ISSN 1846-6168 (Print), ISSN 1848-5588 (Online)
https://doi.org/10.31803/tg-20200523195016

Preliminary communication

Industry 4.0 Readiness Assessment: Comparison of Tools and Introduction of New Tool for SME

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Abstract: This research aims to establish an assessment tool for assessing the readiness of small and medium enterprises (SME) in industry 4.0. The assessment of the current and future status is crucial for companies to decide on the right strategy and actions on the road to a digital company. First will be compared existing tools such as: IMPULS (VDMA), PwC and Uni-Warwick. On that basis, a tool for SME will be introduce. The tool has 12 categories: data sharing, data storage, data quality, data processing, product design and development, smart material planning, smart production, smart maintenance, smart logistic, IT security, machines readiness and communication between machines. Those categories are grouped into three: data, software and hardware. Each category has five levels of readiness (from 1 to 5), with particular criteria that refer to literature studies and expert's opinion.

Keywords: data exchange; digitalization; hardware; Industry 4.0; SMEs; software

1 INTRODUCTION

In last past years, several assessment tools have been created by researchers from university, consultant company, and government institution. The tools can help companies to measure, how ready they are in facing industry 4.0. Each assessment tool has different dimensions of measurement, it depends on the focus and object of research. In this paper, three existing assessment tools (IMPULS, Uni-Warwick, and PwC tools) will be reviewed, and used as basis for establishing new assessment tool which more focus on Small Medium Enterprise (SME). The selection of SMEs, is encouraged by the fact that SMEs as engine growth of global economic, have lack understanding about industry 4.0. With the new assessment tool, SME can assess their current position and determine next step or future target in industry 4.0.

2 LITERATURE REVIEW

2.1 Small Medium Enterprises

Many studies have explained that SMEs play an important role in national economy, they have employed many people and become the engine growth of economic [1], [2], [3]. The definition of SMEs is diverse for each country, the European Commission defines small medium enterprises (SMEs) as company which employ less than 250 employees and have turnover up to 50 million/year [2]. While in Germany, SMEs are defined as companies that have less than 500 employees [4].

The SME is characterized by limited resources (skilled workers, infrastructure and budget), however the flexibility of decision making is relative easier and faster compared to large companies, because the bureaucratic path is short and relies on few people.

2.2 Industry 4.0 and Its Benefit

The fourth industrial revolution or I4.0 was first initiated by a group of business people, academics and German government in 2011. By definition, Industry 4.0 is the collective strategy of company which equip their business process, especially production process with digitalization, internet of thinking, cyber physical systems (CPS), and smart factory to present real time synchronization of business and production flows [5]. However, this definition is not the only one, there are still multiple of definitions and none of them are used as common references [6].

The application of Industry 4.0 has three main goals: shortening time to market, increasing flexibility, and boost efficiency [7], [8]. With achievement those goals, the benefits of I4.0 can be felt by company as well as national economy. In Germany, the adoption of I4.0 has increased 25% of company's efficiency and contribute around 1% / year to Gross Domestic Product (GDP) over 10 years as well as create 390,000 new jobs [9].

3 RESEARCH METHODOLOGY

This research leads to two objectives: comparing the existing tool and establishing a new tool which focus on SMEs. Before comparing existing tools, the author will determine the most relevant categories / dimensions for SMEs. The tool that assess those categories will be scored as (1). While, the tools that do not assess them, will be scored as (0). After all the tools have been scored, the sum of score (each tool) will be divided by the number of relevant categories/dimensions (see Eq. (1)). The tool which has highest assessment index AI (Tool 3) is the most suitable tool for measuring SMEs readiness in industry 4.0 (see Tab. 1 as illustration).

$$Assessment\ Index = \frac{\sum Score\ of\ Tool}{Number\ of\ Relevant\ Categories} \quad (1)$$

In order to provide a complete picture of the existing tools, the author conducts a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis for each tool. With

SWOT analysis, the "internal" strength and weakness and the "external" market driven opportunities and threats of each tool will be made transparent. This is important as a basis for establishing new assessment tool.

Table 1 The illustration of comparison method

Category	Tool 1	Tool 2	Tool 3
Category A	1	0	1
Category B	1	1	1
Category C	0	0	1
∑ Weight	**2**	**1**	**3**
Assessment Index	**0,67**	**0,33**	**1**

Table 2 The illustration of SWOT analysis

Strengths (internal) *What the focus of Tool* *What the unique thing, that available*	**Weaknesses (internal)** *What must be improved* *What common thing, that not available*
Opportunities (external) *How can the strengths of tool turn into opportunities*	**Threats (external)** *What threats could harm the tool*

4 RELEVANT CATEGORIES FOR SME

In establishing a new assessment tool that focuses on SMEs, it is necessary to determine relevant categories that can measure the I4.0 readiness appropriately. The determination of categories must be objective and supported by sufficient arguments. Those can be obtained by literature study, expert opinion, and field observations.

Similar to the house construction, the implementation of industry 4.0 must be supported by at least three readiness pillars, namely: Data, Hardware, and Software. Therefore, the categories of I4.0 readiness will be clustered by those three.

4.1 Data

The company data can be likened as blood in the human body. It must be protected and able to flow smoothly. Therefore, all blockages and constriction that interrupt the data flow must be removed immediately. Otherwise, it will disturb the entire business process and gradually destroy company's reputation. The "**Data**" cluster can be divided into 4 categories: Data sharing, Data Quality; Data Processing and Data Storing.

The use of data as basis for company decision-making process, becomes more intense in the digitalization era (I4.0). The data has become a valuable commodity [10], where many companies hang their fate on data availability. A data must have good quality. The quality of data can be measured by 15 dimensions: accessibility, ease of maintenance, reputation, accuracy, objectivity, credibility, comprehensiveness, constituent interpretability, consistent representation, clarity, relevance, reasonable scope, completeness, value added and timeliness [6], [11].

The intensity of sharing, processing and storing data does not depend on the size of company, but it depends on number of stakeholders which involved to company. Sometimes small and mid-sized companies are more active than larger companies. In the context of security, data sharing activity always brings risk, it becomes hacker`s way to attack the system, therefore data sharing management is absolute necessary for securing system [12].

4.2 Software & Process

Digitalization is the key word in industry 4.0, without digitalization in business processes (product development, production, logistic and others), the company will never turn on industrial 4.0. The digitalization in SMEs will bring some beneficial functions, such as; overcoming fluctuated customer`s demand, smoothing internal and external information flow, accelerating decision making processes and others [13]. Therefore, digital transformation on SMEs is necessary and it must be supported by software that appropriate to requirements and budget of company. In the product development, SMEs are encouraged to use software that is not focused on Product Data Management (PDM) only, but also on Product Lifecycle management (PLM), where the life cycle of a product, from its birth until it is recycled or destroyed, must be well managed.

The second pillar (Software & Process) consists of categories: product design & development, smart material supply, smart production, smart maintenance, and smart logistics. These categories reflect the processes in SMEs that require software support. The software will increase the added value and competitiveness of products through process efficiency.

4.3 Hardware

The biggest obstacle to apply Industry 4.0 in SMEs is unpreparedness hardware (computer, machines, robot, server, and material handling) and IT security, because every replacement and modification of hardware and IT security system require high investment cost. Therefore, those are important parameters for measuring SMEs readiness in Industry 4.0.

Hardware readiness, not only measured by their compatibility, but also the interface and communication infrastructure between them. For example, hardware can be ready individually, but when it is paired to the other or integrated into company system, the hardware will have problems. Therefore, the third pillar will consist of categories: hardware readiness, communication between hardware and how to secure information and data placed in hardware from unauthorized person, hacker and external infiltration (IT Security and Data protection). Data protection and IT security especially for electronic transactions must be a serious concern for SMEs. The use of hardware and software that supports digital signatures, biometric data, ledgers (hardware wallet), smart contracts and block chain technology, must be balanced with the needs and financial capabilities of SMEs [14, 15].

5 OVERVIEWS OF THE EXISTING TOOLS

5.1 IMPULS (VDMA)

In 2015, VDMA sponsored a study to build assessment tool for measuring German company's readiness toward industry 4.0, the assessment tool is designed with simple,

user-friendly and effective principles that allow companies to conduct by their self.

The IMPULS's tool measures six dimensions, namely: strategy and organization, smart factory, smart operations, smart-products, data-driven services, and employees. Each dimension has several sub-dimensions, which explain detail measuring. The company's readiness will be explained by six levels, it is started from level 0 to 5. The level 0 is called outsider, where company does not apply digitalization at all. The level one is beginner level, where the company start to digitalize their business process and adopt industry 4.0 principles. The next levels are: level 2 intermediate, level 3 experienced, level 4 expert, and level 5 top performer, where industry 4.0 is already unified with company's culture [16].

5.2 Uni-Warwick

This assessment tool was developed by Warwick University in collaboration with Crimson & Co and Pinsent Masons. The main objective of this tool development is to provide a simple and intuitive way for companies to measure their readiness as well as their future ambitions in digitalization era.

There are six dimensions of measurement which include; products and services, manufacturing and operations, strategy and organization, supply chain, business model and legal considerations. What's interesting about this tool is, there are special dimensions which never encountered in other assessment tools. Those dimensions are supply chain and legal consideration. In the supply chain there are 4 sub-dimensions, namely; inventory control using real-time data management, supply chain integration, supply chain visibility, supply chain flexibility and lead times. While, in the legal consideration dimension, there are 4 sub dimensions, namely; contracting models, risk, intellectual property and data protection. Unlike the IMPULS's tool, each dimension of Warwick's tool is measured by 4 levels of readiness, namely level 1 beginner, level 2 intermediate, level 3 experience and level 4 expert [17].

5.3 PricewaterhouseCoopers PwC

PwC views the assessment tool that they built is not only as a tool to assess the readiness of company but also as the future planning anchor, toward industry 4.0. The tool consists of 7 dimensions: Digital business models and customer access; Digitisation of product and service offerings; Digitisation and integration of vertical and horizontal value chains; Data and analytics as core capability; Agile IT architecture; Compliance, security, legal and tax; and Organisation employees and digital culture. Each dimension consists of four levels readiness, start from digital novice, vertical integrator, horizontal collaborator, and digital champion.

The unique point of PwC tool is, there is dimension of compliance, security, legal and tax. This dimension measures company compliance in facing the challenges of digitalization, such as security, legal, and taxation. The readiest company in industry 4.0, is the company that most comply to various regulations of I4.0 such as data protection, taxation and other legal aspects [18].

6 THE COMPARISON OF EXISTING TOOLS

Before comparing the existing tools, it should be emphasized that, this section is not intended to find the best tool, but to provide references for new assessment tool creation, which focused on SMEs.

The SWOT analysis (Tab. 3) shows that IMPULS tool is superior in the number of dimensions and categories that relevant to SMEs, while PwC can present the more attractive graphic or design of online self-assessment.

Table 3 SWOT analysis

IMPULS (VDMA)	
Strengths	+ Available Online self-assessment https://www.industrie40-readiness.de/?lang=en + Description of dimensions / categories and its level are clear and understandable + Many dimensions / categories that are relevant for SMEs + Proven to survey around 200 companies in Germany + The questions in online assessment are clear
Weaknesses	– Presentation of online-assessment is clear, simple but not as interesting as the PwC tool – Dimensions and categories are too focused on the manufacturing industry.
Opportunities	Higher possibility to be used by SMEs through measuring relevant dimensions
Threats	Open Online assessments can affect survey statistics (if a survey is conducted)
PwC	
Strengths	+ Available Online self-assessment https://i40-self-assessment.pwc.de/i40/interview/ + The presentation of on-line assessment is clear, simple and eye-catching + The questions in online assessment are clear + Proven to survey 2000 companies in 26 countries
Weaknesses	– Description of dimensions / categories and its level difficult to understand – Complicated for SMEs, due to many irrelevant sub-dimensions' measurement – Dimensions and categories are too focused on the digital business.
Opportunities	The possibility to be used by SMEs through measuring relevant dimensions
Threats	Open Online assessments can affect survey statistics (if a survey is conducted)
Uni-Warwick	
Strengths	+ Measuring the company readiness with a broadly dimensions (Products and services, Manufacturing and operations, Strategy and organisation, Supply chain, Business model and Legal considerations) + Description of dimension and its level are clear and understandable + Proven to survey 53 companies in 22 countries
Weaknesses	– Not available online self-assessment – Complicated for SMEs, due to many irrelevant sub-dimensions' measurement
Opportunities	The possibility to be used by SMEs through measuring relevant dimensions
Threats	The company's reluctance to use this tool, due to difficulty of self-assessment (not available online)

Uni-Warwick tool can capture many readiness aspects of the company, which reflected in many measurement

dimensions / categories. However, the consequences of it, makes Uni-Warwick tool, look complicated. In addition, Uni-Warwick tool is not available in open access online, so companies must judge and calculate the result manually, based on the description of each level in each dimension. All the facts above can make Uni-Warwick tool less attractive then other assessment tool.

From the comparison above it can be seen that the measurement dimensions in the IMPULS tool are most appropriate for measuring the readiness of SMEs in Industry 4.0, this is indicated by the high value of assessment index. This fact is reasonable, considering the economic and industrial structures of Germany which dominated by SMEs, may also influences the perspective of IMPULS tool creator in determining dimensions and categories

Based on the comparison and SWOT analysis, the new assessment tool must meet the requirements:

- The tool must be able to measure SME readiness in industry 4.0, through the relevant categories.
- The tool must be accompanied by a practical guideline which contains different readiness levels
- The categories and their levels must be defined properly, so that companies are able to know their current status and future step in I4.0.
- The description of each category and each level must be clear and understandable.
- The assessment tool must available online to facilitate companies in conducting self-assessment.
- The presentation of online assessment must be clear and eye-catching.
- The questions in online assessment must be clear, simple and understandable

By considering those requirements, the new assessment tool is created with categories and readiness level as level as seen on Tab. 4.

Table 4 Comparison tools with relevant categories for mid-size company

Category	IMPULS (VDMA)	PwC	Warwick
Data			
Data sharing	1	0	0
Data Quality	1	0	1
Data Processing	1	1	1
Data Storage	1	0	1
Software			
Product development	1	1	1
Smart Material supply	0	0	1
Smart Production	1	1	1
Smart Maintenance	0	0	0
Smart Logistic	1	1	1
IT Security	1	1	1
Hardware			
Hardware readiness	1	0	0
HMI or M2M Interface	1	1	1
∑ Weight	**10**	**6**	**9**
Assessment Index	**0,833**	**0,5**	**0,75**

Table 5 New assessment tool

Categories		Level	Description
Data	Data quality	I	No Activity
		II	Clear Responsibility
		III	Effort known + Benefit analysed
		IV	KPI (Key Performance Indicator) defined
		V	Continuous Improvement for Data
	Data sharing	I	No Data sharing
		II	Data is exchanged between the individual devices within the department
		III	The machines and computers in the company can communicate with each other without barrier
		IV	Company-wide sharing (across locations)
		V	Cross-company use (between companies)
	Data processing	I	No Activity
		II	Define standard data format The effort and benefit for all report are known, The biggest waste and idle time are known Selection of processes & data for automation (RPA)
		III	Define "lead software" for data input Determine primary system for data analysis Identification the relevant signal process Selection of Robotic Process Automation (RPA) software
		IV	Define central data storage Create instructions and rules for data entry Optimization the signal process Analysis and description of processes and data flow to implement RPA
		V	Open access for all software to central data storage Continuous improvement of data processing (reporting + production process) Application of RPA
	Data storage	I	The data is stored in the respective machine or PC
		II	The data is stored on the server of the local department
		III	The data is stored on the company server
		IV	Simple cloud technology for data storage
		V	Advanced and optimized use of cloud technology for storage
Software	Product design and development	I	The software is only used to create 2D drawings or 3D models on CAD
		II	Additional technical calculations, simulations and analyses are carried out using software.
		III	Implementation of automated cost calculation software and the use of 3D printing to speed up testing, trial and decision-making
		IV	Integration software and implementation of product data management (PDM) and product lifecycle management (PLM)
		V	The use of Digital Twin technology for the development of complex products
	Smart material planning	I	Start to develop material planning
		II	Applying the refill strategy and MRP software for material planning
		III	Optimization of delivery planning by evaluating the KPIs of suppliers
		IV	the automation of administrative processes in material planning by RPA
		V	Connecting material planning with suppliers
	Smart production	I	Planning is not done by Excel (not special software)
		II	Use of PPS (production planning and control) software but not integrated yet to other software
		III	Creating an interface between CAD and PPS, defining data standards and applying lean principles to avoid waste

Table 5 New assessment tool (continuation)

Categories			Level	Description
Software			IV	Introduction of production data acquisition with MES and SCADA software
			V	Integrate PPS system into the ERP system
	Smart maintenance		I	Start to develop of manual maintenance planning
			II	Identification of critical components
			III	The using of sensors for monitoring critical components and introduction of KPI
			IV	The using of software to evaluate sensor data and for maintenance planning (predictive maintenance)
			V	Connecting the maintenance software with the ERP software
	Smart logistic		I	Traditional logistics system
			II	Use of Microsoft Office for a simple logistics system
			III	Introduction of route planning and a logistics information system
			IV	KPI evaluation and optimization of the logistics system
			V	Excellent logistics system with state-of-the-art IT (e.g. 5G network) and complete automation (AGVs, electric floor conveyors and automated high-bay warehouses)
Hardware	Machines readiness		I	Know critical process parameters
			II	Know the status of the control and sensors of the machines
			III	Sensors and control (hardware) for process optimization available for individual machines
			IV	Sensors and control (hardware) for process optimization available on all machines
			V	Hardware (machines, robots and computers) for process optimization with AI available
	Machine communication		I	The machines do not communicate at all
			II	Individual machines are networked together or via a central computer
			III	The use of Object linking and Embedding (OLE) for process control
			IV	The application of Open Platform Communications (OPC UA)
			V	All machines are networked with each other and OPC UA has been introduced across the board
	IT security		I	Password & user-name
			II	Initiate exchange information and add device´s ID for accessing
			III	Encryption and Decryption the exchanged data
			IV	Data security and digital transaction efficiency through Digital Signature, Biometric data, Ledger (hardware wallet), Smart Contract and Block Chain technology
			V	Continuous monitoring & Security Analytic

7 CONCLUSIONS

The present three assessment tools (IMPULS, PwC and Uni-Warwick) can be used to measure a company's readiness towards industry 4.0, but none of them focuses on SMEs. If the three are compared, the IMPULs tool is the nearest appropriate assessment tool for SMEs, because it contains many dimensions or categories that are relevant and needed by SMEs such as; data sharing, data storage, data quality, data processing, product design and development, smart material planning, smart production, smart maintenance, IT security, hardware readiness and hardware interface.

Establishing an assessment tools for SMEs, must meet requirements such as; the tool must contain relevant categories and accompanied by a practical guideline, the categories and levels must be defined and described clear and understandable, the tool must be available online with eye catching presentation and simple questions.

Notice

The paper will be presented at MOTSP 2020 – International Conference Management of Technology – Step to Sustainable Production, which will take place from 30th September – 2nd October 2020 in Bol, island Brač (Croatia). The paper will not be published anywhere else.

8 REFERENCES

[1] Herr, H. & Nettekoven, Z. M. (2017). The Role of Small and Medium-sized Enterprises in Development What Can be Learned from the German Experience? 11, 2017. Available: https://library.fes.de/pdf-files/iez/14056.pdf. (Accessed on 15.01.2020).

[2] European Commission. (2016). User guide to the SME Definition. 24.02.2016. Available: https://tinyurl.com/wp5ursr. (Accessed on 15.01.2020)

[3] The International Labour Office. (2015). Small and medium-sized enterprises and decent and productive employment creation. in *International Labour Conference, 104th Session, 2015*, Geneva.

[4] The Institut für Mittelstandsforschung (IfM). (2016). KMU-Definition des IfM Bonn. Available: https://www.ifm-bonn.org/definitionen/kmu-definition-des-ifm-bonn/.

[5] Hofmann, E. & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry,* 89, 23-34. https://doi.org/10.1016/j.compind.2017.04.002

[6] Luenendonk, M. (2017). Industry 4.0: Definition, Design Principles, Challenges, and the Future of Employment. Available: https://www.cleverism.com/industry-4-0/. (Accessed on 6 May 2019).

[7] Helmrich, K. (2015). *On the Way to Industrie 4.0: The Digital Enterprise*. Siemens AG, Hannover.

[8] Axmann, B. (2016). Digitalisierung der Fabrik – Industrie 4.0 Motivation, Herausforderungen und Lösungen. *ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb,* 111, 143-147. https://doi.org/10.3139/104.111487

[9] Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., & Harnisch, M. (2015). *Industry 4.0: The Future Productivity and Growth in Manufacturing Industries*. The Boston Consulting Group, Munich,

[10] Dixon, H. (2019). Data now as important a commodity as oil, leading QC says. The Telegraph, 07.01.2019. Available: https://tinyurl.com/y8ho3g2r. (Accessed on 21.01.2020).

[11] Axmann, B., Werner, H., & Liegl, T. (2019). Digitalisierung der Fabrik – Datenqualität als Schlüssel zum Erfolg Welchen Wert haben Daten? *ZWF - Zeitschrift für wirtschaftlichen Fabrikbetrieb,* 114, 302-305. https://doi.org/10.3139/104.112083

[12] VDMA. (2017). *Sharing the future – Industrial Data*. VDMA European Office, Berlin.

[13] Fischer, M., Imgrund, F., Janiesch, C., & Winkelmann, A. (2018). *Approaching Digitalization with Business Process Management*. Lüneburg,
[14] Ilbiz, E. & Durst, S. (2019). The Appropriation of Blockchain for Small and Medium-sized Enterprises. *Journal of Innovation Management,* 26-45. https://doi.org/10.24840/2183-0606_007.001_0004
[15] European Union Agency for Network and Information Security. (2016). *Guidelines for SMEs on the security of personal data processing*. Dec 2016. Available: https://tinyurl.com/yc7sj9rq. (Accessed on 2 May 2020). https://doi.org/10.1016/S1353-4858(16)30082-4
[16] Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M. (2015). *Industrie 4.0 Readiness*. VDMA, Aachen.
[17] Agca, O., Gibson, J., Godsell, J., Ignatius, J., Davies, C. W., & Xu, O. (2017). *An Industry 4 readiness assessment tool*. University of Warwick, Warwick.
[18] Geissbauer, R., Vedso, J., & Schrauf, S. (2016). *Industry 4.0: Building the digital enterprise*. PwC, Munich.
[19] Bernhard, A. & Harmoko, H. (2020). *Der Industrie 4.0 Leitfaden für KMU - Die erste Bereitschaftssäule: Daten*. *ZWF- Zeitschrift für Wirtschaftlichen Fabrikbetrieb,* 1-4, 01.02.2020.

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