

Measurement of Smart Technology Capability for Manufacturing Fields in a Smart Technology Environment

Chui Young Yoon

Abstract—In a smart technology world, manufacturing fields have established their smart technology environment appropriate for its manufacturing fields in order to reinforce its manufacturing efficiency and competitiveness. The smart technology ability of manufacturing fields is very crucial for the innovative production and operation activities, and for efficient enhancement of the manufacturing performance. A scientific measurement framework has been asked to efficiently gauge smart technology capability of manufacturing fields in order to effectively manage and enlarge its smart technology capability. The developed measurement scale for smart technology ability of manufacturing fields is verified by reliability analysis and factor analysis based on previous literature. This study presents an 11-item measurement tool that can examine the smart technology capability of manufacturing fields in a smart technology environment.

Index Terms—Smart technology, smart technology capability, measurement factor and item, measurement tool.

I. INTRODUCTION

With advanced change of science and technology, the rapid development of information technology (IT) has affected whole areas of industries. Especially in manufacturing industry, it helps enterprises deal with various requirements of customers and frequent variations of manufacturing environment [1]. World experts present that the fourth industrial revolution brings big changes and growth in manufacturing fields [2]-[4]. Globalization, unpredictable markets, increased products customization and frequent changes in products, production technologies and machining systems have become a complexity in today's manufacturing environment [5]. Manufacturing industry of the future will be characterized by the smart factory, smart product, and smart service [6].

Manufacturing fields has utilized diverse IT for efficient production activities and innovative operation performance in manufacturing fields. Manufacturing fields also have built smart technology environment to increase its production works and productive performance, and to strengthen its industrial competitiveness in a global industry environment. It is applying smart technology to the production plan, production activities, production management, and product

service activities to improve their manufacturing activities performance. Smart technology is a crucial mediator to control and upgrade a manufacturing productivity in continuous changing industry environment. In this manufacturing environment, smart technology is an important resource for future advanced manufacturing environment. It is indispensable for widely applying smart technology to all manufacturing activities. We have to systematically build smart technology environment to manage and improve reasonable manufacturing capability appropriate for its manufacturing works and performance. That is, we have to control its smart technology capability with a scientific and practical measurement scale in order to effectively build and improve a smart technology environment appropriate for the manufacturing fields. The measurement tool of objective criteria should build up smart technology capability of manufacturing fields based on the measurement results of smart technology ability for them. However, previous studies have not researched a measurement framework related to a smart technology capability of manufacturing fields. We need a reasonable framework that can effectively gauge a smart technology capability of manufacturing fields. This research develops a practical instrument that can objectively measure the smart technology capability of manufacturing fields.

Therefore, this study presents a structural tool that can efficiently measure a smart technology capability of manufacturing fields (STCMF) to effectively perform their manufacturing activities and to systematically improve their smart technology capability in a smart technology perspective.

II. RELATED RESEARCH

New technologies and methods have been researched for the next stage of manufacturing fields. Numerous researches in manufacturing fields to achieve an intelligent manufacturing have been reported in the literature [5]. The research area can be presented as follows: Technologies for the advanced information systems such as networked process planning, industrial network, inheritance of data, and information and communication technology (ICT) for industry [5]; Evolvable hardware/software such as integration of industrial systems, intelligent diagnosis, effective maintenance for equipment and system, hi-tech machinery industry and intelligent sensors [5]; Innovative systems for intelligent manufacturing to flexibly and quickly adapt to new challenges of manufacturing environment [5].

In smart technology of manufacturing industry, smart factory includes smart products (smart service), smart data (big data and machine learning), and smart operation

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(human-technology-integration) in trustworthy cloud infrastructures [7]. It can be explained as an extended version of process innovation to continuously improve the existed process based on collection of data and control of process in real time [7]. Korea Ministry of Trade, Industry and Energy presented the eighteen-detailed technologies of four domains (application, platform, device and network, and interactive operability and security) as smart factory technology development roadmap [8]. Application technology generally includes human-centered work support technology, smart factory integration operation and service technology, and smart retailing and procurement logistics technology. Platform technology indicates big data analysis, cloud systems, cyber physical systems, factory resource modeling and simulation, and production process control technology. Device and network technology presents cognitive smart sensor technology, industrial gateway technology, and smart factory network technology. Interactive operability and security technology refers to smart factory standardization technology, software reliability and security, and data protection and remote control technology [8].

Manufacturing fields are satisfying the diverse needs of customers through reducing product cost, high quality of manufactured goods, and shortening period of delivery and development of products with IT solutions for firms such as ERP (Enterprise Resource Planning), SCM (Supply Chain Management), and PLM (Product Lifecycle Management) [9]. Furthermore, through complete fusion of manufacturing industry and ICT, the existing factories will be changed into perfect smart factories in which not only automated production but also control and maintenance of overall processes and safety management are possible [10], [11]. Smart manufacturing system is a manufacturing system to produce high value products and to build a smart factory, based on various ICT technologies for real-time monitoring, sensor networking, and facility condition diagnosis and equipment operation [12]. To establish a smart manufacturing factory, the equipment in a manufacturing factory is required to be connected with various elements and services in and out of the factory [13]. Smart factory technology is classified by ICT as industrial control systems, MES, ERP, PLM and field device technology as industrial network, RFID systems, industrial robot, and control devices [14].

In previous literature of smart factory solutions, researches have presented solution departments of smart factory as factory field automation, factory operation and optimization in real time, production and process development, optimization of supply chain management, and enterprise resource management [15]-[18]. Finally, the smart technology of manufacturing fields can be explained as smart technology related to smart production, smart data, and smart operation in terms of the efficiency of product production, efficient demand response, and satisfaction of customer service.

With exploring previous literature and this research results, we define the smart technology capability of manufacturing fields (STCMF) as the total smart technology capability that manufacturing fields have to retain to efficiently support for smart production, smart operation, and smart service in terms of a smart technology of manufacturing fields. This research finds the first measurement items for STCMF based on the

definition of STCMF and previous studies related to smart technology of manufacturing fields.

III. RESEARCH METHOD

A. Outline

Our research firstly generated a list of 23 measurement items for STCMF based on definitions and components of smart technology capability of manufacturing fields [5]-[18]. This research investigated the construct validity of the developed measurement items to ensure that the measurement items efficiently gauge STCMF. We examined that the measurement framework had a suitable operational definition of the construct. To investigate reasonable construct of the measurement tool for STCMF, this research utilizes a verification method presented in previous literature. Many previous studies provided various methods to verify the validation of a model construct [19]-[23]. Generally, most studies present two methods to verify a model construct validation: correlations between total scores and item scores; and factor analysis [19]-[23]. The former assumes that the total score is valid, and the extent to which the item correlates positively with the total score is indicative of the construct's validity for the items [20], [21]. Each item score was subtracted from the total score to exclude spurious part-whole correlation [19], [23]: the result was a corrected item-total correlation that was then correlated with the item score. Factor analysis examines the underlying structure or components of the framework [20], [21]. It helped identify factorally pure items that would facilitate more specific hypothesis tests, and identify the components that make up the total measure [21], [23]. The factor-analyzed items were selected, because they were closely related to each other.

Our research also verified a measurement scale of criterion-related validity to identify measurement items that may not be closely concerned with STCMF. The generalized item for efficiently measuring STCMF was utilized as a criterion measurement scale. This scale presented a measurement framework of criterion-related validity to the extent that each measurement item was correlated with this. Measurement items should present a favorable or unfavorable attitude toward the object in question [21]. When the measurement item is ambiguous or shows a neutral attitude, we should delete it [21]. This research analyzed a measurement scale of criterion-related validity to identify measurement items that did not show favorable or unfavorable attitudes. We found all of the measurement items in a measurement scale from the domain of a single construct, and responses to these indicator items should be highly inter-correlated. The corrected item-total correlation refers to a measurement scale of this.

In our questionnaire survey, the measurement questionnaire used a five-point Likert-type scale as presented in previous studies; denoting, 1: not at all; 2: a little; 3: moderate; 4: good; and 5: very good. We carried out our measurement questionnaire for various companies in manufacturing fields. The questionnaire consists of three main sections. The first section represents the backgrounds and objectives, the main contents, and response methods of

this questionnaire. The second section asks respondents to provide general information, such as manufacturing departments and position, firm's size and revenue, and business history of their firms. The last section presents the measurement items for the respondents in manufacturing fields. This research collected questionnaire data from a variety of manufacturing fields so that the measurement results can be generalized. We used two kinds of survey methods: direct collection and e-mail. The respondents either directly mailed back the completed questionnaires or research assistants collected them three-four weeks later. The collected questionnaires indicated 36.9 percent of all the target respondents.

B. Sample Characteristics

This questionnaire survey obtained 131 responses from 355 target respondents in four manufacturing fields. The responses presented a variety of manufacturing fields and position, firm size and revenue, and business history. We excluded five incomplete or ambiguous questionnaires, leaving 126 usable questionnaires for statistical analysis. The respondents in terms of manufacturing departments were classified as electrical and electronics (23.8%), machine (21.4%), chemistry (19.8%), and food and beverage (35.0%). The positions of respondents were identified as top manager (7.1%), middle manager (36.5%), and worker (56.4%). The respondents in four manufacturing areas had on average 8.6 years' experience (S.D. =1.06) in their manufacturing fields, their average age was 36.7 years old (S.D.=5.83), and their gender, male (69.8%) and female (30.2%). This research performed our questionnaire survey focused on various manufacturing fields, and respondents with various experience within manufacturing fields. Namely, it is to get the reasonable and objective analysis results from this questionnaire survey.

C. Analysis and Discussion

Our research picked out the analysis results from the collected questionnaires. The measurement items were excluded when their correlation with the corrected item-total correlation was < 0.5 or when their correlation with the criterion scales was < 0.6 [20], [21]. The correlations with the corrected item-total correlation and the criterion item were significant at $p \leq 0.01$ and similar to those used by others in previous research [19], [21], [22]. We used factor analysis to verify the validity of the developed measurement framework and measurement items.

This study also executed factor analysis to identify the underlying factors or components that consist of the STCMF construct. We excluded inadequate items for the measurement tool based on the factor analysis results. This research considered sufficiently high criteria to extract reasonable measurement items of STCMF. Hence, the first 23 measurement items resulted in a 15-item scale prior to conducting factor analysis. The sample of 126 responses was investigated by using principal components analysis as the extraction technique with the varimax method of rotation. The measurement items with many multiple loadings may be good measurement items of STCMF, but this blurs the distinction between factors by including these items in the

scale [21]. The measurement items, having factor loadings greater than 0.3 on other factors, were excluded from the measurement tool to improve the distinction between factors [21]. In addition, our research deleted four measurement items, since they had the lowest correlations with a criterion and the lowest factor loadings. These deletions resulted in an 11-item scale to gauge STCMF. One factor with Eigen value = 8.1 explained as explaining 69% of the variance. Each of the 11 measurement items had a factor loading > 0.605 . As presented in Table I, each of the 11-measurement items had a corrected item-total correlation > 0.623 . The correlation for each of the 11 measurement items was positive and significant ($p \leq 0.01$). This 11-item tool had reliability (Cronbach's alpha) of > 0.796 .

TABLE I: RELIABILITY, VALIDITY, AND FACTOR LOADING OF STCMF CONSTRUCT

Variable	Factor Loading			Corrected Item-Total Correlation	Coefficients Alpha
	Factor 1	Factor 2	Factor 3		
V02	0.787			0.706	0.803
V04	0.804			0.713	
V05	0.711			0.687	
V07	0.612			0.649	0.809
V09		0.801		0.768	
V12		0.805		0.713	
V15		0.763		0.701	0.796
V17			0.772	0.725	
V19			0.802	0.663	
V20			0.721	0.694	0.796
V22			0.605	0.623	

* Significant at $P \leq 0.01$

Hence, the 11 measurement items present a reliable and valid measurement framework to gauge STCMF. However, we should endeavor to look for additional evidence of the measurement tool's validity and reliability, internal consistency, and more scientific and practical measurement items. Through reflecting the analysis results of many findings and case studies, the developed measurement instrument can be became more objective and practical scale for the application of STCMF in manufacturing industry.

IV. FRAMEWORK OF MEASUREMENT TOOL

This research developed the 11 measurement items appropriate for gauging STCMF. We identified three factor groups from our factor analysis results. The factor groups provide the potential factors as major components to measure STCMF. Through investigating the measurement items of each factor group based on previous studies, our research identified the following three potential factors: factor 1: smart production and process; factor 2: smart data analysis and utilization; and factor 3: smart operation and service. The extracted factors include the overall smart technology measurement content for STCMF. Smart production and

process presents the smart technology domains related to product production and process management for manufacturing fields. It includes production process optimization department, production quality control department, equipment diagnosis and management department, and product and process management department. Smart data analysis and utilization explains the smart technology domains related to analysis and utilization of big data and cloud systems for manufacturing fields. It has big data analysis and utilization department, cloud infrastructure utilization department, and data production and management department. Smart operation and service indicates the smart technology domains including demand forecasting, logistics, integration operation and service, and safety and work to support for manufacturing fields. It includes demand forecasting management department, manufacturing integration operation and service department, retailing and procurement logistics department, and human-centered safety and work support department. Finally, they provide a structural tool to measure STCMF, including 3 measurement factors and 11 measurement items.

Hence, the developed tool consists of three measurement factors such as smart production and process, smart data analysis and utilization, and smart operation and service as presented in Fig. 1. Each factor has three or four measurement items. As shown in Table I and Fig. 1, smart production and process has the measurement items such as V02, V04, V05, and V07. Smart data management includes V09, V12, and V15. Smart operation and service contains V17, V19, V20, and V22.

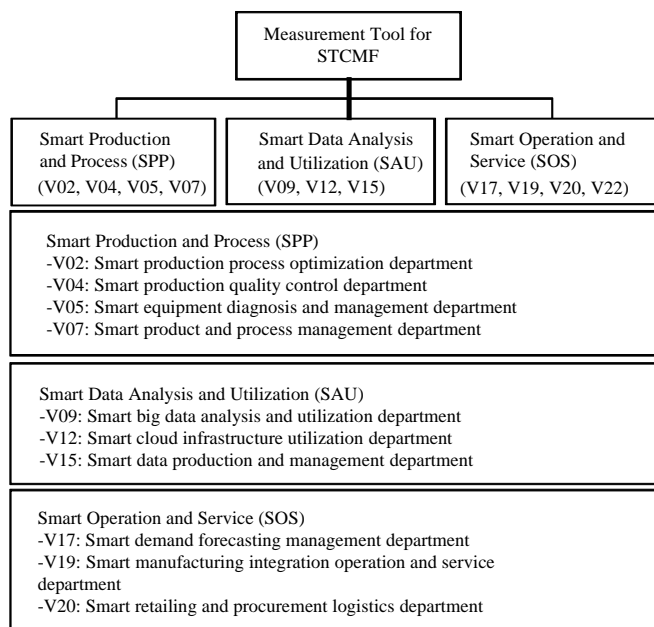


Fig. 1. Framework of the developed measurement tool for STCMF.

These measurement factors influence STCMF that means the smart technology capability of manufacturing fields. It is crucial to manage and improve STCMF by measuring smart technology ability of manufacturing fields with using a valid and reliable measurement framework. These findings can facilitate efficient advance of a smart technology capability for manufacturing fields with reflecting the measurement results by applying the developed measurement tool to

manufacturing fields. Measuring STCMF is an efficient method to understand the real situation for the smart technology capability of manufacturing fields. That is, understanding the STCMF structure is essential to analyze the success of STCMF that denotes the STCMF to efficiently support for manufacturing activities. We can utilize the structural tool to gauge the smart technology capability for manufacturing fields.

In order to understand the mutual influence between measurement factors, and the measurement and STCMF, this research presented the correlation between the measurement factors, and the correlation between each factor and STCMF. Because there are the measurement factors affecting STCMF, understanding their mutual relation is very critical for efficiently improve STCMF and for the effective utilization of the developed measurement tool for manufacturing fields. Their mutual relation is complex and may be affected by other variables. This research analyzed how they were correlated in order to examine the correlation between smart production and process, smart data analysis and utilization, smart operation and service, and STCMF, as presented in Table II. The most effect factor for STCMF is smart operation and service, and the measurement factors of smart data analysis and utilization and smart operation and service have more influence to each other by comparing with other factors.

TABLE II: CORRELATION MATRIX

	(1)	(2)	(3)	(4)
STCMF	(1)	0.43	0.41	0.47
Smart Production and Process	(2)		0.40	0.41
Smart Data Analysis and Utilization	(3)			0.42
Smart Operation and Service	(4)			

V. CONCLUSION

This study provides a generic measurement tool that can gauge perceived STCMF in manufacturing industry. Perceived STCMF provides a smart technology capability of manufacturing fields in a smart technology perspective. The developed measurement framework with adequate validity and reliability presents a reasonable method for grasping the real situations for STCMF in manufacturing industry. We also have some limitations in a specific STCMF perspective. This measurement tool is implicative, concrete, and appropriate for practical and research purposes. Our research results have not studied in previous literature. This research provides an original and scientific method that can measure STCMF in terms of an entire smart technology ability needed to manufacturing fields.

Therefore, this study presents a structural tool that can efficiently measure the STCMF in order to manage and reinforce smart technology capability of manufacturing fields in terms of a smart technology. Our findings contribute to a new direction and foundation for the development and advancement of the efficient measurement framework for STCMF. In future research, our research will find the

practicality and availability of this measurement tool by providing the measurement results by applying it to many case studies in manufacturing fields.

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