EMERGING TECHNOLOGIES IN SUPPLY CHAIN: MATURITY MODEL AND ASSESSMENT INSTRUMENT

Immarita Dinar Fajriyani, S.T.
Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111 Indonesia, E-mail: immarita.dinar14@mhs.ie.its.ac.id

Prof. Ir. I Nyoman Pujawan, M.Eng., Ph.D., CSCP
Department of Industrial Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111 Indonesia, E-mail: pujawan@ie.its.ac.id

ABSTRACT

Industrial 4.0 technology has been significantly studied and to some extent has been applied especially by the developed countries since its emergence in 2011. Such technologies as Internet of Things (IoT), Big Data Analytics, Advanced Robotics, Augmented Reality, Block chain, and others have been implemented at various levels. Their applications have proven to have a significant impact on increasing productivity and competitiveness. On the other hand, the developing countries are still struggling to grasp these advanced technologies. At company level, some have tried to implement some elements of industry 4.0 technology, some are still assessing the possibilities, while many probably do not know what to do. In this study, we develop a maturity model of industry 4.0, which is done primarily based on literature review. For future phase of research, the proposed maturity model should be developed into an assessment instrument so companies can use this instrument to assess at which level they have grasp these technologies.

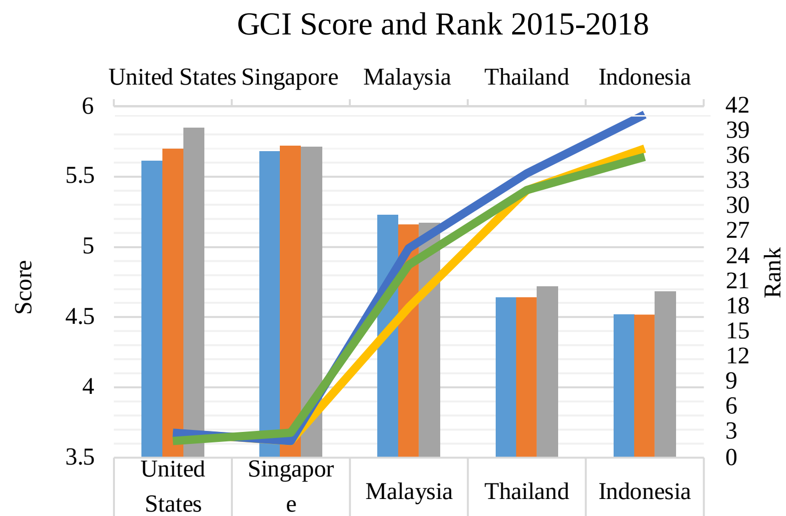
Keywords: Industry 4.0, Maturity Model, Technology Readiness

1. INTRODUCTION

The Fourth Industrial Revolution (FIR) was firstly marked by the declaration from German government regarding the term "Industry 4.0" during the 2011 Hannover Fair. The emergence of this new phase of technology was a manifestation of the adoption of internet and autonomous systems, such as the Internet of Things (IoT), Artificial Intelligence (AI), additive manufacturing, Big Data Analytics, cloud computing, and others (Ustundag, AlpCevikcan, 2018). The emerging technologies are smart technologies that can autonomously communicate, coordinate, interconnected, and support information transparency. It has played an exponential role to develop manufacturing and service sector due to its rapid renewal. Ustundag, AlpCevikcan, (2018) also stated the significant impact regarding productivity. It is proven to increase the productivity by the new and wider employment opportunities. Under that impact, competitiveness level will also increase (Carayannis and Grigoroudis, 2014). This role—increasing competitive advantage—is one important point that drives a country's spirit in achieving successful implementation of emerging technologies.

Based on World Economic Forum (2017), Indonesia's Global Competitiveness Index (GCI) reached its highest value on 2017-2018 at 4.68 out of 7 and ranked 36 out of 137 countries, from which went up 5 rankings since 2016-2017 (ranked 41) under the score of 4.52—the same score with 2015-2016 ranking (ranked 37). However, Indonesia was unfortunately ranked 4th in

ASEAN (consistently from 2015-2018), after Singapore (latest score 5.85, ranked 3rd), Malaysia (latest score 5.17, ranked 23rd), and Thailand (4.72, ranked 32nd). This means Indonesia needs to excel up exponentially, regardless of the current achievement, especially associated with the progress of implementation of the emerging technologies. The summary of information is in Figure 1. Bar chart shows the score (primary axis/left side) and line chart shows the rank (secondary axis/right side). Different colours determine different ranging year.



	United States	Singapore	Malaysia	Thailand	Indonesia
2015-2016	5.61	5.68	5.23	4.64	4.52
2016-2017	5.7	5.72	5.16	4.64	4.52
2017-2018	5.85	5.71	5.17	4.72	4.68
2015-2016 Rank	3	2	18	32	37
2016-2017 Rank	3	2	25	34	41
2017-2018 Rank	2	3	23	32	36

Figure 1. Some Countries' Competitiveness Rank and Index 2015-2018 (World Economic Forum, 2017)

The metrics to find the GCI are comprised of 12 pillars and technological readiness is measured under the efficiency enhancer indicator. Technological readiness is measured by 7 sub-pillars. Those are 1) availability of latest technologies, 2) firm-level technology absorption, 3) FDI and technology transfer, 4) individuals using internet, 5) fixed broadband internet subscriptions, 6) international internet bandwidth, and 7) mobile-broadband subscriptions. Technological readiness is trending upward globally up until 2018. However, there are some populations left behind and Indonesia is one of them. Indonesia's level of technological readiness of individual and firms has increased but insignificant—remains relatively low. In 2015-2016, Indonesia's technological readiness is ranked 85 out of 140 countries, ranked 91 out of 138 countries in 2016-2017, and ranked 80 out of 137 countries in 2017-2018.

"Smart" is one of the keywords that plays an important role in interconnectivity—in this case: implementing Industry 4.0 technology (Mattern and Floerkemeier, 2010). In order to be sufficiently "smart" and able to keep up with the era, there are some underlying indicators to which likely the same with the details from WEF indexes. In terms of both: 1) the amount of information and communication technologies expenditure and 2) the timeline of planning and policy launching, Indonesia is still behind some other countries. The data is shown in Figure 2 and Figure 3 below.

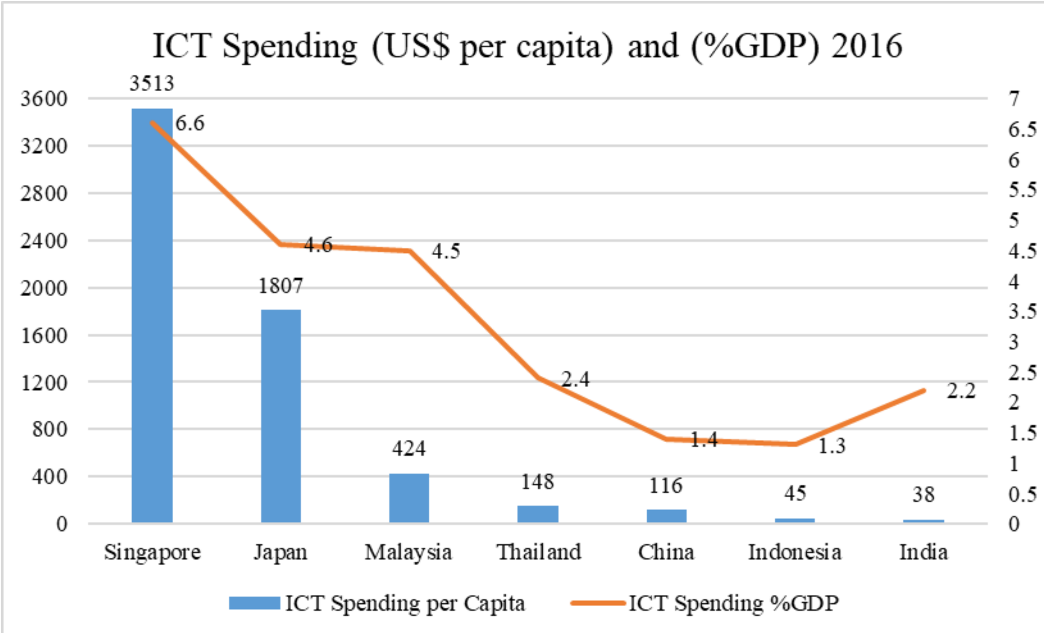


Figure 2. ICT Spending Year 2016 based on US$ per capita and %GDP (Kearney, 2017)

Figure 3. Maturity Level and Policy Launch Timeline of each countries (Kearney, 2017)

Based on the survey from AT Kearney (Figure 2), Indonesia has relatively low expenditure on technology needs both in terms of US$ per capita and percentage of GDP. Even though the population is very large, Indonesia is still below India viewed from the spending per capita. Additionally, based on Figure 3 from the same survey by AT Kearney, Indonesia is still in the planning phase towards the implementation of Industry 4.0 together with Vietnam, the Philippines, and Malaysia. The three levels of maturity represent a position of readiness relative to initiatives in implementing Industry 4.0.

Nevertheless, Indonesia is seen to have great potential to hit the FIR. Currently, Indonesia has set planning initiatives undertaken by the Ministry of Industry, named "Making Indonesia 4.0". The Ministry has set four big targets in 2030 and 5 industrial sectors that are focused on applying emerging technologies. Indonesia, has adopted a self-check program based on studies conducted by McKinsey to formulate its framework named Indonesia 4.0 Readiness Index (INDI 4.0), launched this March 2019, a maturity model that has recently been tested to 328 industries and five of them were appointed as the *lighthouses*. This framework, however, showed a centralized focus on five sectors of industries: chemical, food and beverages, textile, and automotive (Kementerian Perindustrian, 2019)**.** The most prepared industry based on the results is the engineering, procurement and construction industry with the INDI level of 2.74/4. Followed by the textile industry with the INDI level of 2.51/4. The industry with the lowest preparedness level is a metal industry with the INDI level of 1.57/4. Meanwhile, the average score is 2.14 under the moderate-readiness level. How moderate does the readiness level of firms in Indonesia taken place knowing that all competitiveness indexes from WEF showed the same behaviour (which are lacking in technological readiness, ICT adoption, and investments)?

Moreover, in 2018, WEF revised its method in defining country's competitiveness index and developed the framework so that it matches the pressing challenges of the FIR era. Thus, it is called GCI 4.0. However, Indonesia's position is not progressed dramatically, even after launching Making Indonesia 4.0 and INDI 4.0. What explicitly changed is the technological readiness metric is now represented by ICT adoption. Indonesia's GCI 4.0 in 2018 is 64.9 and ranked 45 out of 141 countries (World Economic Forum, 2018). Surprisingly, Indonesia scored 64.6 and ranked 50 in 2019 (World Economic Forum, 2019).

Knowing the significance of maturity model, the framework should be generic that it can be used flexibly to 24,000 Indonesia's manufacturing industries from various sectors, not only 5. Thus, this research intends to explore the application of emerging technologies in supply chain area (following processes in SCOR model) and to develop a comprehensive and robust maturity model because it accommodates information about the readiness level and its suitability with the needs or targets of each industry player. Specifically, this research will focus to make the most representative/suitable maturity model for developing countries, in this case Indonesia, after analyzing several preceding maturity models. This research needs an extensive literature review to have strong fundamental and knowledge awareness regarding the current implementation of Industry 4.0 in real industries. Aside from that, the literature will also focus to review extensively the list of preceding maturity models, as a preliminary foundation to be able to minimize the limitation trend and lacks of preceding maturity model.

The readiness level of firms in Indonesia are still unclear. There is not enough literature regarding any survey assessing the Industry 4.0 maturity levels of manufacturing industry in Indonesia, nor any academic paper developing maturity model in Indonesia. Also, having said that the 65% GDP contributor (the 5 focused sectors for INDI) have an average score of 2.14 (moderate readiness) but the assessment instrument is kept closed (confidential) and WEF indexes showed a contrast, this research will develop a maturity model that is slightly custom but inclusive. In this case, the levels will not be defined up to Advanced/Mature level. Otherwise, Absence until Moderate level will be broken down into some representative levels that are more inclusive. Moreover, the proposed model will not be segmented only for 5 manufacturing sectors but generic. In addition to close the gap, some previous researchers have not accommodated double validation (expert and pilot survey), model combination, model performance test, assess the variance of each industry and each respondent in an industry. However, the first phase of research, complied in this paper, will focus on literature review and building the model. By attempting to minimize the above limitations and gaps, there are two outputs from this paper: the conceptual framework and the proposed maturity model (dimension x level matrix).

2. LITERATURE REVIEW

Extensive literature review is under two big branches: emerging technology and maturity model. The first section mainly pointed out state-of-the-art purpose from each technologies. The second section described the significance of each existing maturity model. In addition, methodology for the literature review is first exposed.

2.1 Methodology for the Literature Review

The guidelines to conduct literature review was inspired by G. Wang *et al.* (2016). Here is how the literature review is obtained.

a. The preceding maturity models incorporated are within the range of 2014-2019 because it depicts the growing trend in researches during that period (not much literature during 2011, the year in which term Industry 4.0 firstly released, until 2013).
b. The main material used in this research is a book published by Springer Series in Advanced Manufacturing under the title of Industry 4.0: Managing The Digital Transformation (Ustundag, AlpCevikcan, 2018).
c. The supporting materials are from journals based on Science Direct, Springer Link, IEEE Explore, ASME, and EconStor. The keywords used are the name of each technology pillar in Industry 4.0, “Industry 4.0”, “Industry 4.0 Maturity Model”, “Maturity Model 4.0”, etc.
d. Press releases, valid news articles, and reports regarding the real applications of the emerging technologies. The keywords used is “application of (technology name) in (company name)” such as “application of Augmented Reality in Zara”. In doing this literature, the real applications shown in Table 1 is not the product of the technology provider, but the companies adopting the technology.

2.1 Emerging Technologies—Nine Pillars of Industry 4.0

1. Big Data Analytics (BDA) and Artificial Intelligence (AI)

The use of massive technology causes high volumes, high speeds, and complex data: Big Data (Lee, Bagheri and Kao, 2015). What defines “big” data can simply be put by 3 V’s: Volume, Velocity, and Variety. The development is fast that now it is more common for 7 V’s to be heard and accepted (Figure 4). There are also 10 V’s, even a satire 42 V’s of big data (Farooqi, Shah and Wahid, 2019). The focus of BDA is more on defining "what will happen" rather than "what has happened", thus the data acts as a prediction of future possibilities or unknown events.

Because of a growing trend, big data shifts its use from data collection to analysis and results of data processing/outcomes (Esmaeilian, Behdad and Wang, 2016). In general, it includes:

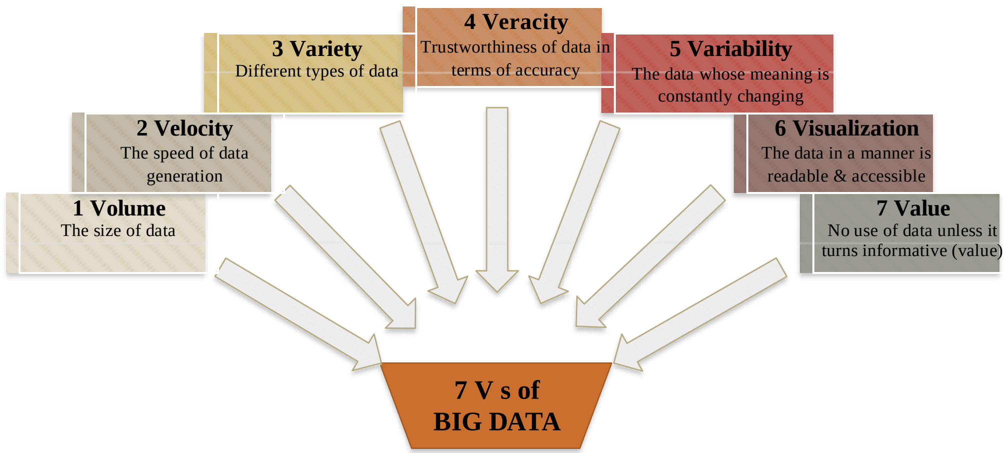


Figure 4. Own work processed from Khourdif, Alami and Bahaj (2018)

1. Descriptive Analysis: summarizes data and reports past conditions. Diagnostic analysis: What occurred and why? And extract information from raw data (Delen and Demirkan, 2013).
2. Predictive Analysis: forecasting phase. The output of descriptive analysis becomes one of the inputs as well as several algorithms and techniques in building predictive models. What will occur and why? (Delen and Demirkan, 2013).
3. Prescriptive Analysis: business value through better strategic and operational decisions. This analysis is about giving guidance and advice. What should I do and why? (Delen and Demirkan, 2013).

Researchers have used various tools to help the data analysis and modelling stage. G. Wang *et al.* (2016) researched the popular techniques for Supply Chain Analytics (SCA). The resulting taxonomy is broken down to three big branches: statistical analysis, simulation, and optimisation. Tan *et al.* (2015) used deduction graph as part of optimisation tools to assist SPEC company (a case study) to manage the production under two manufacturing departments with different competence sets. It overcomes the information connectivity problem. The proposed data analytic technique enable firms to utilise big data to gain competitive advantage by enhancing their supply chain innovation capabilities.

Big Data showed its widespread application. If it is combined with IoT, it can be powerful to change urban populations at different levels. Hashem *et al.* (2016) mentioned the possible applications of big data to support to build smart city are through diverse tools and methods such as smart grid, smart healthcare, smart transportation, and smart government. Meanwhile, Gepp *et al.* (2018) outlines the use of big data technique statistical tools in auditing—which area was considered not as widespread as other related field in using BDA. A possible explanation regarding that is that auditors are reluctant to use techniques that are far ahead of those adopted by their clients. However, greater alignment and future opportunities for big data in auditing is exposed in that paper. BDA is also applicable to use in term of "reducing data". Rehman *et al.* (2016) stated that "big data reduction at the customer end in which early data reduction operations are performed can achieve multiple objectives: (a) lower the service utilization cost, (b) enhance the trust between customers and enterprises, (c) preserve customers' privacy, (d) enable secure data sharing, and (e) delegate data sharing control to customers".

Meanwhile, AI is a broad technology, coined on 1955, that resembles human intelligence, depicted in computer responses. It resembles how human brains work, programmed from experiences. It can be stated as a digital program behaving in a way human used to, which involves continuous learning. It definitely helps the success of BDA through its computational capability and programmable learning in recognizing and processing data. AI is composed from machine learning which resembles an ability to learn without being explicitly programmed (Samuel, 1969). Almost all machine learning is built on neural networks (deep learning) and Natural Language Processing (NLP).

The real implementation of big data is during design and manufacturing processes such as the support for the successful digital manufacturing as Lidong and Guanghui (2016) mentioned. MapReduce and Google File System (GFS) are the programming model to run big data as the example of implementation used by Google (Chen, Mao and Liu, 2014).

2. *Internet of Things (IoT)*

IoT is an advancement that enables a system to communicate autonomously to each other under a set of activities that creates big data for further analysis. Some examples of IoT such as: i) Embedded Systems (Cyber Physical System) using sensors and actuators: 1) Smart Factory, 2) Smart Product, 3) Smart City, and 4) Smart Life: wearable technologies such as smart watch, lenses, smart shirt, etc., ii) Digital Traceability (advanced sensors: RFID, RTLS) and actuators, and iii) Mobile technologies.

Researches have shown the use of IoT in building "things" smartly. From the smallest scale of "things"—household, IoT can play a role. Javed *et al.* (2016) presented Smart Pantry, which used IoT integrated with cloud computing, the technology would monitor the pantry and alert the user, either via text or webapp, about shortages and recommend products for a grocery list. The system uses an Arduino microcontroller to collect weight information about products in the pantry, a Raspberry Pi microcomputer equipped with a camera to take pictures of the pantry, and a gateway server to process this information to be sent to the central server. Bigger scale—Smart Transportation, Handte *et al.* (2016) presented the Urban Bus Navigator (UBN), an IoT enabled navigation system for urban bus riders, which provides micro-navigation and crowd-aware route recommendation. Even Gooch *et al.* (2015) presented the possible involvement of citizens in smart city project.

Advanced Forming Research Center (AFRC) and University of Strathclyde have used an Android tablet to control CNC machine over an internet using an IoT interface named BAUTA (Lee, 2018). In field of fluid power, Alt, Malzahn, and Schmitz (2019) mentioned that Plug-and-Produce business model is proposed to realize the real-time communication, CPS base system, for the electro-hydraulic actuator (EHA).

3. *Virtualization Technologies*

Virtual technology displays information virtually where improved perceptions are accessed and manipulated. Examples are Augmented Reality (AR) and Virtual Reality (VR). One example for VR is like the sport-game that is head mounted. It is not far different from AR which complements the human senses because it can provide more comprehensive information that cannot be understood by humans, such as a smartphone camera, head mounted display (HMD), projection devices, with 3D models, speech instructions, scanners lens, etc. (Ustundag, AlpCevikcan, 2018)**.** It is widely implemented in the manufacturing sector, including production, assembly, maintenance, etc.

Daqri, a smart helmet, is one of the real implementation of AR and it presented a high-performance multimedia and data visualization (Ustundag, AlpCevikcan, 2018). In field of logistics, DHL has applied AR to its warehouse where the workers heading to work and pick by vision. At the storage, the worker merely scans the bar code with smart devices like glasses, which emits codes telling where to go, how many to pick, and where to place next (Ustundag, AlpCevikcan, 2018). Beside DHL, AirBus military generating assembly instruction in its shopfloor using AR namely Project MOON (Servan *et al.*, 2012).

4. *Cloud Computing*

It is a cloud-based operating that includes computing, that frees the company from setting up basic hardware and software infrastructures and the associated investments. Cloud computing is an on-demand delivery of computational power, data storage resources, software, and other IT resources through a platform via the internet (Ustundag, AlpCevikcan, 2018)**.** Everything is a service in a cloud computing (e.g. Software as a Service, Platform as a Service, and Infrastructure as a Service). Saas uses the web to deliver applications that are managed by vendor and the client accesses the interface. IaaS is self-service to access, monitor, and manage remote datacentre infrasrtuctures, such as storage, networking, and networking services, users can purchase IaaS based on needed consumption. PaaS is used for applications and other features while providing cloud components to software. What developers provide with PaaS is a framework they can build upon to develop/customize applications.

The real world implementation has touched widespread areas such as long ago in 2008 came the deal between Google and salesforce.com to share critical documents without having to download/install hardware/software (Buyya *et al.*, 2008). Besides, now, there are numerous cloud platforms such as Kamatera, phoenixNAP, Amazon Elastic Compute Cloud, Microsoft Live Mesh, Sun Grid, GRIDS Lab Aneka, VMWare, etc. Elkay Manufacturing Company has long used cloud-based solutions for their stainless steel business since 2012 (Xu, 2012). Cloud-DPP (Cloud-based Distributed Process Planning) as the result of effort between KTH and Sandvik, Sweden, able to generate any adaptive-to-changes machining process plans (Wang, Törngren and Onori, 2015).

5. *Autonomous Robotics*

Sophisticated robotics is useful for reducing costs in a system, with regard to how to handle dangerous and risky tasks for humans to produce under faster processes and more accurate results. Some advances in robots are face sensors, artificial intelligence, internet of robotic things, cloud robots, cyber-physical robots. (Ustundag, AlpCevikcan, 2018)**.** In supply chain, this technology is implemented in operations such as the assembly process, manufacturing process, and more towards operations that occur in incoming logistics.

The real implementation is a robot named Yumi (ABB manufacturing operations) that has flexible parts-feeding mechanism, location detection system, advanced motion control adaptive towards ABB Contact (2014). Another implementatioin is Kuka KR Quantec Robot that can deliver the ordered KANBAN boxes from the warehouse rack. Another advanced robotics are such as workerbot by pi4, HRP4 Kawada Industries, SpotMini Boston Dynamics, hanson robotics Sophia, etc.

6. *Additive Manufacturing*

Additive manufacturing uses 3D Computer Aided Design (CAD) or commonly called 3D printing. This technology helps decision makers by producing prototypes or layers by layers (Ustundag, AlpCevikcan, 2018). This makes it possible to create complex and custom geometries that cannot be produced using conventional manufacturing techniques. It is clear that this is also widely applied in the manufacturing sector. Real example is ARBURG GmbH that unites injection moulding and additive manufacturing (VDMA, 2016). It is linked with Allrounder injection moulding machine to create high volume plastic products. Besides manufacturing sector, in automotive, CRP Technology (Italy) to has produced parts using AM: MotoGP 250R air boxes, camshaft covers for MotoGP engines, F1 gearboxes, motorbike supports, and dashboards (Guo and Leu, 2013).

7. Horizontal and Vertical integration

Vertical integration applies to the versatile and reconfigurable structures within the factory plant and the extent to which they are fully integrated in order to achieve agility. Meanwhile, horizontal integration deals with each tier integration within the supply chain. In order to optimize system performance and send it into the cloud, the industrial network gathers Big Data. This coordination mechanism creates the framework of the smart factory. Therefore, the manufacturing systems are designed as self-organized structure that integrates every physical objects each other through smart networks. Besides, cloud based systems enable vertical partners to integrate each other through shared platforms. The product and process flows would be visualized and tracked by SC members (S. Wang *et al.*, 2016)

8. Cybersecurity

Cybersecurity is that part of Information Security which specifically focuses on protecting the Confidentiality, Integrity and Availability (CIA) of digital information assets against any threats or cyber-attacks, which may arise from such assets being compromised via (using) the Internet. The perfect example of technology that serves cybersecurity is blockchain. Cybersecurity usually resulted as response to risk. Hence, a company needs to breakdown its cyber or any related risks in order to plan the cybersecurity strategy, framework, policies, and standards (CGI, 2019). One implementation of cybersecurity is the CodeMeter by Wibu-Systems AG that IP protection mechanisms prevent illegal copying, data theft, reverse engineering of software, and product counterfeiting, Freud detection, and cyber-attack identification (Ustundag, AlpCevikcan, 2018).

9. Simulation

Diversified types of simulation including discrete event and 3D motion simulation can be performed in various cases to improve the product or process planning (Kühn, 2006). For example, simulation can be adapted in product development, test and optimization, produc- tion process development and optimization and facility design and improvement. Another example could be given from Biegelbauer (2004) study that handles assembly line balancing and machining planning that requires to calculate operating cycle times of robots and enables design and manufacturing concurrency.

In perspective of Industry 4.0, simulation can be evaluated as a supportive tool to follow the reflections gathered from various parameter changes and enables the visualization in decision-making. Therefore, simulation tools can be used with other fundamental technologies of Industry 4.0. For instance, simulation based CAD integration ensures the working of multiple and dissimilar CAD systems by changing critical parameters. Additionally, simulation can reflect what-if scenarios to improve the robustness of processes. Especially for smart factories, virtual simulation enables the evaluation of autonomous planning rules in accordance with system robustness (Tideman, 2008). One example is Siemens Tecnomatix Plant Simulation, it enables to simulate production facilities, lines, and processes up until the complex process such as robotic path planning, signal definition based on real HW, Boolean and analog logic, etc (Rodič, 2017).

Table 1. Current Technology Implementation in Some Companies

No	Company	Technology	Application
1	Zara	RFID, IoT	Sales tracking data using RFID microchip tagged in clothes updated realtime in Inditex central data processing center. (Hansen, 2012) RFID enables the stockist determine which items need replenishment and where to locate, which has made their inventory and stock takes 80% faster than before (Inditex, 2015).
		Big Data Analytics, AI	Collaborating with Jetlore and El Arte de Medir (Spanish big data company) to have AI-powered consumer behaviour prediction platform. Zara tailors its collections based on the exact ZIP code and demographic that a given location serves (Hansen, 2012).
		Robotics	Use robots in retail backrooms to search for orders and deposit them in drop boxes for in-store collection (RetailWire, 2018).
		AR	AR application for shopper: showing models wearing selected looks from its ranges when a mobile phone is held up to a sensor within a store or designated shop windows and allows customers to click through to buy the clothes (Sandler, 2018).
2	Unilever	Big Data Analytics	Strategic analytics initiative called Project iQ with its solution partner, MindTree, help tracking and improve shelf-availability reducing stockouts (Ackerman and Padilla, 2013).
		Cloud Computing	Using Google Cloud to precisely target its consumers and implemented Global People Data Centres (PDC) for customer engagement center (Sheth, 2019).
		AI	Collaborating with Pymetrics, a specialist in AI recruitment, to create an online platform, which means candidates can be initially assessed from their own homes, in front of a computer or mobile phone screen (Marr, 2018).
		Robot	Unilever's Gloucester (ice cream) factory uses bespoke packaging automation robot pick and place and unloading system by Linkx (2019).
		3D Printing	Unilever has cut lead times for prototype parts by 40% since introducing Stratasys' PolyJet 3D printing technology into its manufacturing process (Stratasys, 2015).
		AR	Unilever launches its on-pack AR on the eco-refill packaging for the Cif detergent. Consumers can refill their already used spray bottles with an "eco-refill" (Reiner, 2019).
3	Toyota	Simulation	Collaborating with Global Institute for Motor Sport Safety to use virtual human modeling to simulate exactly what a body goes through during collisions in racing situations (Toyota, 2015).
		Cybersecurity	PASTA:Portable Automotive Security Testbed with Adaptability developed by Toyota InfoTechnology Center, a platform allowing researcher/engineers to freely construct in-vehicle networks. PASTA will contribute to accelerate research, education, and information sharing of vehicle cybersecurity as an open and handy platform which has typical physical attack surfaces (GitHub, 2019).
		Robot, VR	Toyota Research Institute uses VR to train robots as in-home helpers (Fisher, 2019).
4	Samsung	Cloud Computing	Kinaxis provides RapidResponse technology for Samsung to integrate planning functions especially S&OP, Master Planning & Scheduling (Kinaxis, 2018)
5	Siemens	IoT	MindSphere, open IoT operating system from Siemens with access to Amazon Web Services (AWS) and Microsoft Azure and Alibaba public cloud services (Siemens, 2019).
6	Schneider Electric	Virtualization Technologies	Schneider electric EcoStruxure Augmented Operator Advisor: reduce mean time to repair, superimpose the current data and virtual objects onto a cabinet, machine, or plant (2017).

No	Company	Technology	Application
		IoT	Schneider Electric RFID OsiSense: Eliminated 128 daily fork truck miles and eliminated $500,000 in Work in Progress (WIP) inventory with a 33% first-year ROI (2019).
		Simulation	Schneider Electric integrated Simio simulation with their real-time manufacturing execution systems (2018)
7	Colgate Palmolive	Virtualization Technologies	Realwear HMT-1 device is used by Colgate Palmolive's workers to enhance performance such as noise cancellation prior to voice recognition (RealWear, 2018).
8	Elkay Manufacturing	Cloud Computing	Elkay Manufacturing Company cloud-based solutions for their stainless steel manufacturing (2012).
9	AirBus	Virtualization Technologies	AirBus military generating assembly instruction in its shopfloor using AR namely Project MOON (Servan *et al.*, 2012)
10	Apple	Cloud Computing	Apple iOS used Amazon S3 and Microsoft Azure in 2014, and 2016 started using Google Cloud Platform (2018).
		Simulation	Amazon, Apple, Michelin, Toyota, IBM, ABB, Ford, etc. used FlexSim for their 3D simulation modelling (FlexSim, 2019).
11	Nestle	Cybersecurity	Nestle and Carrefour used blockchain platform of IBM Food Trust for product traceability (Nestle, 2019).
12	Nestle	Cybersecurity	Nestle open new blockchain pilot with OpenSC (Open Supply Chain by BCG) to trace milk from producers in New Zealand to factories and warehouses in the Middle East (Nestle, 2019).
13	GEP	Robot	Robotic Process Automation (RPA) in Procure-to-Pay solution by GEP (2019) for transaction and contract management.
14	DHL	Virtualization Technologies	DHL applied AR Pick-by-Vision: workers scans the bar code with smart glasses with codes telling where to go, how many to pick, and where to place next (2018).
15	DHL	Cybersecurity	DHL Supply Watch: supplier monitoring to mitigate risk by DHL Resilience 360 (2019).
16	ABB	Robot	Yumi (ABB manufacturing operations) that has flexible parts-feeding mechanism, location detection system, advanced motion control adaptive towards ABB Contact (2014).
17	Wibu Systems AG	Cybersecurity	CodeMeter by Wibu Systems AG (2018)
18	PINC AIR	Robot	PINC AIR Hardware: autonomous drone-tech with AI, and RFID for inventory and yard check and replace traditional rolling ladder (PINC, 2019).
19	Boston Dynamics	Robot	Handle, robots for logistic by Boston Dynamics for loading and unloading activities (2019).
20	La Poste France	Big Data Analytics	Supported by Sopra ISD, La Poste Courrier has proposed its platform solution based on the Big Data. It is a new version of search engine using CloudView technology (Zhong *et al.*, 2016).
21	Nippon Express Co. Japan	Big Data Analytics	NEC currently launched a project based on OpenFlow network control technology to manage its Big Data as a datacenter over cloud networks so as to improve efficiency and reduce operating costs (Zhong *et al.*, 2016).

Source: Author's Work of Literature Review

2.2 Literature on Industry 4.0 Maturity Model

Extensive literature review on the preceding maturity model is carried out. The information regarding the model structure (author, year published, country, origin, dimension, and level) is seen in the following Table 2. There are four classifications of origin of the author: 1) Government, 2) Practitioner, 3) Research institute/Academics, and 4) Consulting companies. These 31 models are published in the range of 2014 until 2019 in which the trend is growing. The following narrative will explain some of the models regarding its contribution to the proposed model and some strengths and weaknesses.

INDI 4.0, launched on April 2019, has been tested to 328 manufacturing companies in Indonesia. It only focused on 5 priority sectors: Food and beverage, Textile and garment, Automotive, Electronics, Chemical, based on the reasons that these five industry sectors contribute 60% to the manufacturing GDP, 65% to the total manufacturing export, and 60% manufacturing labor in Indonesia. The average score of those 328 companies is 2.14, which is in Moderate Readiness, with this detail: average score of Technology is 1.95, 2.06 for Factory Operation, 2.12 for Management and Organization, 2.16 for People and Culture, and 2.41 for Products and Services. The questionnaire is not publicly accessible. Thus, it is hard to measure further: how good and how bad is total average score of 2.14 (Kementerian Perindustrian RI, 2019).

Meanwhile, a local government (Munich) in Germany develops maturity model, IHK. The questionnaire is accessible online, self-assessment method, using German language. What can be taken from this model is the final report interface. It reports every dimension maturity model along with the explanations. It has details for each questions in each dimensions. Besides, the assessment method is 5-tiered Likert Scale, the same with its Maturity Levels, which consist of 5 levels. However, in each questions, the options are not in an ordinal naming of scale. Instead, it is described. In addition, each options has its additional information as the elaboration to prevent any misperception from the respondent.

Another model is from IMPULS Foundation that has established Industry 4.0 Readiness online self-check for businesses. The author is IW Consult, subsidiary of the Cologne Institute for Economic Research and Institute for Industrial Management at RWTH Aachen University. This model is advised and commissioned by IMPULS Foundation of German Engineering Federation (VDMA). IMPULS has 6 dimensions and 6 levels. The interesting thing about IMPULS is that it has good model support in terms of questionnaire accessibility and the quality of report. The model structure is also interesting, since the assessment is not purely Likert Scale. It accommodates questions such as the list of technologies that the respondent has, the investment plan, etc. and it is custom regarding either type of industry sector, mechanical or manufacturing. However, the targeted company is limited to only those two and the algorithm remains black box.

The Proposed Industry 4.0 Maturity Model 2018 is done by academics from Turkey. It incorporated the previous studies: IMPULS, Digital Operations Self-Assessment by PwC, the Connected Enterprise Maturity Model by Rockwell Automation, and Industry 4.0 Maturity Model by Schumacher et al (2016). Under various associated fields such as production, logistics, procurement, R&D, after sales service, promotion, human resources, IT, smart finance, business models, etc., the dimensions are: Smart products and services; Smart business processes, the sub-dimensions are: smart production and operations, smart marketing and sales operations, and supportive operations; and Strategy and organization.

The example mentioned in the model is applied to retail sector in Turkey. The questionnaire is accessible. The interface is complete and detail, that being said, the questionnaire is divided into each sub-dimension and showed each principles and technologies related on each sub-dimension. Likert scale is used, however, the questionnaire is not uniformly Likert scale.

Listing technologies and comparing conditions are also incorporated. The remaining preceding maturity models are summarized in Table 2.

3. PROPOSED MATURITY MODEL DEVELOPMENT

This research will analyze 31 preceding maturity models as part of the model development. This research tries to address the gap from three important points in a maturity model: structure, assessment, and support.

1. Model Structure (dimension, level, focus): The trend and growth of this research topic is increasing rapidly. It can be seen easily by the publication year. The above 31 models are not older than 2014. Within the years lately, there are little references assessing the whole supply chain, researchers are focusing on production process. In addition, researchers are trying to cope with a more detailed and specific process to assess (under the maturity model). There are some models addressed specific to limited process or focus of technology, such as:

1. Data Maturity Model by Accenture (focuses on how mature a company in managing big data)
2. Blockchain Maturity Model by KPMG (focuses on one example of Cybersecurity)
3. Big Data & Analytics Maturity Model by IBM (almost the same as Accenture)
4. SMO Maturity Model by Goienetxea et al. (focuses on Simulation)
5. Maturity Levels for Logistics by Sternad et al. (focuses on one candidate of sub-dimension for the proposed model)
6. DPMM by Asdecker et al. (focuses on delivery process or distribution and logistics)

Thus, the Author will close the gap by constructing a thorough model based on the above detail for the respective dimensions and/or technologies. For example, the sub-dimension for Horizontal and Vertical Integration will consider the Maturity Levels for Logistics by Sternad et al. and DPMM by Asdecker et al. Sub-dimension of technology (if any) will cocnsider Blockchain Maturity Model, Big Data & Analytics Maturity Model, SMO Maturity Model, etc. Additionally, the Ministry of Industry of Indonesia has progressively grown in this year, 2019. What lacks is what this country put aside from its big roadmap towards Indonesia 2030. This model targeted all sectors of manufacturing industry operating in Indonesia. Thus, it will include sectors outside the priority sectors in Making Indonesia 4.0: the model is generic. Moreover, there is no or very few academic paper related to maturity model development taking case/survey in Indonesia.

2. Model Assessment: Author may also benefit the proposed model by merging some of the possible assessment method. The Author will take one of 360 DMA Maturity Model's processes that is Validation from expert and external helper. Thus, it will close the gap for those researches to which are launched without validation from relevant stakeholders. The proposed model will also incorporate the most common scoring formula (adopting the principle of mean) for each sub-dimensions such as the maturity model by The University of Warwick and Crimson&Co. The Author will also take into deeper analysis about the maturity model performance/quality test such as through Net Promoter Score (NPS), relevancy, and other measures which originates from some of the above preceding models.

3. Model Support: Lastly, the model support is reflected on the accessibility and interface (the ease in assessment and the comprehensiveness of report). The Author will consider to have a detail and complete explanation (but not confusing) for each questions. It will also have a complete (for each dimension) but easy-to-chew report. It will also take into account the metrics of target (not only as-is or current condition) to process the gap analysis.

Table 2. Preceding Maturity Models

No	Model, Published Year	Author	Origin, Country	Dimension	Level
1	Indonesia 4.0 Readiness Index (INDI 4.0), 2019	Ministry of Industry of Indonesia	Government, Indonesia	Management and organization, People and culture, Products and services, Technology, Factory operation	Level 1 Early stage, Level 2 Medium maturity, Level 3 Mature, Level 4 Industry 4.0 enabler
2	Industrie 4.0 by Munchen und Oberbayern, 2015	IHK (Chamber of Industry and Commerce) Munich	Government, Munich, Germany	Smart products, Smart manufacturing, Smart organization, Smart technology	Level 1 Low, Level 2 Medium, Level 3 High
3	IMPULS—Industrie 4.0 Readiness, 2015	IW Consult and VDMA	Research institute, Germany	Strategy and organizations, Employees, Smart products, Smart factory, Smart operations, Datadriven services	Level 0 Outsider, Level 1 Beginner, Level 2 Intermediate, Level 3 Experienced, Level 4 Expert, Level 5 Top performer
4	Digital Maturity Model 4.0, 2016	Forrester	Research industry, USA	Culture, Organization, Technology, Insight	Level 1 Sceptic, Level 2 Adopters, Level 3 Collaborative, Level 4 Differentiators
5	Industry 4.0 Maturity Test, 2019	Connected Production	Practitioner, Germany	Research and Development, Production, Logistics and warehouse management, Administration, Distribution, Customer service	Level 1 Manual, Level 2 Digitization, Level 3 Networking, Level 4 Structuring, Level 5 Automation, Level 6 Predictability, Level 7 Autonomization
6	Evaluation of Digital Maturity of the Company, 2019	Firma4.cz	Practitioner, Czech Republic	Leadership, human potential, openness of corporate culture to digitalization; Business model, customer orientation and digital product; Operating model, digital value creation environment and digital control; Technology; Working with data and data culture	5 levels without naming
7	Capability Maturity Model Integration (CMMI) Version 2, 2018	CMMI Institute	Practitioner, Czech Republic	Focus and process areas are diverse depend on which CMMI: CMMI-DEV, CMMI-SVC, CMMI-ACQ	Level 1 Initial, Level 2 Managed, Level 3 Defined, Level 4 Quantitatively managed, Level 5 Optimizing
8	Proposed Industry 4.0 Maturity Model, 2018	Kartal Yagiz Akdil, Alp Ustundag and Emre Cevikcan	Academics, Turkey	Smart products and services, Smart business processes, Strategy and organization	Level 0 Absence, Level 1 Existence, Level 2 Survival, Level 3 Maturity
9	Industrie 4.0 Maturity Index, 2017	Acatech	Academics, Germany	Resources, Organizational structure, Information system, Culture	Level 1 Computerization, Level 2 Connectivity, Level 3 Visibility, Level 4 Transparency, Level 5 Predictive capacity, Level 6 Adaptability
10	Industry 4.0 Readiness Assessment Tool, 2017	The University of Warwick in association	Academics, UK	Products and services, Manufacturing and operations, Strategy and organization, Supply	Level 1 Beginner, Level 2 Intermediate, Level 3

No	Model, Published Year	Author	Origin, Country	Dimension	Level
		with Crimson&Co		chain, Business model, Legal consideration	Experienced, Level 4 Expert
11	System Integration Maturity Model Industry 4.0 (SIMMI 4.0), 2017	Leyh et al.	Academics, Germany	Vertical integration, Horizontal integration, Digital product development, Cross sectional technology criteria	Level 1 Basic digitization, Level 2 Cross department digitization, Level 3 Horizontal and vertical digitization, Level 4 Full digitization, Level 5 Optimized full digitization
12	Industry 4.0 Maturity Model, 2018	Andreas Schumacher, Tanja Nemeth, and Wilfried Sihn	Academics, Austria	Technology, Products, Customer and partners, Value creation process, Data & information, Corporate standards, Employees, Strategy and leadership	No specific naming on maturity level, rather, depicted on a scale from 1 to 4 for each dimensions.
13	Industry 4.0 Maturity Model, 2016	Andreas Schumacher, Selim Erol, and Wilfried Sihn	Academics, Austria	Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance, Technology	5 levels without naming.
14	Digital Readiness Assessment Maturity Model (DREAMY), 2017	*Anna De Carolis, Marco Macchi, Elisa Negri, and Sergio Terzi*	Academics, Italy	Process, Monitoring and control, Technology and organization	ML1 Initial, ML2 Managed, ML3 Defined, ML4 Integrated and interoperable, ML5 Digital-oriented
15	360 Digital Maturity Assessment (DMA) Problem Based Learning (PBL), 2018	U. Berger, C. Moller, B. Vejrum Waehrens, M. Bockholt	Academics, Denmark	Governance, Technology, Connectivity, Value creation, Competence	None, Basic, Transparent, Aware, Autonomous, Integrated
16	Digitalization Maturity Model, 2018	Luca Canetta, Andrea Barni, Elias Montini	Academics, Switzerland	Strategy, Processes, Technologies, Products & services, People	Absence, Novice, Intermediate, Expert
17	Delivery Process Maturity Model 4.0 (DPMM), 2018	Björn Asdecker and Vanessa Felch	Academics, Germany	Order processing, Shipping, Warehousing. With 15 SCOR process elements in total	Stage 1 Basic digitization, Stage 2 Cross-department digitization, Stage 3 Horizontal and vertical digitization, Stage 4 Full digitization, Stage 5 Optimized full digitization
18	IoT Technological Maturity Assessment Scorecard, 2017	Bjørn Jæger and Lise Lillebrygfjeld Halse	Academics, Norway	Either or not companies have three characteristics of 4.0-enabled-object: Embedded PLC-element, associated global unique identifier, and global connectivity	Level 1-3.0 maturity, Level 2-Initial to 4.0 maturity, Level 3-Connected, Level 4-Enhanced, Level 5- Innovating, Level 6-Integrated, Level 7-Extensive, Level 8-4.0 maturity
19	Maturity Levels for Logistics 4.0, 2018	Marjan Sternad, Tone Lerher, and Brigita Gajšek	Academics, Slovenia	Purchase logistics, Internal logistics, Distribution logistics, After sales logistics	5 levels without naming (onely Basic, Second, Third, Fourth, Fifth)
20	Simulation and Optimization (SMO) Maturity Model, 2017	A. Goienetxea Uriarte, A. H.C. Ng, M. Urenda Moris, M. Jägstam	Academics, Sweden	Either or not companies are aware, apply, and optimize the use of simulation	Novice, Beginner, Advanced beginner, Intermediate, Competent, Expert

21	Industry 4.0-MM, 2017	Ebru Gökalp, Umut Şener, and P. Erhan Eren	Academics, Turkey	Asset management, Data governance, Application management, Process transformation, Organizational alignment areas	Level 0 Incomplete, Level 1 Performed, Level 2 Managed, Level 3 Established, Level 4 Predictable, Level 5 Optimizing
22	Three Stage 4.0 Maturity Model in SME's, 2016	Jaione Ganzarain, Nekane Errasti	Academics, Spain	Multi perspective map of the overall strategy in all stages: Vision, Roadmap, Projects	Initial, Managed, Defined, Transform, Detailed business model
23	Digital Readiness Assessment, 2019	EY	Consultant, Sweeney	Strategy, innovation & growth, Customer experience, Supply chain & operations, Technology, risk & cyber security, Finance, legal & tax, People & organization	Not described
24	Big Data & Analytics Maturity Model, 2014	IBM	Consultant, UK	Business strategy, Information, Analytics, Culture and execution, Architecture, Governance	Ad hoc, Foundational, Competitive, Differentiating, Breakaway
25	Blockchain Maturity Model, 2017	KPMG	Consultant, Netherlands	Access and user management, Authorization and provisioning management, Data management, Interoperability, Scalability and performance, Change management, Privacy, Security	Level 1 Initial, Level 2 Managed, Level 3 Defined, Level 4 Quantitatively managed, Level 5 Optimizing
26	Data Maturity Model, 2018	Accenture	Consultant, Ireland	Strategy and governance, Architecture, Development, Regulation and ethics, User support	Ad hoc, Organize, Tactical, Critical, Industrial
27	Transforming and Digitizing Maturity Quest, 2017	Accenture	Consultant, Ireland	Design of business transformations, Characteristics of Latin America for business transformation, Execution of business transformations	Beginner, Intermediate, Master
28	Digitalisierungs Index, 2018	Deutsche Telkom	Consultant, Germany	Relationship with customers, Productivity in the enterprise, Digital offers and business models, IT and information security and data protection	Maturity level depicted as a discrete index point.
29	Digital Quotient, 2015	McKinsey	Consultant, USA	Strategy, Culture, Organization, Capabilities	No maturity level described.
30	Digital Acceleration Index, 2019	BCG	Consultant, Boston, USA	Business strategy driven by digital; Digitizing the core: Customer offer & go-to-market, operations, support function; New digital growth; Enablers: Changing ways of working, leveraging the power of data & technology, integrating ecosystem	Level 1 Digital passive, Level 2 Digital literate, Level 3 Digital performer, Level 4 Digital leader
31	Industry 4.0 Self-assessment, 2015	PwC	Consultant, London	Digital business model and customer access; Digitization of products and service offerings; Digitization and integration of vertical and horizontal value chain; Data and analytics as core capability; Agile IT architecture; Compliance, security, legal, and taxes; Organization, employee, and digital culture	Level 1 Digital novice, Level 2 Vertical integrator, Level 3 Horizontal collaborator, Level 4 Digital champion

3.1 Research Methodology

The general process of the proposed maturity model development is shown in Figure 5. This paper established Step 1 until Step 4, which are the preliminary stage before the assessment instrument is tested. Meanwhile, Step 5 until Step 7 are to be established in further research work. Step 5 is the assessment instrument making (questionnaire framework) together with the scoring and the reporting scheme design. Step 6 (Validation I: Expert Assessment) is needed to check the big picture of the proposed model, the logic, and synchronization of calculation. Step 6 (Validation II: Pilot Survey) is an obligatory conduct to validate the ease of use and the relevance to real world industries. Thus, the last Step 7 is model revision: This last step is also used to check whether the questionnaire framework is logic towards the dimension and level proposed, also to check the comprehensiveness and robustness of model seen from the dimension and the defined level. Here is a brief explanation of Step 1 – Step 4.

Step 1 and Step 2 define the result of doing extensive literature review, collection of references, on maturity models framework and the emerging technologies. The output of these 2 steps will be analysed in Step 3 in order to formulate the dimension and level formulation in Step 4 The output of Step 4 are the output of this research: conceptual model and maturity model matrix (dimension x level). Step 1 and Step 2 are already established in the previous section. Thus, the remaining steps are Step 3 (Analysis of Preceding Maturity Model) and Step 4 (Maturity Model Development: Dimension and Level Formulation).

3.2 Analysis of Preceding Maturity Models

There are some most-used dimensions in the 31 preceding models. Those are business strategy, people and culture, organizations, information and technology system, customer service, and legal considerations. This research focuses on the supply chain process, thus, the highlight of contribution is in the exploration of maturity of emerging technology adoption in supply chain— that being said: the Horizontal and Vertical Integration is taken into account as the dimension.

There are preceding models concerning on specific process, in this case will contribute to the Horizontal and Vertical Integration dimension. Those models are:

1. Industry 4.0 maturity model for the delivery process in supply chains, by Asdecker and Felch (2018): this model accommodates SCOR model and help provide the digitization efforts in delivery process. However, it only focuses on outbound logistics.
2. Maturity Levels for Logistics by Sternad (2018): it adopts the NRW's model. This model incorporates purchase logistics, internal logistics, distribution logistics and after sales logistics.
3. Industry 4 readiness assessment tool by Crimson&Co (2017): one of its dimension is supply chain. In this case, there is one sub-dimension that can be used that is the Inventory Control. However, the dimension name is supply chain but the sub-dimension talking specific about supply chain process is only the inventory control. The rest is supply chain visibility and integration in general.

The next obviously taken into account dimension is the IT system. In this case is associated with the emerging technologies. There are some reference models specific to each of 9 pillars of Industry 4.0:

1. Data Maturity Model by Accenture (focuses on how mature a company in managing big data)
2. Blockchain Maturity Model by KPMG (focuses on one example of Cybersecurity)
3. Big Data & Analytics Maturity Model by IBM (almost the same as Accenture)

4. SMO Maturity Model by Goienetxea et al. (focuses on Simulation)

The following dimensions which always exist in almost every preceding models are business strategy and organization. Business strategy drives the vision and mission, while the organization resembles how healthy the people and culture including the structure and the internal business. Customer service and factory operation are also everywhere. Thus, the concluding dimensions are Business Strategy, People and Culture (representing the most-used dimension: organization), Products and Service offerings (representing the customer service), and factory operation is merged into the Horizontal and Vertical Integration.

3.3 Conceptual Model

In this conceptual model, dimensions formulated based on the previous analysis are shown. This conceptual model acts as a big picture and basis of thinking in doing the model development. The dimensions are people and organization, products/services, business strategy, horizontal and vertical integration, and industry 4.0 technologies (IT system).

It all started and driven strategically by the resources: people and organization. Organization determines how great the business strategy will be—in this case, how much Industry 4.0 will be incorporated in their vision and mission. These two dimensions will drive the internal business (products, service offerings, and the IT systems) and the supply chain. The supply chain is broken down to SCOR processes: Plan, Source, Make, Deliver, and Return. The IT system remarks how well the information flow, the interconnection, and information feasibility, and also the adoption of Industry 4.0 technologies which will in turn influence the competitive advantage.

Based on the above principles, the proposed maturity model will ensure:

1. The awareness level regarding the exposure of Industry 4.0 technologies and current needs
2. The adoption level of Industry 4.0 technologies in each phase of SCOR model and strategic level (business and organization)
3. Whether the current implementation is significant in achieving company's goals, increasing productivity and competitiveness level

The conceptual model is shown on Figure 6.

3.4 The Proposed Maturity Model

After the dimensions (conceptual model) is proposed, the level definition is needed. The formulation is based on the developing countries condition, in which, the preceding maturity models may attribute to the early implementation stage. It is signed by the fast and trending research topics incur only in the developed countries. Additionally, based on the aforementioned background, Indonesia has not much improved in any competitiveness indexes even after launching the framework and roadmap. The result of INDI 4.0 showed that 5 manufacturing sectors in Indonesia is in moderate level of maturity (scored 2.14 in average over 4).

Thus, justification is needed in order to make it more representative and corresponds to the real life. The preceding models were all in average have 4 up to 6 levels, from absence to say: completely mature. Meanwhile, Indonesia generally has the awareness widespread but the implementation scattered. Table 3 showed the initial proposed maturity model—full description of each level. The Table 3 Survival and Maturity level are for company with integration-ready, meanwhile most companies in Indonesia still grapple with initial implementation, in the phase of changes from awareness to real application. Thus, this work focuses only to map out to two levels with Existence divided into 3—break the bones the middle/moderate level into smaller detailed levels, shown in Table 4.

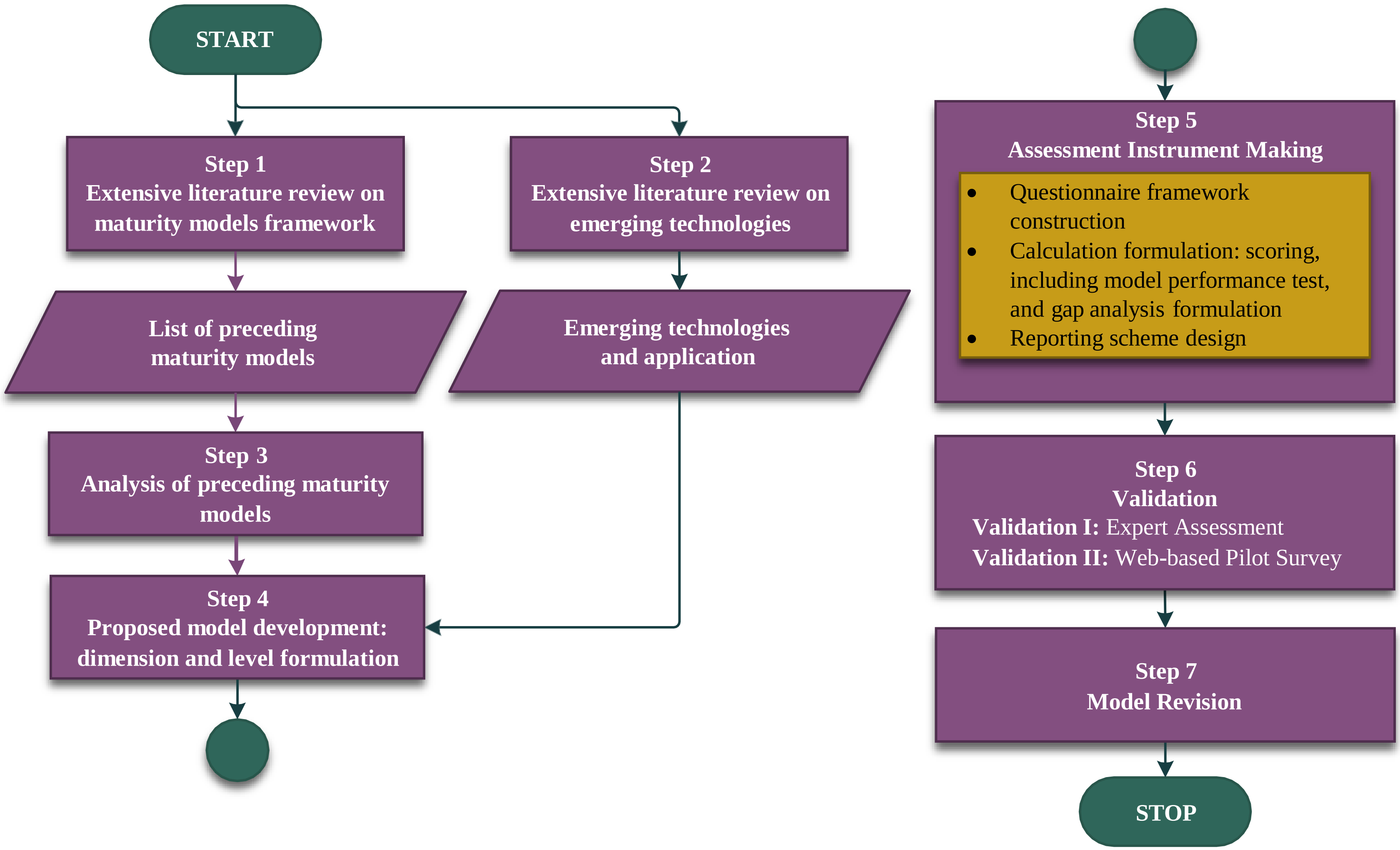


Figure 5. Methodology for the Proposed Maturity Model Development

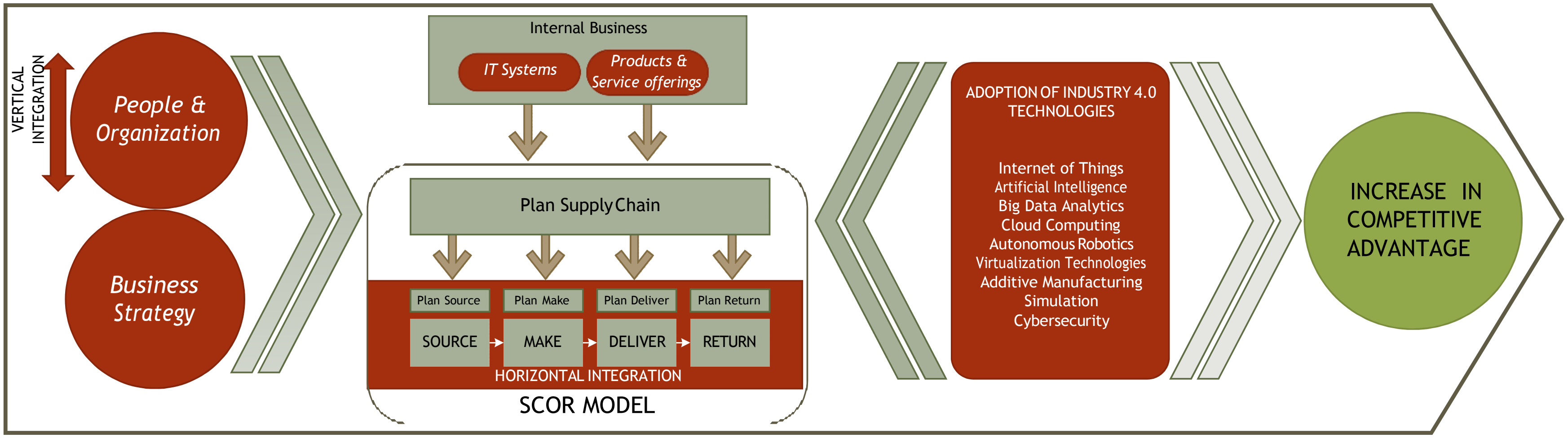


Figure 6. Conceptual Model

Table 3. Initial Proposed Maturity Model's Dimension and Level

Dimension/Level	Absence	Existence	Survival	Maturity
Business strategy	No awareness of implementing Industry 4.0 or recognized at departmental level only. No vision or direct statement regarding Industry 4.0 in business strategy.	Industry 4.0 is in the business strategy, but implementation is unclear. Alternatively, Industry 4.0 is not in the strategy but somehow with sparse implementation.	Industry 4.0 strategy has the hype and communicated, understood and implemented.	Industry 4.0 strategy has been implemented across the business
People and culture, org	Functionally dedicated. No digital culture at all.	Cross-function cooperation exist, but not structured and continuous. Cooperation starts to spark initiatives with/without digital culture.	Wider and frequent cross-function cooperation with digital culture.	Collaboration and digital are both a culture.
Customer, products, and service offerings	Online channel is separated from the offline, product focus instead of customer focus. No Industry 4.0 implementation in service offerings.	Integrated use of online and offline channels, initiatives or little implementation of Industry 4.0 in service offerings.	Proactive customer focus with Industry 4.0 service offerings.	Customer focus capturing empathy integrated with Industry 4.0 service offerings and breakthroughs.
Information and	Separated IT architecture,	Homogeneous IT architecture	Homogenous IT structure in	Data lake is created, data flows

Dimension/Level	Absence	Existence	Survival	Maturity
Technology System	paper/paperless work with less use of internet and/or Industry 4.0.	in-house. Connection between departments is developing. Paperless work increased. Works are around internet, not yet Industry 4.0 or little usage.	the partner network, linked data, Paperwork decreased and optimized, speedy and information transparent, Industry 4.0 technology implemented but not yet integrated.	real-time, transparent and integrated, capable and flexible organization. CPS applied thoroughly as needed.
Value and Supply chain: horizontal and vertical integration	Digitized and automated sub processes. No supply chain 4.0 technology, no integration between partners.	Vertical digitization and integration of process and data flows within the company. Supply chain 4.0 technology implemented functional and only some.	Horizontal integration of processes and data flows with customers and external partners, intensive data use	Fully integrated ecosystem with self-optimized, virtualized processes decentralized autonomy.

Table 4. Proposed Maturity Model (Dimension and Level)

Dimension/Level	Absence	Existence I	Existence II	Existence III
Business strategy	No awareness of implementing Industry 4.0 or recognized at departmental level only. No vision or direct statement regarding Industry 4.0 in business strategy.	- Aware of Industry 4.0 - No vision or direct statement regarding Industry 4.0 in strategy	- Aware of Industry 4.0 - There is a vision or direct statement of Industry 4.0 in business strategy	- Aware of Industry 4.0 - There is a vision or direct statement of Industry 4.0 in business strategy - Industry 4.0 strategy is communicated, spread, and understood - Industry 4.0 strategy keyword is integration and information transparent
People and culture	Functionally dedicated. No digital culture at all.	- Cross-functional cooperation - Cooperation is not structured and continuous - No digital culture	- Cross-functional cooperation - Cooperation is not structured and continuous - No digital culture	- Wider cross-functional cooperation - Cooperation is not structured and continuous - Digital culture initiatives
Customer, products, and service offerings	Product focus instead of customer focus. No Industry 4.0 implementation in service offerings.	- Shift to customer focus - There is innovation in service offerings but not yet Industry 4.0	- Shift to customer focus - Service offerings using internet, paperless, but not all Industry 4.0 characteristics e.g. has not autonomously been	- Shift to customer focus - Service offerings using Industry 4.0 is started (AI chatbot, image processing, etc.)

Dimension/Level	Absence	Existence I	Existence II	Existence III
			connected, etc.	
Information and Technology System	Separated IT architecture, paper/paperless work with less use of internet and/or Industry 4.0. Not one of any Industry 4.0 pillars is implemented.	- Homogenous IT architecture for some departments, not all, no ERP and CPS technology - Some information is accessible cross-departments as needed - Consider the importance of data mining and analysis but not yet been implemented - Paperwork decreased, shifting to cloud - Aware in simulation, VR, AR, 3D printing, robots - Unaware of cybersecurity	- Homogenous IT architecture throughout the company. Has ERP software. - Some has sensors and actuators: IoT enabler - Speedy and information transparent - Start to implement descriptive big data analytic - Paperwork decreased, shifting to cloud - Aware in simulation, VR, AR, 3D printing (implementing one that is feasible and appropriate) - Aware of cybersecurity	- Homogenous IT architecture throughout the company (ERP) - Some has sensors and actuators: IoT enabler - Speedy and information transparent - Start to implement predictive/prescriptive big data analytic - Paperwork decreased, shifting to cloud - Start to implement advance/smart technologies: VR/AR, 3D printing, simulation, or robotics - Aware of and consider to invest in cybersecurity
Value and Supply chain: horizontal and vertical integration	Digitized and automated sub processes. No supply chain 4.0 technology, no integration between partners.	- Vertical digitization - No Industry 4.0 technology to support supply chain flow. Flow is conventional but paperless - No horizontal integration between partners in supply chain	- Vertical digitization and integration - Industry 4.0 technology start to support supply chain flow. Flow is paperless - There is horizontal integration between partners in supply chain: information transparent in inbound or outbound logistics	- Vertical digitization and integration - Industry 4.0 technology start to support supply chain flow. Flow is paperless - Value exchange between partners in horizontal, integrated and transparent in some/all of SCOR processes

4. ANALYSIS

From the previous assessment, known that the most adopted dimensions are: business and strategy, people/employee, culture, IT systems, customer service, products, and market. Thus, the proposed maturity model in this research has five dimensions: business strategy; people and culture; customer, products, and service offerings; information system and technology; horizontal and vertical integration. Meanwhile, the levels are varied. From three up to six existing model levels, the core leveling distinct the “absent” towards the “exist”, the “exist” towards the growing or “survive”, the “survive” towards the upmost performer or “mature”. Therefore, the proposed maturity model has four levels.

However, Indonesia is still grappling with initial implementation, in changes from awareness to real application. It is novel regarding its practical usage specific for manufacturing companies, all sectors, in Indonesia. Thus, the Survival and Maturity level are omitted and replaced by breaking down the Existence into three levels together with the detailed criteria. Still, the generality of the proposed model is kept. Hence, the detailed information of the initial four levels are kept indicated.

5. CONCLUSION AND FUTURE WORK

The goal of this research is to develop a maturity model of industry 4.0, which is developed into an assessment instrument for companies to self-check at which level they have been in this FIR. After an extensive literature review regarding the existing maturity model and mapping out the current technology implementation in some manufacturing companies worldwide, it is obtained that the dimensions in the proposed model are: business strategy; people and culture; customer, products, and service offerings; information system and technology; and value and supply chain: horizontal and vertical integration. Meanwhile, the levels are: Absence, Existence, Survival, and Maturity.

This research comprises of three preliminary stages prior to the field study: pilot survey and model adjustment. The main aim that this proposed model is a self-check assessment instrument can be achieved only after the model revision is finished. Pilot survey is obligatory to validate the ease of use and the relevance to real world industries. Hence, the model can be adjusted to final check whether the questionnaire framework is logic towards the dimension and level proposed, also to check the comprehensiveness and robustness of model seen from the dimension and the defined level, through double validation. After the stages’ completion, it can be widely spread.

6. REFERENCES

ABB Contact. (2014). ‘Connecting the world - Industry 4.0’.

Acatech Study. (2017). *Industrie 4.0 Maturity Index*. Available at: https://www.acatech.de/wp-content/uploads/2018/03/acatech_STUDIE_Maturity_Index_eng_WEB.pdf.

Accenture Labs. (2017). ‘Transforming and Digitizing Maturity Quest’. Available at: https://www.accenture.com/t20170601t203531_w_/cr-en/_acnmedia/pdf-53/accenture-transforming-and-digitizing-maturity- quest.pdf.

Accenture Labs. (2018). *BECOMING A DATA-DRIVEN ENTERPRISE*. Available at: https://www.accenture.com/_acnmedia/pdf- 83/accenture-becoming-data-driven-enterprise-data-industrialization.pdf.

Ackerman, A. and Padilla, A. (2013). *Unilever Targets Growth in Emerging Markets through Analytics*. Available at: https://consumergoods.com/unilever-targets-growth-emerging-markets-through-analytics.

Alt, R., Malzahn, J. and Schmitz, K. (2019). ‘A SURVEY OF INDUSTRIAL INTERNET OF THINGS

IN THE FIELD OF FLUID POWER - BASIC CONCEPT AND REQUIREMENTS FOR PLUG-AND-PRODUCE', pp. 1–11.

Antara, N. T. (2019) *Making Indonesia 4.0*. Jakarta.

Asdecker, B. and Felch, V. (2018). *Development of an Industry 4. 0 maturity model for the delivery process in supply chains*. doi: 10.1108/JM2-03-2018-0042.

BCG. (2019). *Digital Acceleration Index*. Available at: https://www.bcg.com/capabilities/technology-digital/digital-acceleration-index.aspx.

Biegelbauer, G. (2004). 'Sensor Based Robotics for fully automated Inspection of Bores at Low Volume High Variant Parts', (April), pp. 4852–4857.

Boston Dynamics. (2019). *Handle*. Available at: https://www.bostondynamics.com/handle.

Buyya, R. *et al.* (2008). 'Market-Oriented Cloud Computing: Vision, Hype, and Reality for Delivering IT Services as Computing Utilities'.

Canetta, L., Barni, A. and Montini, E. (2018). 'Development of a Digitalization Maturity Model for the manufacturing sector', *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*. IEEE, pp. 1–7. doi: 10.1109/ICE.2018.8436292.

Carayannis, E. and Grigoroudis, E. (2014). 'Linking innovation, productivity, and competitiveness: Implications for policy and practice', *Journal of Technology Transfer*, 39(2), pp. 199–218. doi: 10.1007/s10961-012-9295-2.

Carolis, A. De, Macchi, M. and Kulvatunyou, B. (2017) 'Maturity Models and Tools for Enabling Smart Manufacturing Systems: Comparison and Reflections', pp. 23–35. doi: 10.1007/978-3-319-72905-3.

CGI. (2019). 'Understanding Cybersecurity Standards'.

Chen, M., Mao, S. and Liu, Y. (2014) 'Big Data: A Survey', (January), pp. 171–209. doi: 10.1007/s11036-013-0489-0.

CMMI Institute. (2018). *Build Capability, Drive Performance*. Available at: https://cmmiinstitute.com/.

Colli, M. *et al.* (2018). 'Contextualizing the the outcome of a maturity assessment for Industry 4.0', *IFAC-PapersOnLine*. Elsevier B.V., 51(11), pp. 1347–1352. doi: 10.1016/j.ifacol.2018.08.343.

Connected Production. (2019). *INDUSTRY 4.0 MATURITY TEST*. Available at: https://www.connected-production.de/industrie-4-0- reifegrad-test/#%23step3.

Crimson&Co. (2017). *An Industry 4 readiness assessment tool*. Available at: https://www.crimsonandco.com/wp- content/uploads/2017/10/Industry-4-readiness-assessment-tool-report-Oct-2017.pdf.

Delen, D. and Demirkan, H. (2013). 'Data, information and analytics as services', *Decision Support Systems*. Elsevier B.V., 55(1), pp. 359–363. doi: 10.1016/j.dss.2012.05.044.

Deutsche Telkom. (2018). *Make the Self-Check Now!* Available at: https://benchmark.digitalisierungsindex.de/.

DHL Resilience 360. (2019). *DHL Supply Watch*. Available at: https://www.resilience360.dhl.com/risk-management- products/supply-watch/.

Esmaeilian, B., Behdad, S. and Wang, B. (2016). 'The evolution and future of manufacturing: A review', *Journal of Manufacturing Systems*. The Society of Manufacturing Engineers, 39(April), pp. 79–100. doi: 10.1016/j.jmsy.2016.03.001.

EY. (2019). *Digital Readiness Assessment*. Available at: https://digitalreadiness.ey.com/.

Farooqi, M. M., Shah, M. A. and Wahid, A. (2019). 'Big Data in Healthcare: A Survey Big Data in Healthcare: A Survey', (November 2018). doi: 10.1007/978-3-319-96139-2.

Fisher, C. (2019) *Toyota is using VR to train robots as in-home helpers*. Available at: https://www.engadget.com/2019/10/04/toyota-research-institute-robots-vr-training/.

FlexSim. (2019). *3D Simulation Modeling and Analysis Software*. Available at: https://www.flexsim.com/#clients.

Forrester. (2016). *The Digital Maturity Model 4.0*. Available at: https://forrester.nitro-digital.com/pdf/Forrester-s Digital Maturity Model 4.0.pdf.

Ganzarain, J. and Errasti, N. (2016). 'Three Stage Maturity Model in SME's towards Industry 4.0'.

GEP (2019) *Robotic Process Automation*. Available at: https://www.gep.com/robotic-process-automation.

Gepp, A. *et al.* (2018). 'Big data techniques in auditing research and practice: Current trends and future opportunities', *Journal of Accounting Literature*. Elsevier, 40(May 2017), pp. 102–115. doi: 10.1016/j.acclit.2017.05.003.

GitHub. (2019). *PASTA: Portable Automotive Security Testbed with Adaptability*. Available at: https://github.com/pasta- auto/PASTA1.0.

Gooch, D. *et al.* (2015). 'Reimagining the role of citizens in smart city projects', *UbiComp and ISWC 2015 - Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and the Proceedings of the 2015 ACM International Symposium on Wearable Computers*, pp. 1587–1594. doi: 10.1145/2800835.2801622.

Guo, N. and Leu, M. C. (2013). 'Additive manufacturing: technology, applications and research needs', 8(3), pp. 215–243. doi: 10.1007/s11465-013-0248-8.

Handte, M. *et al.* (2016). 'An Internet-of-Things Enabled Connected Navigation System for Urban Bus Riders', *IEEE Internet of Things Journal*, 3(5), pp. 735–744. doi: 10.1109/JIOT.2016.2554146.

Hansen, S. (2012). *How Zara Grew Into the World's Largest Fashion Retailer*. Available at: http://www.nytimes.com/2012/11/11/magazine/how-zara-grew-into-the-worlds-largest-fashion-retailer.html?pagewanted=all.

Hashem, I. A. T. *et al.* (2016) 'The role of big data in smart city', *International Journal of Information Management*. Elsevier Ltd, 36(5), pp. 748–758. doi: 10.1016/j.ijinfomgt.2016.05.002.

Hua, K. *et al.* (2015) 'Int. J. Production Economics Harvesting big data to enhance supply chain innovation capabilities: An analytic infrastructure based on deduction graph', *Intern. Journal of Production Economics*. Elsevier, pp. 1–11. doi: 10.1016/j.ijpe.2014.12.034.

IHK (2015) *SELF-TEST FOR DIGITAL MATURITY*. Available at: https://ihk-industrie40.de/selbstcheck/.

IMPULS. (2015). *Industry 4.0 Readiness Online Self-Check for Businesses*. Available at: https://www.industrie40- readiness.de/?lang=en.

Inditex. (2015). *Inditex Annual Report 2015*. Available at: http://static.inditex.com/annual_report_2015/en/our-priorities/innovation- in-customer-services.php.

Jæger, B. And Lillebryg, L. (2017) 'The IoT Technological Maturity Assessment Scorecard: A Case Study of Norwegian Manufacturing Companies', pp. 143–150. doi: 10.1007/978-3-319-66923-6.

Javed, A. *et al.* (2016). 'Development of an Internet of Things (IoT) Enabled Household'.

Jónasdóttir, H. *et al.* (2018) 'Upgrading Legacy Equipment to Industry 4. 0 through a Cyber-Physical Interface', 1, pp. 1–8. Kearney (2017) 'Bringing the Fourth Industrial Revolution to Indonesia', *National Seminar Outlook Industry Held by Ministry of Industry*, (December 2017).

Kementerian Perindustrian (2019) *Making Indonesia*. Jakarta. Available at: www.kemenperin.go.id/download/18384.

Kementerian Perindustrian RI. (2019). *Kementerian Perindustrian RI*. Available at: https://kemenperin.go.id/artikel/20814/Produsen-Elektronik-di-Batam-Jadi-Percontohan-Industri-4.0-Tingkat-Dunia.

Khourdif, Y., Alami, A. and Bahaj, M. (2018) 'A new approach for migration of a relational Database into column-oriented NoSQL Database on Hadoop', *Journal of Theoretical and Applied Information Technology*, (November).

Kinaxis. (2018). 'Kinaxis to Provide Supply Chain Management Solutions for Samsung Electronics'. Available at: https://www.kinaxis.com/en/news/press-releases/2016/kinaxis-provide-supply-chain-management-solutions-samsung- electronics.

KPMG. (2017). *Blockchain Maturity Model*.

Kühn, W. (2006). 'Proceedings of the 2006 Winter Simulation Conference L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds.', pp. 1899–1906.

Lee, G. M. (2018). *Advances in Production Management Systems. Smart Manufacturing for Industry 4.0*. doi: 10.1007/978-3-319- 99707-0.

Lee, J., Bagheri, B. and Kao, H. A. (2015). 'A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems', *Manufacturing Letters*. Society of Manufacturing Engineers (SME), 3(December), pp. 18–23. doi: 10.1016/j.mfglet.2014.12.001.

Leyh, C. *et al.* (2017) 'Assessing the IT and Software Landscapes of Industry 4. 0-Enterprises: The Maturity Model SIMMI 4. 0', 1, pp. 103–119. doi: 10.1007/978-3-319-53076-5.

Lidong, W. and Guanghui, W. (2016) 'Big Data in Cyber-Physical Systems, Digital Manufacturing and Industry 4.0', *International Journal of Engineering and Manufacturing*, 6(4), pp. 1–8. doi: 10.5815/ijem.2016.04.01.

Linkx. (2019). *ROBOT PICK AND PLACE UNLOADING FOR UNILEVER*. Available at: https://www.linkxpackaging.com/robot- pick-and-place-unloading-system/ (Accessed: 23 October 2019).

Marr, B. (2018) *The Amazing Ways How Unilever Uses Artificial Intelligence To Recruit & Train Thousands Of Employees*. Available at: https://www.forbes.com/sites/bernardmarr/2018/12/14/the-amazing-ways-how-unilever-uses-artificial- intelligence-to-recruit-train-thousands-of-employees/#1a05daac6274 (Accessed: 23 October 2019).

Mas, A. *et al.* (2017) 'Software Process Improvement and Capability Determination', in.

Mattern, F. and Floerkemeier, C. (2010) 'From the Internet of Computers to the Internet of Things', pp. 242–259.

McKinsey (2015) *Digital Quotient*. Available at: https://www.mckinsey.com/solutions/digital-20-20/our-assessments/strategy. Nestle (2019) 'Nestlé breaks new ground with open blockchain pilot'. Available at:
https://www.nestle.com/media/pressreleases/allpressreleases/nestle-open-blockchain-pilot.

Nott, C. (2014) 'Big Data & Analytics Maturity Model'. Available at: https://www.ibmbigdatahub.com/blog/big-data-analytics- maturity-model.

PINC. (2019). *WAREHOUSE DRONES: REAL-TIME INVENTORY TRACKING BY AIR*. Available at:
https://www.pinc.com/warehouse-drone-inventory-management.

Prumsyl Industry (2019) *Digital Maturity Assessment Company 4.0*. Available at: http://firma4.cz/hodnoceni-digitalni-zralosti- firmy/.

PwC (2015) *Industry 4.0 - Enabling Digital Operations Self-Assessment*. Available at: https://i40-self-assessment.pwc.de/i40/landing/.

RealWear (2018) 'RealWear Announces That Colgate-Palmolive to Roll Out HMT-1 Hands-Free Wearable Computers to 20 Manufacturing Sites in 11 Countries'. Available at: https://www.realwear.com/newsroom/press-releases/colgate-palmolive- press-release/.

Rehman, M. H. U. *et al.* (2016) 'Big data reduction framework for value creation in sustainable enterprises', *International Journal of Information Management*. Elsevier Ltd, 36(6), pp. 917–928. doi: 10.1016/j.ijinfomgt.2016.05.013.

Reiner, T. (2019) *On-pack AR on eco-refill packaging from Unilever*. Available at: https://bp-group.de/en/digital-transformation- on-pack-ar-on-eco-refill-packaging-from-unilever/.

RetailWire (2018) *Robots become the moving force behind Zara's click and collect ops*. Available at: https://www.retailwire.com/discussion/robots-become-the-moving-force-behind-zaras-click-and-collect-ops/.

Rodič, B. (2017) 'Industry 4. 0 and the New Simulation Modelling Paradigm', 50(3). doi: 10.1515/orga-2017-0017.

Samuel, A. L. (1969) 'Some Studies in Machine Learning Using the Game of Checkers. II-Recent Progress', *Annual Review in Automatic Programming*, 6(1), pp. 1–36. doi: https://doi.org/10.1016/0066-4138(69)90004-4.

Sandler, E. (2018) *Zara Stores Target Millennials with Augmented Reality Displays*. Available at: https://www.forbes.com/sites/emmasandler/2018/04/16/zara-stores-targets-millennials-with-augmented-reality- displays/#715c7b102315.

Schneider Electric (2017) *Reality just got better: EcoStruxure Augmented Operator Advisor*.

Schneider Electric (2019) 'Launch of our first Smart Factory in the U.S.' Available at: https://www.schneider- electric.com/en/about-us/press/news/corporate-2019/launch-smart-factory-us.jsp.

Schumacher, A., Erol, S. and Sihn, W. (2016) 'A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises', *Procedia CIRP*. The Author(s), 52, pp. 161–166. doi: 10.1016/j.procir.2016.07.040.

Schumacher, A., Nemeth, T. and Sihn, W. (2018) 'Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises', in *12th CIRP Conference on Intelligent Computation in Manufacturing Engineerin*. Elsevier B.V., pp. 409–414. doi: 10.1016/j.procir.2019.02.110.

Servan, J. *et al.* (2012) 'Assembly Work Instruction Deployment using Augmented Reality', (January 2015). doi: 10.4028/www.scientific.net/KEM.502.25.

Sheth, R. (2019) *How Unilever uses Google Cloud to optimize marketing campaigns*. Available at: https://cloud.google.com/blog/topics/customers/how-unilever-uses-google-cloud-to-optimize-marketing-campaigns.

Siemens (2019) 'MindSphere - The Internet of Things (IoT) Solution'. Available at: https://new.siemens.com/global/en/products/software/mindsphere.html.

Sternad, M. (2018) 'MATURITY LEVELS FOR LOGISTICS 4 . 0 BASED ON NRW ' S INDUSTRY 4 . 0 MATURITY MODEL', pp. 695–708.

Stratasys (2015) *Unilever Leverages 3D Printing Injection Molds, Slashing Lead Times for Prototype Parts by 40%*. Available at: http://investors.stratasys.com/news-releases/news-release-details/unilever-leverages-3d-printing-injection-molds-slashing-lead (Accessed: 22 October 2019).

The Verge (2018) *Apple confirms it now uses Google Cloud for iCloud services*. Available at: https://www.theverge.com/2018/2/26/17053496/apple-google-cloud-platform-icloud- confirmation.

Tideman, M., Mascha C. van der Voort and Houten, F. J. A. M. van (2008) 'A new product design method based on virtual reality, gaming and scenarios', pp. 195–205. doi: 10.1007/s12008-008-0049-1.

Toyota (2015) *THUMS*. Available at: https://www.toyota-europe.com/world-of-toyota/articles- news-events/2016/thums. Uriarte, A. G. *et al.* (2017) 'Lean, Simulation and Optimization : A Maturity Model', pp. 1310–1315.

Ustundag, AlpCevikcan, E. (2018) *Industry 4.0: Managing the Digital Transformation*. Edited by D. T. Pham. Istanbul: Springer International Publishing. doi: 10.1007/978-3-319-57870-5.

VDMA (2016) *Industrie 4.0 in practice –Solutions for industrial applications*.

Wang, G. *et al.* (2016). 'Big data analytics in logistics and supply chain management: Certain investigations for research and applications', *International Journal of Production Economics*. Elsevier, 176, pp. 98–110. doi: 10.1016/j.ijpe.2016.03.014.

Wang, L., Törngren, M. and Onori, M. (2015) 'Current status and advancement of cyber-physical systems in manufacturing',
Journal of Manufacturing Systems. The Society of Manufacturing Engineers. doi: 10.1016/j.jmsy.2015.04.008.

Wang, S. *et al.* (2016). 'Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination', *Computer Networks*, 101, pp. 158–168. doi: 10.1016/j.comnet.2015.12.017.

World Economic Forum (2015). *The Global Competitiveness Report 2015-2016*, *World Economic Forum*. Edited by K. Schwab.
Geneva. doi: 92-95044-35-5.

World Economic Forum. (2016). *The Global Competitiveness Report 2016–2017*. Geneva. doi: 10.1080/11263507809427944. World Economic Forum (2017) *The Global Competitiveness Report 2017-2018*, *World Economic Forum*. Edited by K. Schwab.
Geneva. Available at: http://www3.weforum.org/docs/GCR2017-2018/05FullReport/TheGlobalCompetitivenessReport2017– 2018.pdf.

World Economic Forum. (2018). *The Global Competitiveness Index 4.0 Report 2018*. Geneva. Available at:
http://www3.weforum.org/docs/GCR2018/05FullReport/TheGlobalCompetitivenessReport2018.pdf.

World Economic Forum. (2019). *The Global Competitiveness Index 4.0 Report 2019*, *World Economic Forum*. Edited by K. Schwab. Geneva. doi: ISBN-13: 978-92-95044-73-9.

Xu, X. (2012) 'Robotics and Computer-Integrated Manufacturing From cloud computing to cloud manufacturing Ubiquitous Product Life cycle Support', *Robotics and Computer Integrated Manufacturing*. Elsevier, 28(1), pp. 75–86. doi: 10.1016/j.rcim.2011.07.002.

Zhong, R. Y. *et al.* (2016) 'Big Data for supply chain management in the service and manufacturing sectors: Challenges, opportunities, and future perspectives', *Computers and Industrial Engineering*. Elsevier Ltd, 101, pp. 572–591. doi: 10.1016/j.cie.2016.07.013.