Comparative Study of Crossing the Chasm in Applying Smart Factory System for SMEs

Young-Hwan Choi, Sang-Hyun Choi

Abstract: This paper describes the practical methodology which encourages manufacturing SMEs in adopting smart factory system utilizing rapidly changing innovative technology. The focus is supporting manufacturing SMEs to cross the chasm successfully between the basic and middle level of smart factory environment. Based on 140 manufacturing SMEs who are between 10 and 300 employees and less than 100 billion Korean won revenue in 2014, survey was taken with 25 questionnaires. The objectives of this survey are to identify chasm situation, which SMEs with initially implemented smart factory might face in advancing to next maturity level for higher productivity. This study analyzed the status of SMEs in terms of current satisfaction level, equipment I/F rate, target level of smart factory in 5 years, type of Information system implemented and government support to find what factors are influential or correlated with the advancement from the 2nd basic level to the 3rd Mid-1 level of smart factory. Findings: This study explains that 140 SMEs who responded to the survey are satisfied relatively with their smart factory implementation. However they have a funding problem even if they want to go further for the advancement to the 3rd level of smart factory, which bottom lines are to have all machines interfaced with MES (Manufacturing Execution System) and to collect data from shop floor in a real time manner. The survey describes that 102 out of 140 SMEs explains the insufficient budget as the 1st issue for continuing improvement of smart factory with higher satisfaction score, 16 SMEs with unclear performance as the 2nd, 13 SMEs with insufficient experts as the 3rd, and 9 SMEs with low level of innovative passion as the 4th. In general, SMEs with higher equipment interface rate expect high about 1 more advanced Mid-1 level of smart factory system. And the more advanced level of smart factory SMEs have, the better quality SMEs have. SMEs implemented with MES system are more achieving the quality improvement than other information systems such as, ERP, PLM, SCM, and EMS etc. This research explains that SMEs with their 1st smart factory implementation which some manual operations are switched to automation will face the chasm in advancing to next level of smart factory. Therefore, It suggests government' efficient strategy, sharing economy and stable system operation with security to overcome the chasm.

Key Word*: *Chasm, Industry 4.0, Big Data, Smart Factory, Cyber Physical Systems

I. INTRODUCTION

With the rapid advancements of ICT(Information and Communications Technology) , digital sensing, equipment control and big data analysis are enabling new levels of the automated shop floor control system for better efficiency and improving product quality with less operational costs for delivering reliable products to customers in time.

They made it possible to bring shop floor control systems into real time based production monitoring and created new business model in a way with the connected value chain for customers.

Hereafter, based on this innovative period in time, the research explains especially the case of South Korea, in which MOTIE (Ministry of Trade, Industry and Energy) organization has been supporting "Manufacturing Innovation 3.0" for SMEs' smart factory implementation since Jun of 2014, which may be similar with "Industry 4.0" started by Germany in 2011. MOTIE's goal is to apply smart factory systems to 10,000 SMEs by 2020 if possible, for enhancing relatively low manufacturing performance index compared to other countries; Germany, US, Japan etc. In South Korea, between Jun. 2014 and Dec. 2016, Smart Factory Systems were implemented to 2,611 SMEs for the 2nd Basic level, in which only part of machines are connected to primarily MES (Manufacturing Execution System) to collect the data automatically or if any, with supporting ERP (Enterprise Resource Planning), PLM (Product Life-Cycle Management), SCM (Supply Chain Management) and FEMS (Factory Energy Management System). The scope of this research is limited to the fact which 140 SMEs responded to the survey with 25 questions and explained about their smart factory system, of which some completed and are already operating the system, and others are ready to go soon.

This paper discusses the strategic analysis to overcome the chasm, which may incur between the 2nd basic level and the 3rd mid-1 level of smart factory out of 5 levels (No ICT, Basic, Mid-1, Mid-2 and Advanced) defined by MOTIE in South Korea. The focus is to enable SMEs to go forward with full connectivity of all machines at their shop floor with flexibility, being required for the advanced next level successfully to maximize their competitiveness since their 2nd Basic level of smart factory.

The survey explains that most of SMEs strongly feel unaffordable in view of project funding when moving forward from the 2nd level (Basic) to the next 3rd level (Mid-1). However they are satisfied with 3.51 out of 5 scores about their 2nd Basic level project taken for about 6 months to 1 year from bare

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ground level (No ICT) in most cases, having no ICT environment for long years.

The proposed strategy and analysis to cross the chasm might be applicable to solve SMEs' current challenges in advancing to the 3rd Mid-1 level especially, which requires much cost with all machines connected at shop floor.

II. Materials and Methods

In terms of implementing a smart factory system, As shown in <figure 1> all levels of smart factory are described below, with 5 levels of maturity depending on the shop floor system environment [9]. Between levels, sub-level points; such as 1.5, 2.1 etc may be definable with more detailed maturity level and combinational assessment of all business information systems; MES, ERP, PLM, SCM and EMS in view of system perspective.

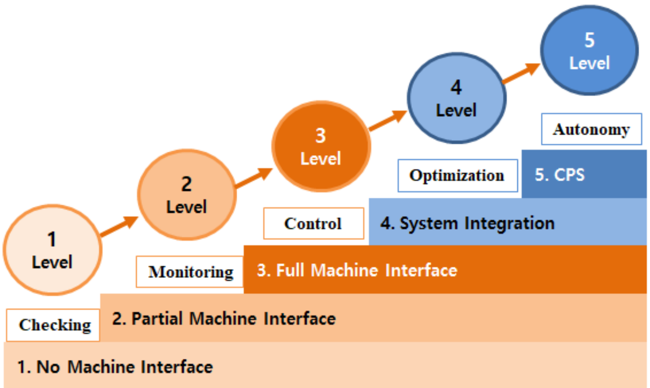

Figure 1. Maturity Level of Smart Factory [9]

As shown in <Table 1>, Level 1 (No ICT) is that they are not with ICT environment and all engineering information at work centers must be recorded by workers manually. So it might have an incorrect data with human error and no agility in reporting quality problem which might cause product quality problem eventually.

Level 2 (Basic) is that only partial equipments are connected to MES (Manufacturing Execution System) to deliver data automatically. The connection might be some of process machines or measurement machines. This level is actually the starting point for smart factory with primarily MES system executing job dispatch orders based on production planning and display real status of machines connected. However they are not fully connected with MES system, which means that cannot identify all machines' real status and collect data for the right time decision.

Level 3 (Mid-1) is the status which is fully connected about the process and measurement equipments with MES system. Therefore manufacturing shop floor could provide real time [13] and reliable information, and under system monitoring with real data collection and all equipment status. Here, system environment for handling big data must be provided so that real time data analysis may be available for checking product quality just after collecting data at all operations. For SMEs, this level might not be easy in implementing all machines fully with many reasons. We explain those in later part about details based on survey activities.

Level 4 (Mid-2) is that all business systems are integrated if any, so that consistent information between them will be available among systems; MES, ERP, PLM, SCM and EMS which are sharing information seamlessly with interoperation. However SMEs may not be affordable due to high cost, lack of system engineers etc within short years.

Level 5 (Advanced) might be last destination for smart factory system environment with CPS (Cyber Physical Systems) and AI (Artificial Intelligence) systems in which real objects are connected digitally and taken real data into consideration when executing processes in a cyber physical system and bringing a strong link with the cyber factory to support workers with daily operations. CPS based manufacturing innovations are inevitable trends and also challenges for manufacturing industries [30]. The challenges may be in dealing with big data for rapid decision making to improve productivity [21][25].

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TABLE 1
DESCRIPTION OF SMART FACTORY MATURITY LEVEL

Level	Description	Function
1 (No ICT)	Hand operation and writing data on paper at all workstations . Not available input to system directly.	Recording run sheet manually
2 (Basic Level)	Some equipments (Process, measurement) are connected to shop floor system directly to collect data automatically at some operations. It provides the information of lot tracking, material flow etc. using barcode or RFID as well.	Partial Equipment Monitoring
3 (MID-1)	All machines are connected to shop floor system(MES). And other supporting systems, ERP, PLM, SCM and EMS might be integrated if they exist. It provides all monitoring with data collection automatically.	Automatic Data Collection with full machine connection
4 (MID-2)	All systems (MES, ERP,PLM,SCM and EMS) are integrated fully and can be controllable from the system with production optimization.	Equipment Control
5 (Advanced)	Integrated systems with CPS (Cyber Physical System) and AI for production management	Autonomy

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III. CHALLENGES

An author of "Crossing the Chasm" in 2001, Geoffrey Moore describes the technology lifecycle as a business model [5] as shown in <figure 2>. One of the key insights is that there may be a chasm in technology adoption between early adopters and early majority. For especially SMEs, to cross the chasm effectively for widespread technology adoption, different ways of supporting strategy with realization of SMEs' post basic level of smart factory may be necessary [3].

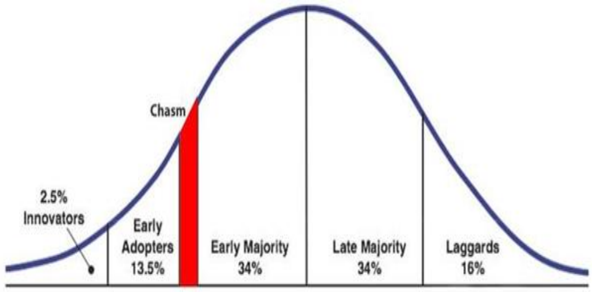

Figure 2. Smart Factory Adoption Lifecycle

By the end of 2016 in Korea, 2,611 of manufacturing 67,068 SMEs (based on Year 2014) implemented the smart factory system, which are top 3.89% and 1.39% advance of early adopters 13.5% stage passing innovators stage 2.5% of total. As shown in <Table 2> below, MOTIE is planning to support the smart factory for 10,000 SMEs by 2020 who are about 15% of total SMEs [17][22] in Korea. At this time, the chasm between early adopters and early majority might be happening with several issues we need to identify in advance and solve them to speed up the smart factory evolution, which eventually bring manufacturing innovation with global competency [7].

Innovators who applied smart factory system with government support in mid 2014 are pioneers having the insight to implement an emerging technology rapidly for a strategic business opportunity despite of taking high risks [14]. They enjoy starting out with a new technology, which makes their goal come true because they are doing it which no other competitors have done before.

Early adopters are willing to sacrifice for the advantage of being first whilst the early majority will wait until they know that the technology actually provides reliable improvements in productivity. The challenge for early adopters and early majority is to narrow the chasm between them and finally expedite smart factory adoption across every segment5.

Early majority may expect to join the smart factory project just after 2020, considering whether chasm after early adapter's stage is successfully passed through. When smart factory performance is recognized with successful publicly they will hurry up to implement smart factory system and bring late majority.

TABLE 2.
MANUFACTURING SMEs WITH SMART FACTORY ADOPTION [17]

Year	2014	2015	2016	2017	2018	2019	2020	Remarks
Accumulated Total	277	1,240	2,611				10,000	Expect 10,000 SMEs by Year 2020 (Manufacturing SMEs with >10 & <300 employees)

IV. SMART FACTORY OF KOREA SMEs

SMBA (Small and Medium Business Administration) in Korea explains that there are 67,068 manufacturing SMEs which are between 10 and 300 employees and under 100 Billion revenue (In Korean Won) per year as of 2014. As shown in <figure 3>, by 2020, 10,000 SMEs will be implemented with smart factory starting basic level (few machines connected) by the planned strategy of MOTIE in Korea. And based on the ratio of smart factory implementation for last 2.5 years since June 2014, we could forecast its evolution by year 2025 as described below. And we discuss about few countries' approaching concept and initiatives [18]. In view of global standard initiatives US and Germany are working closely between their respective the Industrial Internet Consortium (IIC) and Industry 4.0 in 2016 [29].

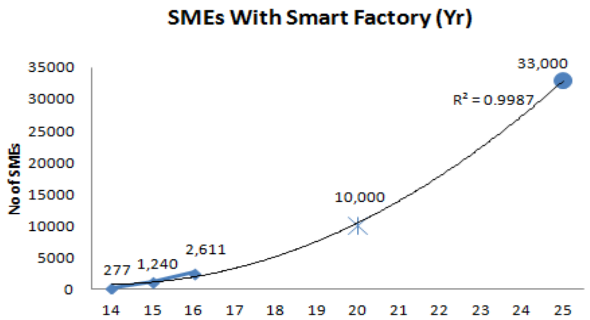

Figure 3. Forecasting SMEs with Smart Factory System (By Year)

● ADVANCED MANUFACTURING IN US

As shown in <Table 3>, organizations such as the Smart Manufacturing Leadership Coalition (SMLC) and the Industrial Internet Consortium (IIC) are supporting the concept of advanced manufacturing, which the integration of new technologies are applied to the manufacturing section to improve product quality and processes. Advanced Manufacturing Partnership (AMP) has been working hard and reporting to the US President's Council of

Advisors on Science and Technology. Advanced Manufacturing Office (AMO) is sponsoring their recommendation which is smart manufacturing which supports the design, scheduling, dispatching, and execution throughout factories to enhance efficiency [4]. With the name of Industrial Internet Consortium (IIC), big companies such as, GE, Intel and CISCO are more active than small companies and announced the Industrial Cloud Platform "Prefix" in 2015 [18][24].

TABLE 3
MANUFACTURING SMES WITH SMART FACTORY ADOPTION

	Korea	Germany	US	Japan
SME Policy	SMBA (Small and Medium Business Administration) http://www.smba.go.kr	BMWi (Federal Ministry For Economic Affairs and Energy) http://www.bmwi.de	SBA(Small Business Act of 1958) https://www.sba.gov Public Law85-536	SMEA(The Small and Medium Enterprise Agency) http://www.chusho.meti.go.jp/
SME Qualification	Employees: Less than 300 Revenue(Yr): <100B₩	Employees: Less than 500 Revenue(Yr): <50M€	Employees: Less than 500	Employees: Less than 300 Capital: < 300M ¥
Manufacturing SMEs	67,068 SMEs (99.9% of total companies, 2014) 16.3% of total employees 30.6% of GDP 2014	245,977 SMEs (97.3% of total companies, 2014) 44.1% of total employees 23% of GDP 2014	252,737 SMEs (98.6% of total companies, 2012) 45.5% of total employees 12% of GDP 2014	213,156 SMEs (98.6% of total companies, 2012) 69.4% of total employees('12) 19% of GDP 2014

SMART FACTORY IN JAPAN

The Small and Medium Enterprise Agency (SMEA) is supporting SMEs in Japan [8]. Their concept is with e-Factory using an Industrial Internet of Things (IIOT) which supports manufacturing control and data analysis to improve the productivity and energy saving [6][16]. Their strong industrial robots and other process machines, such as computerized numeric control (CNC), measurement devices etc might be key players in implementing e-Factory with sensors. Eventually big data [15][28] from shop floor will be powerful manufacturing environment to have big opportunity especially in automobile, ICT, Machine and Sensor areas [4][23]. In 2015, with government' interesting on smart factory, 60 companies; Mitsubishi, Toyota, Panasonic had consortium of Industrial Value Chain Initiative (IVI) with loose standard and open-and-close concept with actually implemented 5,000 standards [12].

● INDUSTRY 4.0 IN GERMANY

Since 2011, smart factory is under way with the collaboration of university and companies with the leadership of government and industrial association. Their open technology platform, Industry 4.0 was created with several companies; Siemens, Boshi, SAP and other small companies; FESTO, ifm, SEW and Beckhoff etc, which are hidden champions with strong technology in machines, parts, and engineering areas. Since 2011, Germany government is actively supporting smart factory. BMWi (The Federal Ministry for Economic Affairs and Energy) is supporting their initiative Industry 4.0 which is connected with machines, technologies and processes. Its vision is to realize the cyber physical systems (CPS) with Industry 4.0 to cover various production facilities from production and supply chain for customers [4][18].

V. RESULT AND DISCUSSION

To expedite smart factory implementation for manufacturing SMEs in Korea, during last 2.6 years between June 2014 and Dec 2016, with the help of MOTIE which is one of Korea government organizations, 2,611 manufacturing SMEs joined to apply the basic level of smart factory system at their shop floor. MOTIE is planning its goal with 10,000 SMEs[17] by the end of 2020. Our survey says that respondent 140 SMEs are favorably satisfied with the current basic level of smart factory in general because it reduces human error, labor time, quality problem and daily reporting effort etc.

However their current level of smart factory is low level, which is the 2^{nd} maturity level, just out of no ICT (Information and Communication Technology) level environment. This 2^{nd} level (Basic) can support partial equipment connectivity which means not all machines connected to the system, primary MES. Therefore the 2^{nd} level (Basic) of smart factory cannot have real time and reliable data from all machines including process and measurement. So, real time data analysis and right time decision may not be applicable in finding quality problem rapidly, which may bring much more cost and less accurate in recognizing the quality defect than advanced 3^{rd} level (Mid-1) of smart

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factory having all machines connected. For SMEs at the 2nd level (Basic) to arrive at the 3rd level (Mid-1) of smart factory successfully, we may need to understand their challenges [20] and support with the strategies we propose in this research.

As shown in <Table 4>, survey explains that most of respondents are less than 40% of equipment connectivity to the system, actually MES. Measurement equipments are more connected than process ones because the result data from measuring the product at some operation is much more important in checking product quality whereas process equipments are just working as specified by operators in general. So, system has no accurate processing time and real time data because only few types of equipment are connected to the system to deliver the data automatically.

TABLE 4
EQUIPMENT I/F RATE ON ADVANCING TO 3RD LEVEL (MID-1) SMART FACTORY FROM THE 2ND LEVEL

No of Employees	Number of SMEs	Process EQ I/F Rate	Measurement EQ I/F Rate
20 >	21	30.76%	40.09%
50 >	44	16.36%	30.53%
100 >	35	23.42%	35.71%
200 >	18	25.00%	33.89%
200 <	22	25.45%	30.90%

In view of what challenges are in crossing the chasm (1 Swift L., 2015 and 2 Jonathan S. L., 1999) to arrive at the 3rd level (Mid-1: full machine connectivity), as shown in <Table 5 >, the survey explains that 102 (73%) out of 140 SMEs say they do not have available financial resources to go ahead from the 2nd level (Basic) of few machines connectivity to the 3rd level of full machine interface with the system.

TABLE 5
SATISFACTION LEVEL ON ADVANCING TO 3RD LEVEL (MID-1) SMART FACTORY FROM THE 2ND LEVEL (BASIC)

Issues	Number of SMEs	Satisfaction Level	Mid-1 Expected Due (Yr)
Employee Reduction	0	N/A	N/A
Insufficient Budget	**102**	**3.51**	**3.09**
Unclear Performance	16	3.37	3.50
Insufficient Expert	13	2.77	2.77
Innovation Passion	9	3.11	2.89

SMEs are depicted graphically with top issue, which is an insufficient budget, as shown in <figure 4>.

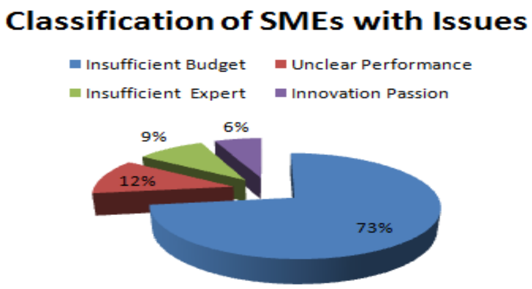

Figure 4. Classification based on Issues

In terms of what level will respondent SMEs be in 5 years, as shown in <Table 6>, the survey explains that 14% will stay at the 2nd level (Basic: partial machine connectivity), 11.8% at the level 3 (Mid-1: full machine connectivity), 16.5% (business system integration; MES, ERP, PLM, SCM and EMS if any) and 17.5% at final level with CPS (Cyber Physical System) implementation. Noticeably, SMEs experienced long about current 2nd basic level of smart factory seem to be more aggressive in implementing higher level than short time experienced SMEs.

TABLE 6
SMART FACTORY TARGET IN 5 YEARS FROM CURRENT 2ND LEVEL (BASIC)

Smart Factory Level	**Number of SMEs**	**Years of Adoption**	**Quality Upgrade**
Level 1 (No ICT)	NA	NA	NA
Level 2 (Basic)	11	0.45	14.09%
Level 3 (Mid-1)	55	0.97	11.81%
Level 4 (Mid-2)	56	1.07	16.50%
Level 5 (Advanced)	18	1.14	17.50%

As shown in <Table 7>, it explains that most of SMEs are installed primarily with MES and ERP system for their 2nd basic level of smart factory environment. They expresses that product quality was enhanced 15.54 % with MES system and 14.03% with ERP respectively. And their equipment interface rate is 32.85% with MES system and 29.39 with ERP system. In general, MES system is connected to machines through gateway or middleware but ERP system has extended features to handle machines similar to MES system. So, for SMEs MES and ERP functions seems to be mixed with the type of hybrid system, which is called extended MES system supporting core requirement functions and lower maintenance cost.

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TABLE 7
SYSTEM TYPES ON ADVANCING TO 3RD LEVEL (MID-1) SMART FACTORY FROM THE 2ND LEVEL (BASIC)

System Adoption	Number of SMEs	EQ I/F Rate	Quality Up
MES	**65**	**32.85%**	**15.54%**
ERP	67	29.39%	14.03%
PLM	5	18.00%	5.00%
SCM	2	57.50%	7.50%
EMS	1	20.00%	10.00%

VI. CONCLUSION

So far, manufacturing might be a process that transforms raw materials into market products through manual operation on machines with the posted instruction. However recent technologies, like sensors, robotics, smart machines and big data etc encourage manufacturing SMEs to be adaptive with fully connected shop floor environment to improve their customer service with better product quality, and competitive advantages globally. However, we need to realize that manufacturing SMEs would be more productive and successful on applying smart factory system initially and government is well prepared in supporting them with full understanding of SMEs' current satisfaction and challenges.

Based on the survey in Jan 2017, 2,611 manufacturing SMEs applied with smart factory system since June of 2014 in Korea, their maturity of smart factory is basically at the 2nd level (Basic), in which only few machines are connected to MES (Manufacturing Execution System) and waiting to advance for next 3rd level (Mid-1) requiring all machines connected according to the full connectivity concept of smart factory, so that real time data and reliable information will be available in checking the status of machines and result data in a real time manner, and eventually prevent further mistaken operations, and save the cost with quick correction at wrong operation step. In view of this situation, Korea unlike other advanced manufacturing countries; US, Germany and Japan, will need to focus on understanding the issues in supporting their manufacturing SMEs, which have conventional manual manufacturing with no ICT environment having a few administrative PCs and MS office applications (PowerPoint, Word, Excel) etc.

The survey says that the 3rd level (Mid-1) of smart factory would provide more competitive advantages in competing globally and like to advance after the 2nd basic level, which is not supporting all machines connected (half & half with manual & automation). However most of SMEs responded to the survey says that they can't afford to advance to reach at the 3rd level (Mid-1) with the investment and other challenges. To solve issues, our research recommends 3 primary points as below,

First, government' efficient support with detailed analysis in view of successfully implementing the 2nd level (Basic) of smart factory for manufacturing SMEs and repetitive support to further advance to next level (Mid-1).

Second, sharing economy [2][10], in which resources; such as machines (Robotics, Sensors, and Digital measurement tools), applications (PLC, Firmware etc), business process, smart factory and big data [1][23] experts are transferable or sharable through value added network (VAN) among SMEs [19][20].

Third, stable system maintenance and security, which are quite important after the smart factory implementation, need to be ready and rapidly taken whenever with unexpected system problems or security risks.

In reality, manufacturing SMEs in Korea have to cope with many challenges to improve their smart factory system continuously just after implementing the 2nd level (Basic) with the government support, having just few machines connected as mentioned in earlier section. We present some insights to solve their potential chasm, being questioned from recent survey about smart factory evolution. In future, we may explain with more detailed information in realizing SMEs' smart factory challenges with the statistical analysis.

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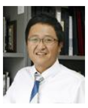

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