the Industrial 4.0. Conventional supply chain assessment has not touched on the assessment system by including technology and information dissemination, as well as the involvement of stakeholders such as suppliers, company partners, and customers. These measurements not explain the extent of integration built by the supply chain system. Performance assessment of the supply chain has been widely used, such as the Supply Chain Operation Research (SCOR) method, which was developed to meet customer satisfaction (Kocaoğlu et al. 2013). The performance attributes in SCOR are reliability, responsiveness, and agility, and the last two are cost and asset management. The characteristics of SC performance are reliability, responsiveness, and agility tend to focus on the customer, whereas asset management focuses on the internal organization. The SCOR attribute does not indicate process integration, leading to efficiency and productivity in the entire system (Supply Chain Council 2012).

Supply chain 4.0 is an approach to enhance efficiency in companies. One of the efficiencies carried out in the supply chain is automation technology usage in supply chain operations such as the robotics in material handling, automation processes in receiving and unloading goods, packing, and shipping in the warehouse. This automation process also discussed about delivering product information systems (Alicke et al. 2016). The SC 4.0 creates opportunities including transparency, competitive advantage, customer satisfaction, compliance with environmental regulations in green supply chain issues, logistics efficiency, waste reduction, developments in supply chain coordination, reduction in transportation volume cargo, reduction of errors in shipping, and development of industrial processes (Acioli et al. 2021). The previous research has not measured the extent to which this supply concept and framework is applied in the measurement tools of Industry 4.0. The existing concepts and frameworks are still embryonal and not described Industry 4.0 measurement.

The formulation of the problem in this article is how to compare Industrial 4.0 assessment tools in a supply chain scope. This article aims to reach SC assessment tools in various Industrial 4.0 assessment tools. Moreover, this study develops a framework for supply chain measurement by considering Industrial 4.0 indicators. The industry 4.0 readiness assessment tools are analyzed including INDI, SIRI, IMPULS, and PwC. INDI is tools from Indonesia, SIRI is from Singapore, IMPULS is Germany, and PwC is from global organizations focusing on making industry 4.0. Equivalence assessment is created by integrating the concepts and elements of supply chain 4.0, which are used to design specific categories for supply chain assessment in technology 4.0. The contribution of this article is a comparison of tools to identify more specific supply chain

elements that can be considered for companies to assess SC 4.0. This paper aims to compare the existing measurement tools for industry 4.0 with a point study evaluating supply chain 4.0. In addition, the study to build a framework for developing SC 4.0 criteria related to Industry 4.0 measurement. The results of this measurement are used as a reference for the supply chain assessment framework based on 4.0 technology.

2. Methods

This study uses qualitative methods (Figure 2.). First, the study was conducted by searching for literature related to supply chain measurements and Industry 4.0 research in indexed journals. The selection paper used a snowball approach to collect the relevant documents. This study uses the keywords "Supply Chain 4.0" and "Industrial 4.0 assessment" in journal searches on Scopus and Google scholar. The number of papers related to this study was sixteen from 2016 until 2022. The second stage is looking for articles related to Industrial 4.0 measurement tools in several countries that used Industrial 4.0 measurement tools. This study discussed Industrial 4.0 assessment tools, including Indonesia Industry 4.0 Readiness Index (INDI), Industry 4.0 Readiness Check (IMPULS) from Germany, Smart Industry Readiness Index (SIRI) from Singapore, and PricewaterhouseCoopers (PwC) from PricewaterhouseCoopers International Limited, United Kingdom. INDI 4.0, SIRI, and IMPULS are studied by dissecting the guidelines and assessment methods. PwC is investigated by using an online self-assessment simulation. According to the literature review, it was found that the components of the supply chain in Industry 4.0 maturity measurement tools and some missing criteria. Development of framework based on Industrial 4.0 criteria and SC process to adopt the technology.

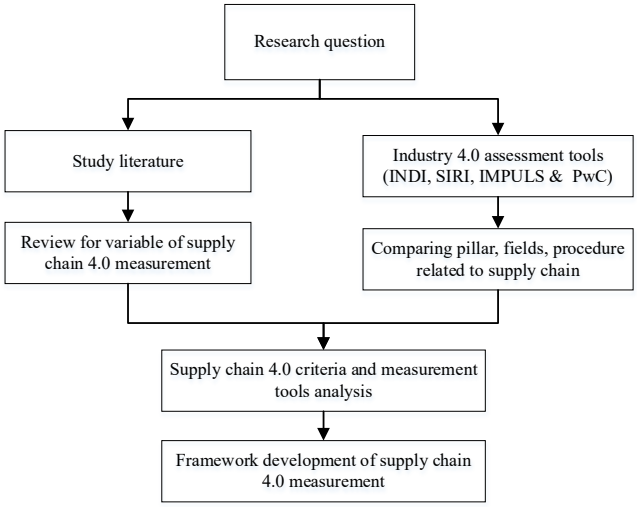

Figure 1. Flowchart of research method

A comparison of measurement tools is used to find pillars and fields that match industry 4.0 measurement factors, particularly in the supply chain. The analysis of assessment tools and paper review were used to find a gap in the SC 4.0 measurement. Based on the gap analysis, the next step is to develop a framework for SC measurement in the application of Industry 4.0. The assessment mechanism for each tool uses the sum of the category values divided by the total number of categories. The formula is expressed as follows

$$Assessment\ index = \frac{\sum value\ of\ supply\ chain\ categories}{\sum\ total\ value\ of\ categories} \qquad (1)$$

(Axmann and Harmoko 2020)

The assessment index is obtained by looking for essential components related to the supply chain in measurement tools. The categories for supply chain 4.0 involves the characteristics of instrumented, interconnected, intelligent, automated, integrated, and innovative. If the category is available, a value is 1; if not, a value is 0.

3. Results and Discussion

3.1 Measurement tools of Industrial 4.0

Currently, many measurement tools have been developed for Industry 4.0. Several Industrial 4.0 measurement tools in several countries, such as Indonesia Readiness Index 4.0 (INDI 4.0), Industry 4.0 Readiness developed by the IMPULS foundation of the German Engineering Federation, Smart Industry Readiness Index (SIRI), and PricewaterhouseCoopers. INDI 4.0 is a measure of industrial readiness 4.0 created by the Ministry of Industry and launched in 2020. The aim of INDI 4.0 is to be a guide for industrial companies transforming towards Industry 4.0 with a national scope (Kementrian Perindustrian 2020). The INDI 4.0 pillar comprises management and organization, people and culture, smart products and services, smart technology, and factory operations (Figure 2). The management and organization pillars focus on strategy and leadership, investment toward industry 4.0, and policies in innovation. The pillars of people and culture focus on potential development, work culture, and openness to change. The product and service pillars focus on data-driven services, intelligent products, and customization. Technology covers cyber security, connectivity, intelligent machines or systems, and digitization. Moreover, the factory operation pillars focus on data storage and sharing, supply chain and intelligent logistics, and intelligent maintenance systems (Kementrian Perindustrian 2020). The assessment on INDI 4.0 uses levels 0–4 for readiness level.

The second tool is the industrial readiness 4.0 IMPULS, which has six pillars: employee, strategy and organization, smart factory, smart operations, and intelligent product and data-driven services (Figure 1). The IMPULS assessment uses levels 0–5 for each answer to the questions on the pillars. A scale of 0 indicates that the company does not carry out any activities or carries out very few that lead to Industry 4.0. A scale of 5 indicates that the company has fully implemented the target vision and has integrated all parts of the target (Lichtblau et al. 2015). The level of readiness model used by IMPULS is from 0 to 5. Level zero (0) indicates outsider, level 1 is beginner, level 2 is intermediate, level 3 is experienced, level 4 is expertise, and level 5 is the top performer. The third tool is Smart Industrial Readiness Index (SIRI). SIRI means measuring tools that developed by the *Singapore Economic Development Board* (EDB), a government agency under the Singapore Ministry of Trade and Industry. SIRI has three fields covering process, technology, and organization. Each field has pillars for the second layer and dimensions for the third layer.

The building block of the SIRI measurement process consists of the operations pillar with a vertical integration dimension, the supply chain field with a horizontal integration dimension, and the product lifecycle pillar. The technology building block considered automation, connectivity, and intelligence pillars to assess the maturity level of Industrial 4.0. The pillar in SIRI focuses on the shop floor, enterprise, and facility. The organizational building block consists of the pillars of talent readiness and structure & management. The talent readiness pillar defines human resources learning & development dimensions and leadership ability. The structure & management pillar has inter- and intra-enterprise collaboration, strategy, and governance dimensions (EDB Singapore 2020). SIRI does not use readiness levels like INDI and IMPULS. The level classification in SIRI is focused on each pillar and does not provide weighting for calculating the value of each pillar like INDI.

In contrast to the three measuring tools above, the PwC is measuring instrument with pillars that called dimensions. PwC has six dimensions, including 1.) business model product & service portfolio, 2.) market & customer access, 3.) value chain & processes, 4.) IT architecture, 5.) compliance legal, risk, security & tax, and 6.) organization & culture. The dimension that identifies the supply chain is the value chain & process dimensions (Geissbauer et al. 2016). The primary value of the SC measured from the PwC assessment is the level of collaboration, both collaboration on vertical integration (production planning from the factory floor to product) and collaboration on horizontal integration, (i.e., collaboration with partners, customers, and suppliers). The limitation of this PwC is only focuses on digital business. PwC has the opportunity to measure Industrial 4.0 in small and medium industries by simplify the dimension measurement in assessment tool (Axmann and Harmoko 2020).

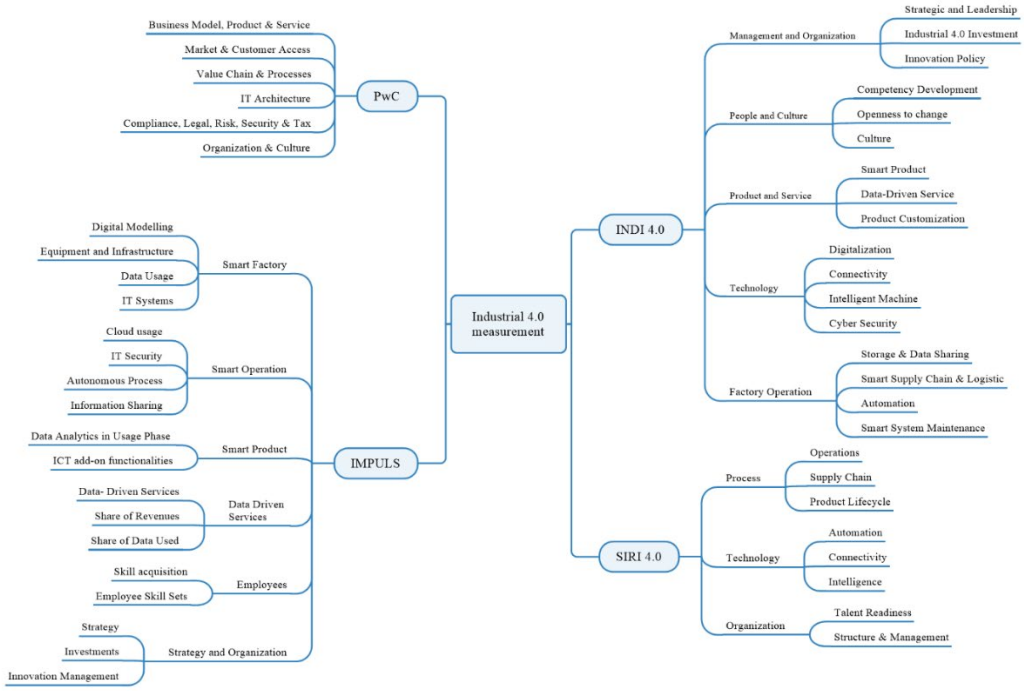

Figure 2. Industrial 4.0 pillar in several assessment tools
(EDB Singapore 2020; Geissbauer et al. 2016; Kementrian Perindustrian RI 2018; Lichtblau et al. 2015)

2.3 **Dimension of the supply chain in Industrial 4.0 Assessment**

Categories of SC 4.0 lead to Industry 4.0 consisting of instrumented criteria, interconnected, intelligent, automated, integrated, and innovative (Wu et al. 2016). Instrumented criteria mean a system was operated with sensors, radio frequency identification tags, and other integrated parts capable of producing data for determining decisions (Garay-Rondero et al. 2020). The instrumented criteria defined that the company has adopted digital technology in the SC process (Garay-Rondero et al. 2020; García-Reyes et al. 2022). The adoption of digital technology is intended to assist companies in coordinating tracking and increasing flexibility. Digital technology is also applied in one part of the supply chain, namely, inbound, and outbound logistics. Instruments in the supply chain are described as technology levers dimensions such as IoT, 3D Printing, augmented reality, artificial intelligence, ERP, RFID, big data, and other technologies (Majeed and Rupasinghe 2017). An instrumented supply chain uses the technology system or components that support integration with business partners. Interconnection occurs when stakeholders of the supply chain are fully linked, including assets such as products, information technology systems, and other smart objects. Interconnection between component, process, actor, and flow of technology, connection inbound and outbound logistics (Butner 2010). Intelligence is a smart system that proficiently making decisions to optimize supply chain performance by collecting and analyzing large amounts of data. The intelligence in supply chain measurement denotes intelligent systems on technology that capable of making and analyzing optimal decisions (Wu et al. 2016).

Automated category explained how many automatic activities are aimed to replace inefficient resources, including labor (Fatorachian and Kazemi 2021). The instrumented category description focuses on intelligent technology applications for the supply chain. The percentage of intelligent technology applications in terms of smart technology is 40 to 50% of its company operations (Mckinsey 2015). Automated assessment describes the level of smart technology used to replace human intervention. Autonomous deliver the flow of goods and services using distribution robotic or autonomous vehicles. Innovative categories explain continuous research and innovation in systems (Garay-Rondero et al. 2020). Innovativeness is explained by the capability to advance and

incorporate new values through more resourceful solutions (Wu et al. 2016). Table 1 is shown the definition in Supply Chain 4.0.

The supply chain performance in terms of Industry 4.0 discussed information sharing, long-term relationships, collaboration, and integration processes (Ariani and Dwiyanto 2013). Industry 4.0 efforts in manufacturing impact changes in the performance measurement of supply chain activities. The challenge of Industrial 4.0 is to collaborate between suppliers, producers, and clients to develop transparency in every activity, from sending orders to using the product (Tiwari 2021). This process requires digitalization and automation capabilities in the supply chain management structure (Alicke et al. 2016). The design of assessment tools for the supply chain is obtained using the SC category 4.0 and adopting several categories in the overall industry 4.0 tools. Assessment of SC readiness is needed to equalize industry perceptions in Industry 4.0 changes. Industry 4.0 technology adoption, in term of cyber-physical systems (CPS) application, use more than 40 percent of machines. It gives connectivity and generates real-time data reports that able to gain the efficiency of operation, capital, materials, energy, and time invested by 30 to almost 50 percent and reduce resource consumption by twenty to twenty-five percent (Mckinsey 2015).

The measurement of technology 4.0 adoption is related to the supply chain lever. The supply chain has four key activities: buying, storing, shipping, and selling. Each technology, such as virtual, augmented reality, big data, cloud technology, cybersecurity, automatic identification, and data collection radio frequency identification (RFID), machine-to-machine communication (M2M), and business intelligence, is linked to the domain activity in supply chain indicator measurement (Tjahjono et al. 2017). Measurement criteria in the supply chain are mainly integrated, such as process and activity integration between chain members (Tiwari 2021), technology and system integration, and actor or supply chain partner integration (Govindan et al. 2022). The intelligent supply chain discusses planning demand and optimizing the process (Monteiro and Barata 2021). Supply chain 4.0 categories in previous research are described in Table 2. A literature review generates supply chain criteria by analyzing the previous research that discussed the fourth industrial revolution application in the supply chain context.

3.2 Comparison of Industrial 4.0 measurement tools in the supply chain context

The assessment of SC readiness in Industry 4.0 assessment tools has existed in several pillars. The supply chain components in these measuring tools differ in naming, and some instruments are not explicitly mentioned as supply chain components. The equivalence of the pillars is shown in Table 1. The readiness of industry 4.0 in SIRI and PwC uses the specific field for assessing the supply chain. The SIRI measurement tool uses a process building block with supply chain pillars. The supply chain, referred to as SIRI, is horizontally integrated, which identifies the extent to which supply chain systems and processes are actively used automatically to analyze and react to data. In addition, SIRI shows companies' ability to use IT systems in the supply chain that are integrated from end to end. It also indicates optimized processes through insights generated from data analysis. Supply chain readiness measurement with PwC is categorized into value chain and process. The value chain for the supply chain is focused on integrating IT technology for the entire supply chain process.

Each tool was used in analysis that has a different pillar name. Among the measuring instruments analyzed in this article, only SIRI provides an explicit name for the pillars associated with the supply chain (Table 2). The Indonesia Industry Readiness Index 4.0 (INDI) incorporates supply chain assessment into the pillars of factory operations. The questions used to evaluate supply chain readiness in Industry 4.0 are interrelated to systems implemented in supply chains and logistics in companies, such as the use of RFID, GPS barcodes, real-time inventory control, ERP, and other systems that support real-time monitoring. The management and organization pillar explains investment to transform to industry 4.0 and the use of technology in the form of connectivity in infrastructure and service between company systems and other companies (Kementrian Perindustrian 2020). The tools have weaknesses in measuring tool that are not specifically intended for functional parts in the company but are used throughout the company's processes and lines. These claims can be used to assess a company's supply chain, but it is not yet easy to categorize the level of technology adoption associated with the supply chain.

Table 1. Supply chain 4.0 research

Authors	Supply Chain 4.0 Categories						Scope	Journal
	IS	IC	IG	AU	IL	IO		
García-Reyes et al. (2022)	v	-	v	-	-	-	SC digitalization and organization awareness	Procedia Computer Science
Osunsanmi et al. (2022)	-	-	v	-	-	-	SC 4.0 building in the construction industry	Journal of Engineering, Design, and Technology
Simonetto et al. (2022)	v	v	v	-	-	-	SC performance	International Journal of Production Economics
Govindan et al. (2022)	v	-	v	-	-	-	Digitalization in Closed Loop Supply Chains (CLSCs)	Transportation Research
Ambrogio et al. (2022)	-	-	v	-	-	-	SC and organization performance	Computers & Industrial Engineering
Tiwari (2021)	-	-	v	-	-	-	SC sustainability	Benchmarking: An International Journal
Monteiro and Barata (2021)	-	-	-	-	v	-	Logistics intelligent	Procedia Computer Science
Caiado et al.(2021)	-	-	-	-	v	-	Intelligent supply chain	International Journal of Production Economics
Garay-Rondero et al. (2020)	v	v	-	v	-	v	SC process	Journal of Manufacturing Technology Management
Frederico et al. (2020)	v	v	v	-	-	-	SC maturity	Supply Chain Management: An International Journal
Xie et al. (2020)	-	-	-	-	v	-	SC performance	System Research and Behaviour Science
Chauhan and Singh (2020)	v	-	-	-	-	-	Digitalization in supply chains	Journal of Manufacturing Technology Management
Petrucco et al. (2019)	v	-	-	-	-	-	SC in the construction industry	Business Process Management Journal
Asdecker and Felch (2018)	v	-	-	-	-	-	Outbound logistics	Journal of Modelling in Management
Iddris (2018)	v	-	v	-	-	-	Digital supply chains	International Journal of Business Research and Management
Wu et al. (2016)	-	-	v	v	-	-	SC system and performance	International Journal of Logistics Management

Note: IS= instrumented, IC=Interconnected, IG= Integrated, AU=Automated, IL=Intelligent, IO=Innovative

Table 2. Equality of pillars for supply chain in Industry 4.0 readiness assessment

Tools	Industrial 4.0 Pillar	Description	Supply chain 4.0 criteria
INDI	Management and organization pillar, technology, and factory operation	INDI emphasizes a smart supply chain through digitalization, integration, and connection between production systems and logistics systems to monitor the condition and location of goods. Measurements at each level are qualitative and non-specific (Kementrian Perindustrian RI 2018).	Instrumented, integrated, interconnected
SIRI	The specific process in operation and supply chain pillar	Classify supply chain performance in the direction of digitizing processes, integration, and automation, focusing on horizontal integration that describes integration systems between companies and stakeholders. Criteria of supply chain efforts include digitalization, integration, automation, and intelligence. Measurements calculated at each level are precise (EDB Singapore 2020).	Instrumented, integrated, automation, interconnected, intelligent
IMPULS	Smart factory, smart operation, strategy & organization	Supply chain performance is included in the smart factory pillar, which focuses on digitization in the SC process, integration, automation, and real-time connection. The measurements at each level are qualitative (Vdma 2016).	Instrumented, integrated, automation, interconnected
PwC	Value chain and processes	The integration process measures the level of digitization, continuity, and automation. Focus on horizontal integration and measurement at each level is qualitative (Geissbauer et al. 2016).	Instrumented, interconnected, integrated, automation, intelligent

The IMPULS measurement tool uses supply chain assessment with a smart operation pillar that focuses on integrating cross-departmental information sharing in the system and distinguishing information sharing within the company's internal and external scope. The assessment uses questions filled with yes (agree), or no (disagree) answers addressed to each department within the company. The smart factory pillar is indicated by a question about the amount of investment implemented technology for Industry 4.0 in the SC implementation, specifically logistics. The supply chain is also reflected in the strategic and organizational pillars that focus on planning and implementing investments, which lead to an integrated supply chain.

A comparison of supply chain assessments by INDI, IMPULS, SIRI, and PwC is shown in Table 4. The categories used in segregating supply chain measurements towards Industry 4.0 include instrumented, interconnected, automated, intelligent, integrated, and innovative. The basis for determining the category for each supply is by comparing the assessment categories on each Industrial 4.0 tool with Supply chain 4.0 criteria. The value used is a binary value (1 or 0) to determine whether there is (1) or not (0) in the intended category. The assessment index is calculated from the average of each measuring tool based on the supply chain measurement criteria 4.0 (Axmann and Harmoko 2020).

Table 3. Comparison of supply chain assessment categories on INDI, IMPULS, SIRI, and PwC

Categories	INDI	IMPULS	SIRI	PwC
Instrumented	1	1	1	1
Interconnected	1	1	1	1
Integrated	1	1	1	1
Automated	1	0	1	1
Intelligent	0	1	1	1
Innovative	0	0	0	0
Assessment index	**0.67**	**0.67**	**0.83**	**0.83**

The design of measuring tools for the supply chain is obtained by using the Supply Chain 4.0 categories and adopting several categories in the overall Industry 4.0 tools. Table 4 shows that SIRI and PwC provide the same value of 0.83 points. Furthermore, INDI and IMPUS have the same value for measurement results. These results indicated that innovative categories in the Industrial 4.0 tools were not considered. The instrumentation level is measured using the supply chain process tool. Intelligent criteria in INDI are not explained in the frame of the supply chain. The instrumented, interconnected, and integrated criteria have been included in the SC measurement in all Industry 4.0 assessment tools.

Figure 3 illustrates the development of the supply chain framework in Industry 4.0 adoption. The measurement stages start from the instrumentation stage to the innovative stage. The supply chain measurement begins with instrumented criteria, namely the availability of digital devices in supply chain activities. The second criterion indicated integration, such as horizontal integration. The instrumented measurement is based on digital technology used to support SC activities. The use of digital technology in the SC process for inbound and outbound logistics activities is a criterion that indicates the level of digitization. Integrated criteria measure all chain members from end to end as being integrated, and connected with the digital and physical supply chains. Interconnected discusses virtual and physical connections to generate real-time data in the supply chain process.

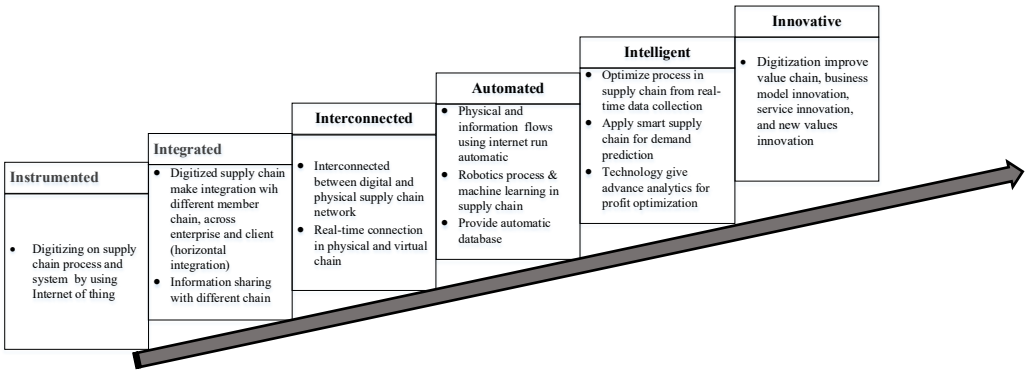

Figure 3. Framework development of supply chain 4.0 performance assessment

The automation criteria are a hallmark of the use of technology 4.0. Automation defines the supply chain as the use of technology to carry out the physical flow and supply chain information without human intervention (fig.3). The automation referred to in the supply chain is characterized by the adoption of technology based on robotics and machine learning. Intelligent criteria measure the extent to which supply chain technology enables process optimization and prediction of future demand. The impact of using this technology is characterized by innovation. Innovativeness in the supply chain is characterized by value chain improvement, business model innovation, service innovation, and new value innovation.

5. Conclusion

The comparison of supply chain criteria on industrial measuring tools 4.0 has provided a review of the digitalization of measurement development in the supply chain. The supply chain assessment tools in Industry 4.0 include instrumented, interconnected, intelligent, automated, integrated, and innovative criteria. The study concludes that there is a gap between existing tools for supply chain measurement and SC 4.0 criteria. The criterion unconsidered in the measuring tool is an innovation that arises due to the use of digital technology in the supply chain. This study measured the SC level by adopting Industry 4.0 criteria. In the INDI and IMPULS tools, the supply chain criteria are found in several different pillars. In SIRI and PwC, it is easy to identify because supply chain measurement becomes a separate sub-pillar. The assessment index showed that SIRI and PwC have the highest index for supply chain context in Industrial 4.0 tools. This study has limitations, but there are still many opportunities to categorize levels and develop assessment tool designs with the value of performance in mind. The supply chain 4.0 research has opportunities to design index measurements for each category in the supply chain framework. Future research in supply chain research on supply chain 4.0 is still very open for innovative measurement as the impact of Industry 4.0 applications.

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